Veerasamy Sejian · John Gaughan
Lance Baumgard · Cadaba Prasad *Editors*

Climate Change Impact on Livestock: Adaptation and Mitigation

Springer

Climate Change Impact on Livestock: Adaptation and Mitigation

Veerasamy Sejian • John Gaughan
Lance Baumgard • Cadaba Prasad
Editors

Climate Change Impact on Livestock: Adaptation and Mitigation

Springer

Editors
Veerasamy Sejian
Animal Physiology Division
ICAR-National Institute of Animal Nutrition and Physiology
Bangalore, Karnataka, India

John Gaughan
School of Agriculture and Food Sciences
The University of Queensland
Gatton, QLD, Australia

Lance Baumgard
Department of Animal Science
Iowa State University
Ames, IA, USA

Cadaba Prasad
ICAR-National Institute of Animal Nutrition and Physiology
Bangalore, Karnataka, India

ISBN 978-81-322-2264-4 ISBN 978-81-322-2265-1 (eBook)
DOI 10.1007/978-81-322-2265-1

Library of Congress Control Number: 2015936905

Springer New Delhi Heidelberg New York Dordrecht London

Printed on acid-free paper

Springer (India) Pvt. Ltd. is part of Springer Science+Business Media (www.springer.com)

This book is dedicated to all who have lost their lives to the devastating effects of climate change and to all farmers around the world who rely heavily on livestock production for their principal livelihood security and to all researchers who are actively involved in research pertaining to improving livestock production in the changing climate scenario.

Preface

Climate change and food security are two emerging issues faced by almost every nation. Climate change as a result of green house gases (GHGs) emissions poses a serious threat to the environment, economy and well-being of both human and animals. While livestock's role in contributing to food security is well acknowledged, its negative impacts, by way of contributing to GHG in the atmosphere, raise criticism. Livestock agriculture accounts for significant amount of methane (CH_4) and nitrous oxide (N_2O) emitted worldwide. The negative impact of climate change is evident on all animals, but its effect on ruminant livestock are of huge concern as these animals apart from getting affected by climate change also directly contribute to the phenomenon through enteric CH_4 emission and manure management. It is therefore imperative that animal agriculture practices and the welfare of animals be considered when developing climate change policies and programmes, both as potential victims and causes. Under the changing climatic scenarios, efforts are equally needed to reduce the impacts of climate change on livestock production and reproduction as well as to identify suitable mitigation strategies to reduce CH_4 production.

With dynamic climate shifts, endeavours are needed to hoist platforms for suitable adaptation and mitigation strategies to reduce genesis of climate change. This forms the basis of this book *Climate Change Impact on Livestock: Adaptation and Mitigation*. This volume was specifically prepared by a team of multi-disciplinary scientists to be a valuable reference source for researchers as the primary target group for this compendium. In addition, the material contained in this volume is also relevant to teaching undergraduates, graduates, policy makers, politicians and other professionals involved in livestock production. With information and case studies collated and synthesized by professionals working in diversified ecological zones, this book attempts to study the climate change impact, adaptation and mitigation in livestock production system across the global biomes.

The 27 chapters provide the reader with an insight into the impact of climate change on livestock production and role of livestock in contributing to climate change. An attempt is also made to discuss the various mitigation strategies to reduce livestock related GHGs. Further, efforts have also been made to highlight several housing management and feeding practices to reduce climate change's impact on livestock production and reproduction. In addition, this book also emphasizes the various policy issues that require focus to understand in depth the impact of climate change and its mitigation by 2025. Therefore, this book is a comprehensive resource for the researchers to understand climate change impact and its management to improving livestock production.

The contributors of various chapters are world class professionals with vast experience in the chosen field supported by several peer-reviewed publications. The Editorial Committee take this opportunity to thank all the contributors from different parts of the world for their dedication in preparing these chapters, for their prompt and timely response, and for sharing their knowledge and experience with others. The efforts of many others, all of those cannot be individually listed, were also very pertinent in completing this relevant and an important volume.

Bangalore, Karnataka, India	Veerasamy Sejian
Gatton, QLD, Australia	John Gaughan
Ames, IA, USA	Lance Baumgard
Bangalore, Karnataka, India	Cadaba S. Prasad
9th December, 2014	

Contents

Part I Green House Gas Emission and Climate Change

Part II Climate Change Impact on Livestock

Part III Livestock Role in Climate Change

Part IV Methane Mitigation Strategies in Livestock

Part V Adaptation Strategies to Improve Livestock Production Under Changing Climate

Part VI Research and Development Priorities

Contributors

M. Abuajamieh Department of Animal Science, Iowa State University, Ames, IA, USA

Neeta Agarwal Animal Nutrition Division, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

Prasad Ambazamkandi Department of Livestock Production Management, College of Veterinary and Animal Sciences, Mannuthy, Thrissur, Kerala, India

M. Bagath Animal Nutrition Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore, Karnataka, India

Lance Baumgard Department of Animal Science, Iowa State University, Ames, IA, USA

Raghavendra Bhatta ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore, Karnataka, India

Arianna Buccioni Dipartimento di Scienze delle Produzioni Agro-alimentari e dell'Ambiente, University of Florence, Florence, Italy

Alice Cappucci Dipartimento di Scienze Agrarie, Alimentari e Agro-ambientali, University of Pisa, Pisa, Italy

A.J. Cawdell-Smith Animal Science Group, School of Agriculture and Food Sciences, The University of Queensland, Gatton, QLD, Australia

Laura M. Cersosimo Department of Animal Science, College of Agriculture and Life Sciences, University of Vermont, Burlington, VT, USA

Vikash Chandra Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

L.C. Chaudhary Animal Nutrition Division, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

S.K. Chikara Xcelris Genomics, Xcelris Labs Ltd, Ahmedabad, Gujarat, India

Ashish Chopra Arid Regional Campus, ICAR-Central Sheep and Wool Research Institute, Beechwal, Bikaner, Rajasthan, India

S.S. Dangi Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

Justin Davis Department of Livestock Production Management, College of Veterinary and Animal Sciences, Mannuthy, Thrissur, Kerala, India

Kalyan De Division of Physiology and Biochemistry, ICAR-Central Sheep and Wool Research Institute, Avikanagar, Rajasthan, India

T. Ezeji Department of Animal Sciences, The Ohio State University, Wooster, OH, USA

Emma J. Gagen School of Earth Sciences, The University of Queensland, Brisbane, QLD, Australia

M.R. Garg National Dairy Development Board, Anand, Gujarat, India

John Gaughan Animal Science Group, School of Agriculture and Food Sciences, The University of Queensland, Gatton, QLD, Australia

Kandalam Giridhar ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore, Karnataka, India

Gopal R. Gowane Division of Animal Genetics and Breeding, ICAR-Central Sheep and Wool Research Institute, Avikanagar, Rajasthan, India

Mahesh Gupta Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

N. Haque Department of Physiology and Biochemistry, College of Veterinary and Animal Husbandary, Sardarkrushinagar Dantiwada Agriculture University, Dantiwada, Gujarat, India

Iqbal Hyder Department of Veterinary Physiology, NTR College of Veterinary Science, Gannavaram, Andhra Pradesh, India

J.S. Johnson Department of Animal Science, Iowa State University, Ames, IA, USA

Biya Ann Joseph Department of Livestock Production Management, College of Veterinary and Animal Sciences, Mannuthy, Thrissur, Kerala, India

C.G. Joshi Department of Animal Biotechnology, College of Veterinary Science and Animal Husbandry, Anand Agricultural University, Anand, Gujarat, India

D.N. Kamra Animal Nutrition Division, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

A.F. Keating Department of Animal Science, Iowa State University, Ames, IA, USA

Alicja Kolasa-Więcek Department of Economics, Finances and Regional Research, Faculty of Economy and Management, Opole University of Technology, Opole, Poland

R.K. Kothari Department of Bioscience, Saurashtra University, Rajkot, Gujarat, India

D. Kumar Division of Physiology and Biochemistry, ICAR-Central Sheep and Wool Research Institute, Avikanagar, Rajasthan, India

Ankita Kushwaha Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

J. Lakritz Department of Veterinary Clinical Sciences, The Ohio State University, Columbus, OH, USA

Rattan Lal Carbon Management and Sequestration Center, School of Environment and Natural Resources, The Ohio State University, Columbus, OH, USA

N.K. Lenka Indian Institute of Soil Science, Indian Council of Agricultural Research, Nabibagh, Bhopal, India

Sangeeta Lenka Indian Institute of Soil Science, Indian Council of Agricultural Research, Nabibagh, Bhopal, India

P.K. Malik Bioenergetics and Environmental Sciences Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore, Karnataka, India

V.P. Maurya Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

Marcello Mele Dipartimento di Scienze Agrarie, Alimentari e Agro-ambientali, University of Pisa, Pisa, Italy

M. Mohanty Indian Institute of Soil Science, Indian Council of Agricultural Research, Nabibagh, Bhopal, India

Serge Morand Department Environment and Societies, CNRS-CIRAD AGIRs, Centre d’Infectiologie Christophe Mérieux du Laos, Vientiane, Lao PDR

S.M.K. Naqvi Division of Physiology and Biochemistry, ICAR-Central Sheep and Wool Research Institute, Avikanagar, Rajasthan, India

Soumen Naskar ICAR-National Research Centre on Pig, Rani, Guwahati, Assam, India

J. Nteeba Department of Animal Science, Iowa State University, Ames, IA, USA

Samuel M. Otenyo Department of Climate Change Technology & Training, Greenhouse Gas Projects Accounting Services (GHGPAS), Nairobi, Kenya

Cadaba S. Prasad ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore, Karnataka, India

J.P. Ravindra Animal Physiology Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore, Karnataka, India

R.P. Rhoads Department of Animal and Poultry Sciences, Virginia Tech University, Blacksburg, VA, USA

J.W. Ross Department of Animal Science, Iowa State University, Ames, IA, USA

L. Samal College of Agriculture, Odisha University of Agriculture and Technology, Bhawanipatna, Odisha, India

Smitha Sambasivan Department of Livestock Production Management, College of Veterinary and Animal Sciences, Mannuthy, Thrissur, Kerala, India

Mohamed Samer Associate Professor, Department of Agricultural Engineering, Faculty of Agriculture, Cairo University, Giza, Egypt

Anandan Samireddypalle International Livestock Research Institute, IITA Ibadan, Ibadan, Oyo, Nigeria

M.V. Sanz Fernandez Department of Animal Science, Iowa State University, Ames, IA, USA

Mihir Sarkar Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

J.T. Seibert Department of Animal Science, Iowa State University, Ames, IA, USA

Veerasamy Sejian Animal Physiology Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore, Karnataka, India

Sankaralingam Shanmugam Department of Poultry Science, College of Veterinary and Animal Sciences, Mannuthy, Thrissur, Kerala, India

G. Taru Sharma Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

P.L. Sherasia National Dairy Development Board, Anand, Gujarat, India

Gyanendra Singh Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly, Uttar Pradesh, India

K.M. Singh Xcelris Genomics, Xcelris Labs Ltd, Ahmedabad, Gujarat, India

Smita Sirohi Dairy Economics, Statistics and Management Division, ICAR-National Dairy Research Institute, Karnal, Haryana, India

N.M. Soren Animal Nutrition Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Bangalore, Karnataka, India

S.K. Stoakes Department of Animal Science, Iowa State University, Ames, IA, USA

Giggin Thyagarajan KrishiVigyan Kendra, Kannur, Kerala, India

André-Denis G. Wright Department of Animal Science, College of Agriculture and Life Sciences, University of Vermont, Burlington, VT, USA

School of Animal and Comparative Biomedical Sciences, The University of Arizona, AZ, USA

About the Editors

Dr. Veerasamy Sejian is the Senior Scientist of Animal Physiology at National Institute of Animal Nutrition and Physiology, Bangalore, India. Dr. Sejian is primarily involved in research pertaining to stress and climate change impact and mitigation in small ruminants. Dr. Sejian has been awarded the prestigious Lal Bahadur Shasthri Outstanding Young Scientist Award by Indian Council of Agricultural Research for his novel concepts on multiple stresses simultaneously impacting sheep production. He has published 49 peer-reviewed research articles, 38 book chapters, 62 lead/invited papers, 9 technical manuals and 60 abstracts. He is also the corresponding editor for a Springer book on "Environmental Stress and Amelioration in Livestock Production". Dr. Sejian was also bestowed with the prestigious Endeavour Research Fellowship by the Australian Government for his outstanding contribution in the field of climate change impacting livestock production. He is also serving as editorial board member in 20 international peer-reviewed journals.

Dr. John Gaughan is an Associate Professor in the School of Agriculture and Food Sciences at The University of Queensland, Gatton, Australia. John has 129 publications, in the areas of impacts of harsh climatic conditions on livestock, modeling the impact of climate change on animal production (beef, dairy, sheep), and ruminant nutrition. He is part of an international team which has recently developed new thermal stress indices for livestock, a heat stress risk assessment model for feedlot beef cattle, and is currently developing a heat stress risk assessment model for dairy cows. He is currently focusing on the likely impact of future climatic conditions on animal production. John is also part of a team investigating greenhouse gas abatement strategies for cattle, and has on-going collaborative projects with colleagues in the USA. John is the Treasurer of the International Society of Biometeorology (ISB) and the Chair of the Animal Biometeorology Commission within ISB.

Dr. Lance Baumgard received his Ph.D. from Cornell University and joined the University of Arizona faculty as an Assistant Professor in 2001. He joined the Iowa State University faculty in 2009 and is the Norman Jacobson Professor of Nutritional Physiology. Baumgard's research focuses on the metabolic and endocrine consequences of heat stress in both ruminant and monogastric farm animals. Lance also studies the energetics and metabolism of the periparturient dairy cow. Lance has mentored or co-advised 23 graduate students and has been the PI or co-PI on over $6 million in research funding. Lance's group has published 82 peer-reviewed research articles, 150 abstracts, and 75 conference proceedings.

Dr. Cadaba S. Prasad was the Director of National Institute of Animal Nutrition and Physiology, Bangalore, India. Prior to this he was also serving as Vice Chancellor and Assistant Director General. Prasad's primary research interests have been on micronutrients augmenting production, enhancing the bioavailability of nutrients, and climate change impact on animal production. Prasad has coordinated several national and international projects like Indo-Dutch, ICAR-CSIRO, ICAR-ILRI, World Bank. Prasad's group has published more than 100 research papers in high-impact journals, 100 abstracts and 70 conference proceedings. Prasad and his team have won the ICAR Team research award thrice for outstanding contribution in animal production. Prasad has been awarded fellow of National Academy of Agriculture Science, Indian Dairy Association, Animal Nutrition Association and National Academy of Dairy Science.

Introduction to Concepts of Climate Change Impact on Livestock and Its Adaptation and Mitigation

1

Veerasamy Sejian, Raghavendra Bhatta, N.M. Soren,
P.K. Malik, J.P. Ravindra, Cadaba S. Prasad,
and Rattan Lal

Abstract

This chapter provides an overview of the impact of climate change on livestock production and its adaptation and mitigation. Animal agriculture is the major contributor to increasing methane (CH_4) and nitrous oxide (N_2O) concentrations in Earth's atmosphere. Generally there are two-way impacts of livestock on climate change. The first part is the livestock contribution to climate change, while the second part is concerned with livestock getting affected by climate change. Hence, improving livestock production under changing climate scenario must target both reducing greenhouse gas (GHG) emission from livestock and reducing the effect of climate change on livestock production. These efforts will optimize livestock production under the changing climate scenario. The role of livestock on climate change is primarily due to enteric CH_4 emission and those from manure management. Various GHG mitigation strategies include manipulation of rumen microbial ecosystem, plant secondary metabolites, ration balancing, alternate hydrogen sinks, manure management, and modeling to curtail GHG emission. Adapting to climate change and reducing GHG emissions may require significant changes in production technology and farming systems that could affect productivity. Many viable opportunities exist for reducing CH_4 emissions from enteric fermentation in rumi-

V. Sejian (✉) • J.P. Ravindra
Animal Physiology Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India
e-mail: drsejian@gmail.com

R. Bhatta • C.S. Prasad
ICAR-National Institute of Animal Nutrition
and Physiology, Adugodi, Hosur Road, Bangalore,
Karnataka 560030, India

N.M. Soren
Animal Nutrition Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India

P.K. Malik
Bioenergetics and Environmental Sciences Division,
ICAR-National Institute of Animal Nutrition and
Physiology, Adugodi, Hosur Road, Bangalore,
Karnataka 560030, India

R. Lal
Carbon Management and Sequestration Center,
School of Environment and Natural Resources, The
Ohio State University, Columbus, OH 43210, USA

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_1, © Springer India 2015

nant animals and from livestock manure management facilities. To be considered viable, these emission reduction strategies must be consistent with the continued economic viability of the producer and must accommodate cultural factors that affect livestock ownership and management. The direct impacts of climate change on livestock are on its growth, milk production, reproduction, metabolic activity, and disease occurrences. The indirect impacts of climate change on livestock are in reducing water and pasture availability and other feed resources. Amelioration of environmental stress impact on livestock requires multidisciplinary approaches which emphasize animal nutrition, housing, and animal health. It is important to understand the livestock responses to the environment and analyze them, in order to design modifications of nutritional and environmental management, thereby improving animal comfort and performance.

Keywords

Adaptation • Climate change • Enteric fermentation • Manure • Mitigation • Shelter design

Livestock production is the world's dominant land use, covering about 45 % of the Earth's land surface, much of it in harsh and variable environments that are unsuitable for other uses. Climate change could impact the amount and quality of produce, reliability of production, and the natural resource base on which livestock production depends. Climate is an important factor of agricultural productivity. The changing climate is expected to have severe impact on livestock production systems across the world. World demand for animal protein will rise as the population and real incomes increase and eating habits change. Therefore, animal production plays and will continue to play a key role in food supply. While the increasing demand for livestock products offers market opportunities and income for small, marginal, and landless farmers, livestock production globally faces increasing pressure because of negative environmental implications particularly because of greenhouse gas (GHG) emission.

Global climate change is expected to alter temperature, precipitation, atmospheric carbon dioxide (CO_2) levels, and water availability in ways that will affect the productivity of crop and livestock systems (Hatfield et al. 2008). For livestock systems, climate change could affect the costs and returns of production by altering the thermal environment of animals, thereby affecting animal health, reproduction, and the efficiency by which livestock convert feed into retained products (especially meat and milk). Climatic changes could increase thermal stress for animals and thereby reduce animal production and profitability by lowering feed efficiency, milk production, and reproduction rates (St. Pierre et al. 2003). Climate changes could impact the economic viability of livestock production systems worldwide. Surrounding environmental conditions directly affect mechanisms and rates of heat gain or loss by all animals (NRC 1981). Environmental stress reduces the productivity and health of livestock resulting in significant economic losses. Heat stress affects animal performance and productivity of dairy cows in all phases of production. The outcomes include decreased growth, reduced reproduction, increased susceptibility to diseases, and ultimately delayed initiation of lactation. Heat stress also negatively affects reproductive function (Amundson et al. 2006). Normal estrus activity and fertility are disrupted in livestock during summer months. Economic losses are incurred by the livestock industries because farm animals are generally raised in locations and/or seasons where temperature conditions go beyond their thermal comfort zone. The livelihood of the rural poor in developing countries depends critically on local natural resource-based activities such as crop and livestock production. As a result of negative weather impact on livestock rearing, the poor shepherds/farmers whose principal livelihood security depends on these animal performances are directly on stake. Housing and management technologies are available through which climatic impacts on livestock can be reduced, but the rational use of such technologies is crucial for the survival and profitability of the livestock enterprise (Gaughan et al. 2002).

The relationship between the livestock sector and climate change is likely to greatly influence the overall nature of the approach to adaptation within the livestock sector (Havlík et al. 2014). The sector has been much maligned since the publication of *Livestock's Long Shadow* by FAO in (2006) and the allegation that the industry contributes more to climate change than the automobile industry does. However, the real relationship between livestock and climate change is much more complex, and the environmental services of extensive livestock systems have generally been overlooked. Such services could become crucial to adaptation in the sector in the future. Livestock play a critical role in rural poverty reduction; therefore, livestock development is vital for farmers in developing world in particular. Development in all sectors will be increasingly scrutinized for its "clean" credentials, and it is desirable that livestock development can be carried out without significantly contributing further to climate change. This volume is an attempt to collate and synthesize all relevant information pertaining to how livestock contributes to climate change, in addition to getting impacted by the same. Further, the volume will address in detail the various mitigation strategies available to prevent livestock-related climate change by highlighting measures to be taken to curtail greenhouse gas (GHG) emission. In addition, the volume will address in detail the various adaptation and amelioration strategies to counter the impact of climate change on livestock production. Lastly, this volume also emphasizes the importance of visioning climate change impact 2025 and addresses the various steps to be taken to increase the resilience of livestock production systems and livestock-dependent livelihoods to climate change. All these crucial information pertaining to sustaining livestock production under changing climate scenario are dealt elaborately in six different parts in this volume. Figure 1.1 describes the various concepts pertaining to climate change impact on livestock production and its adaptation and mitigation.

1.1 GHG Emission and Climate Change

Part I of this volume comprises two chapters covering in detail the general principles governing the sources and sinks of GHGs and their contribution to climate change. Special emphasis has been given to highlight the significance of agricultural-related activities' contribution to GHGs and its importance to global climate change.

The temperature of the Earth's surface and atmosphere is determined by the balance between incoming and outgoing energy. Surface temperatures rise when more energy is received than lost. The Earth's surface receives about 50 % of the incoming solar radiation (after some losses by atmospheric absorption and reflection), and this energy heats the surface. The warmed surface reradiates heat back out at longer infrared wavelengths. This radiation is known as terrestrial radiation, as opposed to solar radiation coming in from the sun. The greenhouse effect is a result of the partial absorption and reradiation back to Earth of this outgoing infrared radiation. A change in the net radiative energy available to the global Earth-atmosphere system is termed as a radiative forcing, and changes in the concentrations of GHGs in the troposphere (such as CO_2, CH_4, N_2O, H_2O, etc.) are one such forcing (Rogelj et al. 2012). Increases in the concentrations of GHGs will reduce the efficiency with which the Earth's surface radiates to space. More of the outgoing terrestrial radiation from the surface is absorbed by the atmosphere and reemitted at higher altitudes and lower temperatures. These result in a positive radiative forcing that tends to warm the lower atmosphere and surface. Because less heat escapes to space, this is the enhanced greenhouse effect – an enhancement of an effect

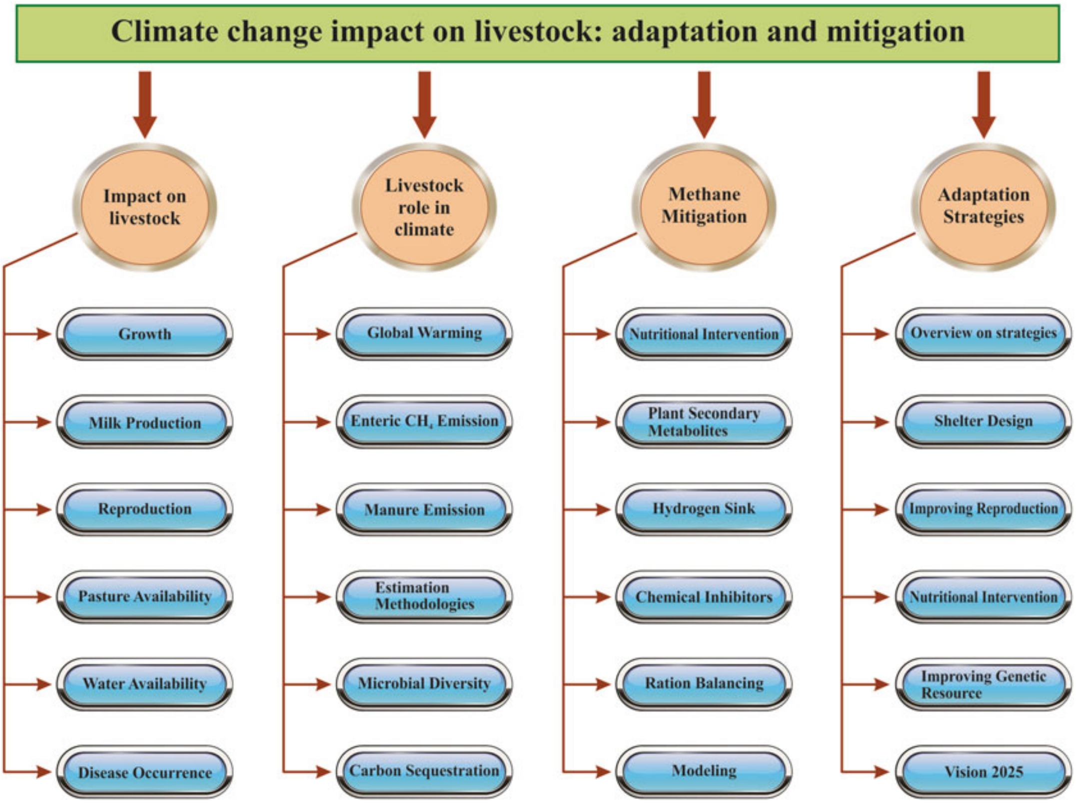


Fig. 1.1 Concepts of climate impact on livestock and its adaptation and mitigation

that has operated in the Earth's atmosphere for billions of years due to the presence of naturally occurring GHGs: water vapor, carbon dioxide (CO_2), ozone, methane (CH_4), and nitrous oxide (N_2O).

Different GHGs have differing abilities to warm the atmosphere. The net warming from an ensemble of GHGs depends on the size of the increase in concentration of each GHG, the radiative properties of the gases involved, and the concentrations of other GHGs already present in the atmosphere. Further, many GHGs reside in the atmosphere for centuries after being emitted, thereby introducing a long-term impact to positive radiative forcing. When radiative forcing changes, the climate system responds on various time scales. The longest of these are due to the large heat capacity of the deep ocean and dynamic adjustment of the ice sheets. This means that the transient response to a change (either positive or negative) may last for thousands of years. Any changes in the radiative balance of the Earth, including those due to an increase in GHGs or in aerosols, will alter the global hydrological cycle and atmospheric and oceanic circulation, thereby affecting weather patterns and regional temperatures and precipitation.

1.1.1 Different Sources of GHGs

There are two ways that GHGs enter Earth's atmosphere. One of them is through natural processes like animal and plant respiration. The other is through human activities. The main human sources of GHG emissions are fossil fuel use, deforestation, intensive livestock farming, use of synthetic fertilizers, and industrial processes. There are four main types of forcing GHGs: CO_2, CH_4, N_2O, and fluorinated gases. The main feedback of GHG is water vapor. The GHGs that humans do emit directly in significant quantities are (1) carbon dioxide – accounts for around three-quarters of the warming impact of current human GHG emissions. The key source of CO_2 is the burning of fossil fuels such as coal, oil, and gas, though deforestation is also a very significant contributor. (2) Methane – accounts for around 14 % of the impact of current human GHG emissions. Key sources of CH_4 include agriculture (especially livestock and rice fields), fossil fuel extraction, and the decay of organic waste in landfill sites. Methane doesn't persist in the atmosphere as long as CO_2, though its warming effect is much more potent for each gram of gas released. (3) Nitrous oxide – accounts for around 8 % of the warming impact of current human GHG emissions. Key sources of N_2O include agriculture (especially nitrogen-fertilized soils and livestock waste) and industrial processes. N_2O is even more potent per gram than methane.

1.1.2 Agricultural Contribution to Climate Change

Modern agriculture and food production and distribution are major contributors of GHGs. Agriculture is directly responsible for 14 % of total GHG emissions, and broader rural land use decisions have an even larger impact. Deforestation currently accounts for an additional 18 % of emissions. In this context, a historical perspective needs to be considered: Dr. Rattan Lal, professor of soil science at Ohio State University, has calculated that over the last 150 years, 476 billions of tonnes (Pg) of carbon have been emitted from terrestrial ecosystems which converted to agroecosystems through deforestation, soil cultivation, drainage, etc. since the dawn of settled agriculture.

Agriculture has significant effects on climate change, primarily through the production and release of GHGs such as CO_2, CH_4, and N_2O (Tubiello et al. 2013). Further, alterations in land cover can change its ability to absorb or reflect heat and light, thus contributing to radiative forcing. Land use changes such as deforestation and desertification together with fossil fuels are the major anthropogenic sources of CO_2. In addition, animal agriculture is the major contributor to increasing CH_4 and N_2O concentrations in the Earth's atmosphere.

The global food system, from fertilizer manufacture to food storage and packaging, is responsible for up to one-third of all human-caused GHG emissions, according to the latest figures from the Consultative Group on International Agricultural Research (CGIAR), a partnership of 15 research centers around the world. Using estimates from 2005, 2007, and 2008, the researchers found that agricultural production provides the huge share of GHG emissions from the food system, releasing up to 12 Pg of CO_2 equivalents a year – up to 86 % of all food-related anthropogenic GHG emissions. The global release of CH_4 from agricultural sources accounts for two-thirds of the anthropogenic CH_4 sources (Moss et al. 2000). These sources include rice growing, fermentation of feed by ruminants (enteric CH_4), biomass burning, and animal wastes. CH_4 is a potent GHG, and its release into the atmosphere is directly linked with animal agriculture, particularly ruminant production (Sejian et al. 2012a). Apart from this, livestock wastes also contribute enormously to the agricultural sources of CH_4 and N_2O.

1.2 Impact of Climate Change on Livestock Production

The second part of this volume addresses in detail the impact of climate change on livestock production. This part comprises of six chapters covering the direct impacts of climate change on livestock growth, milk production, reproduction, metabolic activity, and disease occurrences. This part also discusses elaborately on the indirect impacts of climate change on livestock, water and pasture availability, and other feed resources. In addition, this part highlights the significance of different inherent mechanisms by which livestock adapts to the changing climate.

1.2.1 Impact on Growth

It is known that livestock that are exposed to high ambient temperatures augment the efforts to dissipate body heat, resulting in the increase of respiration rate, body temperature, and consumption of water and a decline in feed intake (Marai et al.

2007; Sejian et al. 2010a). Apart from feed intake, feed conversion also significantly decreases after exposure to heat stress (Padua et al. 1997). Exposure of the animal to a high environmental temperature stimulates the peripheral thermal receptors to transmit suppressive nerve impulses to the appetite center in the hypothalamus and thereby causes a decrease in feed intake (Marai et al. 2007). The decrease in feed intake could be due to the adaptive mechanism of animal to produce less body heat. Growth, the increase in the live body mass or cell multiplication, is controlled both genetically and environmentally (Marai et al. 2007). Elevated ambient temperature is considered to be one of the environmental factors influencing growth and average daily weight gain in livestock (Habeeb et al. 1992; Ismail et al. 1995). The reason for the effects of elevated ambient temperature on growth reduction could be due to the decrease in anabolic activity and the increase in tissue catabolism (Marai et al. 2007). The increase in tissue catabolism could be attributed to the increase in catecholamines and glucocorticoids after exposure to heat stress in livestock.

1.2.2 Impact on Milk Production

The effect of elevated temperature on milk production is probably most deleterious for any animal production system which forces animal to reduce feed intake, resulting in lowered milk yield (Dunn et al. 2014). The heat stress not only decreases the milk yield in the animals but it also drastically affects the quality of milk (Bernabucci and Calamari 1998). Apart from high temperature, humidity is also an important factor influencing milk yield in the animals. The Jersey crossbreds were less affected by climate than Holstein crossbreds for average milk yield per day. The decreases in milk production can range from 10 to >25 %. As much as 50 % reduction in milk yield can be due to reduced feed intake during thermal stress, and other 50 % might depend on heat-related lactogenic hormone fluctuations (Johnson 1987). Besides the thermal stress, the decline in milk yield is also dependent upon breed, stage of lactation, and feed availability (Bernabucci and Calamari 1998). The effect of heat stress is more in high-yielding cow as compared to low-yielding cow.

The cow exposed to heat stress produces milk and colostrums with lower percentage of protein and fat (Nardone et al. 1997). Milk fat, milk protein, solid not fat (SNF), and total solid percentages were lower in the summer season in dairy cows (Bouraoui et al. 2002; Ozrenk and Inci 2008). Thermal stress also appears to bring about some decrease in percentage of lactose and acidity in the milk which in turn affects the milk freezing point. In addition to this, the heat stress-exposed animals' milk has lower value of calcium (Ca), phosphorus (P), and magnesium (Mg) and high chloride (Bernabucci et al. 2013). In heat-stressed cow, the proportion of short-chain (C4–C10) and medium-chain (C12–C16) fatty acids are low, while long-chain fatty acid (C17–C18) are more in milk (Bernabucci et al. 2013). These changes in the fatty acid chain may be due to reduced synthesis of these free fatty acids (FAA) in the mammary glands as well as due to negative energy status of the cow exposed to thermal stress. Heat stress also has a negative impact on the milk casein (α- and β-casein). The lower content of α- and β-casein tends to increase the pH of milk and lower P content, during the summer months (Kume et al. 1989).

1.2.3 Impact on Reproduction

Reproductive axis is one plane where stress effects are the most pronounced and have gross economic impact. Livestock farmers in arid and semiarid environment primarily depend on their livestock for their livelihood security. The key constraints in arid and semiarid tropical environment are their low biomass productivity, high climatic variability, and scarcity of water (Sejian 2013). All these constraints make these regions a major challenge for sustainable livestock production. In particular, the reproductive potential of livestock in these areas is influenced by the exposure to harsh climatic conditions, namely, high ambient temperature, and long-distance walking in search of food and water resources. It is an established fact that reproduction processes are influenced during thermal exposure in ruminant species (Naqvi et al. 2004) and glucocorticoids are paramount in mediating the inhibitory effects of stress on reproduction (Kornmatitsuk et al. 2008). Heat stress significantly reduces the level of primary reproductive hormone estradiol (Sejian et al. 2011a, 2013). Decreased concentration of estrogen may result from diminished ovarian follicular development caused by suppressed peripheral concentration of gonadotrophins following heat stress (Gougeon 1996). The impact of heat stress on plasma estradiol concentration could be both due to reduced GnRH secretion and reduced feed intake in ewes. Further, glucocorticoids are capable of enhancing the negative feedback effects of estradiol and reducing the stimulation of GnRH receptor expression by estrogen (Adams et al. 1999; Daley et al. 1999). Glucocorticoids may also exert direct inhibitory effects on gonadal steroid secretion and sensitivity of target tissues to sex steroids (Magiakou et al. 1997). Thermal stress influence on estrous incidences and embryo production is a well-established fact (Naqvi et al. 2004; Tabbaa et al. 2008; Sejian et al. 2014a). In the changing scenario of climate change, thermal stress along with feed and water scarcity is the major predisposing factor for the low productivity of ruminants under hot semiarid environment.

Livestock grazing under hot semiarid environment face extreme fluctuations in the quantity and quality of feed on offer throughout the year (Martin et al. 2004). It has been postulated that nutrition is one of the main factors affecting ovulation rate and sexual activity in sheep (Vinoles et al. 2005; Forcada and Albecia 2006). It is generally accepted that nutrition modulates reproductive endocrine functions in many species (Polkowska 1996; Martin et al. 2004). Further, undernutrition affects reproductive function in ruminants at different levels of the hypothalamic-pituitary-gonadal axis (Boland et al. 2001; Chadio et al. 2007). Nutrient deficiency that results following reduced feed intake after heat exposure potentially acts on the reproductive process and affects estrus behavior and ovulation rate. Further, undernutrition lowers estradiol concentration in sheep (Kiyma et al. 2004; Sejian et al. 2014b).

1.2.4 Impact on Pasture and Feed Availability for Livestock

Climate change and associated environmental stress such as drought, high/low temperature, ozone, elevated CO_2, soil water logging, and salinity affect the pasture and forage availability to livestock (Dawson et al. 2014). Collectively, stresses may reduce the harvested forage yield, alter its nutritive value, and change species composition of the sward. With the current societal emphasis on climate change and its related impact, forage crop production will become more important, and thus, the scientific knowledge of how abiotic or environmental stresses limit forage production must increase.

The most important impacts of climate change on grazing lands will likely be through changes in both pasture productivity and forage quality. However, there are several other impacts on grazing lands that researchers will have to address including botanical changes in vegetation composition; pests, diseases, and weeds; soil erosion; and animal husbandry and health (Hall et al. 1998). Rising temperatures could benefit pastures in cooler and boreal climates by increasing the length of the growing season and reducing frost damage. However, increased plant growth in the cooler months could deplete soil moisture at the expense of subsequent pasture growth in the spring. Changes in seasonal patterns of forage availability could pose additional challenges for grazing management. In warmer climates, increased heat stress and increased evaporative demand would likely have negative effects on pastures (Cobon and Toombs 2007). Further, drought, an environmental stress with periods of limited or no water during the growing season, reduces forage production for grazing and haymaking. Prolonged drought forces livestock and hay producers to better manage their fields to minimize recovery after the drought ends. Modeling studies that have calculated "safe" livestock carrying capacity from resource attributes and climate data have indicated that pasture growth is sensitive to small variations in climate and that responses to rainfall are nonlinear (Scanlan et al. 1994; Day et al. 1997).

1.2.5 Impact on Water Availability for Livestock

Researches pertaining to impact of climate change on water resources for livestock are very scanty. Water resources in particular are one sector which is highly vulnerable to climate change. Climate change and variability have the potential to impact negatively on water availability and access to and demand for water in most countries. Climate change will have far-reaching consequences for livestock production, mainly arising from its impact on rainfall patterns which later determine the quantity and quality of grassland and rangeland productivity (Assan 2014). Overall, the net impact of climate change on water resources and freshwater ecosystems will be negative due to diminished quantity and quality of available water (IPCC 2013). Increasing heat stress as a result of climate change will significantly increase water requirements for livestock. Climate change can often exacerbate water problems, for instance, where climate change has led to overgrazing in some areas which then suffer rapid runoff and flooding. The impact of climate change can aggravate water problem in hot semiarid areas leading to overgrazing which ultimately culminate in rapid runoff in these areas leading to flooding. Frequent droughts might be a cause of concern in terms of disease and parasites distribution and transmission, apart from the physical losses to livestock. As a result of climate change, all water resources will dry up due to extreme temperatures, and livestock production will be severely hampered in such cases (Rust and Rust 2013). Further, the drying of water resources will create a situation where livestock need to walk long distances in search of water, creating an additional stress to these animals. Hence, it's going to be a huge challenge for livestock researchers across the globe to develop appropriate strategies to ensure access to water for livestock production.

1.2.6 Impact on Disease Occurrences in Livestock

Global climate change alters ecological construction which causes both the geographical and phonological shifts (Slenning 2010). These shifts affect the efficiency and transmission pattern of the pathogen and increase their spectrum in the hosts (Brooks and Hoberg 2007). Increased spectrum of pathogen increases the disease susceptibility of the animal, and thus climate change supports the pathogenicity of the causative agent. Heavy rainfall causes flood and increases atmospheric humidity which results in favorable condition for the proliferation of pathogen, ticks, flies, and mosquitoes. These pathogens and insects may serve as vector or invader for the transmission of diseases in humans and livestock. Recent disease outbreaks are consistent with model projections that warmer and wetter conditions lead to greater transmission potential even at high altitudes and elevations. Mosquito-borne diseases are now reported at higher elevations than in the past at sites in Asia, Central Africa, and Latin America (Epstein et al. 1998). Environmental changes caused either by natural phenomenon or anthropogenic interference change the ecological balance and context within which disease hosts or vectors and parasites breed, develop, and transmit disease (Patz et al. 2000). Climate change affects the occurrence and spread of disease by impacting the population size and range of hosts and pathogens, the length of the transmission season, and the timing and intensity of outbreaks (Epstein et al. 1998). Pathogens from terrestrial and marine taxa are sensitive to hot temperature, heavy rainfall, and humidity. Climate warming can increase pathogen development and survival rates, disease transmission, and host susceptibility (Harvell et al. 2002). Understanding the spatial scale and temporal pattern of disease incidence is a fundamental prerequisite for the development of appropriate management and intervention strategies. It is particularly important given the need to understand the elevated risks linked to climate change (Rose and Wall 2011).

Global climate change predictions suggest that far-ranging effects might occur in the population dynamics and distributions of livestock parasites, provoking fears of widespread increases in disease incidence and production loss (Morgan and Wall 2009). Climatic restrictions on vectors, environmental habitats, and disease-causing agents are important for understanding the outbreak of several animal diseases. Changes in temperature and precipitation regimes may result in spread of disease and parasites in new regions or produce high incidence of diseases with concomitant decrease in animal productivity and increase in mortality (Baker and Viglizzo 1998). Baylis and Githeko (2006) evaluated the effect of climate change on parasites, pathogens, disease hosts, and disease vectors on domestic livestock. The potential clearly exists for the increased rate of development of pathogens and parasites due to early arrival of spring and warmer winters, and such seasonal change allows greater proliferation and survivability of these organisms. Warming and changes in rainfall distribution may lead to changes in spatial or temporal distributions of diseases such as anthrax, blackleg, hemorrhagic septicemia, and vector-borne diseases that thrive in the presence of moisture.

1.2.7 Adaptation Mechanisms of Livestock to Climate Change

The process by which the animals respond to extreme climatic condition includes: genetic or biological adaptation, phenotypic or physiological adaptation, acclimatization, acclimation, and habituation (Gaughan 2012). The behavioral and physiological mechanisms are the initial response by which livestock tries to adapt when exposed to adverse environmental condition. Neuroendocrine responses to stress play an integral role in the maintenance of homeostasis in livestock. Substantial evidence suggests that neuroendocrine responses vary with the type of stressor and are specific and graded, rather than “all or none.” While acute responses have important adaptive functions and are vital to coping and survival, chronic stressors elicit endocrine responses that may actually contribute to morbidity and mortality (Sejian et al. 2010b; Mohankumar et al. 2012). Integration of these responses is possible through the network of mutual interactions that exist between the immune system, the central nervous system, and the endocrine system. A crucial component of this network is the stress axis or hypothalamic-pituitary-adrenal (HPA) axis. Activation of the stress axis is accomplished through the release of several neurotransmitters and hormones.

Heat shock response is a rapid molecular mechanism, transient, and short acting which emerges via production of heat shock proteins (HSPs), subsequent to exposure of the cells to sublethal stress (Saxena and Krishnaswamy 2012). The heat shock response involves both heat shock factors (HSFs) and HSPs. The heat shock response is induced by accumulation of mis-folded proteins in the cytoplasm and is mediated by HSFs. HSF-1, HSF-2, HSF-3, and HSF-4 have been identified to date. HSF-1 plays a major role in heat shock response, while other members (HSF-2, HSF-4) are activated after prolonged stress or participate in normal cellular processes, embryonic development, and cellular differentiation. Once activated, the HSF-1 monomer trimerizes with other HSF-1 molecules which is essential for DNA binding. The activated complex can then enter the nucleus and initiate transcription of heat shock proteins.

Genetic selection has been a traditional method to reduce effects of environment on livestock by development of animals that are genetically adapted to hot climates. Despite the strong knowledge base about the physiological aspects, the effects of heat stress at the cellular and genetic level are not clearly understood. It is the cellular/molecular level at which stress also has its deleterious effects. Thus, the adaptive response is observed at cellular level as well, and an insight into the molecular/cellular mechanism of stress relieve is important (Naskar et al. 2012). As a result of stress, there are an increased number of nonnative conformational proteins with anomalous folding. Heat shock proteins, as we know, are evolutionary conserved, and many of them act as regulator of protein folding and structural functions of proteins. There is a presence of common environment-specific response genes, making 18–38 % of the genome. These genes induce expression of classical heat shock proteins, osmotic stress protectants, protein degradation enzyme, etc.

Functional genomic research is providing new knowledge about the impact of heat stress on livestock production and reproduction. Using functional genomics to identify genes that are regulated up or down during a stressful event can lead to the identification of animals that are genetically superior for coping with stress and toward the creation of therapeutic drugs and treatments that target affected genes. Given the complexity of the traits related to adaptation to tropical environments, the discovery of genes controlling these traits is a very difficult task. One obvious approach of identifying genes associated with acclimation to thermal stress is to utilize gene expression microarrays in models of thermal acclimation to identify changes in gene expression during acute and chronic thermal stress. Further, gene knockout models in single cells also allow for better delineation of the cellular metabolic machinery required to acclimate to thermal stress. With the development of molecular biotechnologies, new opportunities are available to characterize gene expression and identify key cellular responses to heat stress. These new tools enable to improve the accuracy and the efficiency of selection for heat tolerance. Epigenetic regulation of gene expression and thermal imprinting of the genome could also be an efficient method to improve thermal tolerance.

1.3 Role of Livestock in Climate Change

Part III of this volume deals with livestock role in climate change. The primary focus of this part is to address contribution of livestock and its related activities to global climate change. Globally, ruminant livestock are responsible for about 85 Tg of the 550 Tg CH_4 released annually (Sejian et al. 2011b). This part comprises six chapters covering in depth the livestock-related sources and sinks for GHG emission, enteric CH_4 emission, enteric CH_4 emission in different feeding systems, different methodologies to estimate enteric CH_4 emission, role of metagenomics in understanding rumen microbial diversity, and opportunities and challenges for livestock C sequestration.

1.3.1 Enteric Methane Emission

Ruminant animals, particularly cattle, buffalo, sheep, goat, and camels, produce significant amounts of CH_4 under the anaerobic conditions present as part of their normal digestive processes. This microbial fermentation process, referred to as "enteric fermentation," produces CH_4 as a by-product, which is released mainly through eructation and normal respiration, and small quantities as flatus. CH_4 production through enteric fermentation is of concern worldwide for its contribution to the accumulation of GHGs in the atmosphere, as well as its waste of fed energy for the animal. Among livestock, CH_4 production is greatest in ruminants, as methanogens are able to produce CH_4 freely through the normal process of feed digestion. Globally, ruminant livestock produce ~ 80 Tg of CH_4 annually, accounting for ~ 33 % of anthropogenic emissions of CH_4 (Beauchemin et al. 2008). CH_4 produced by cattle and other ruminants is actually a loss of feed energy from the diet and represents inefficient utilization of the feed. Enteric CH_4 is produced under anaerobic conditions in the rumen by methanogenic archaea, using CO_2 and H_2 to form CH_4, thus reducing the metabolic H_2 produced during microbial metabolism (McAllister and Newbold 2008). The amount of CH_4 produced from enteric fermentation is influenced by various factors including animal type and size, digestibility of the feed, and the intake of dry matter, total carbohydrates, and digestible carbohydrates (Wilkerson et al. 1995). Typically, about 6–10 % of the total gross energy consumed by the dairy cow is converted to CH_4 and released via the breath (Eckard et al. 2010). Therefore, reducing enteric CH_4 production may also lead to production benefits.

As animal production systems are vulnerable to climate change and are large contributors to potential global warming through CH_4, it is very vital to understand in detail the enteric CH_4 emission in different livestock species. Before targeting the reduction strategies for enteric CH_4 emission, it is very important to know the mechanisms of enteric CH_4 emission in livestock, the factors influencing such emission and prediction models, and estimation methodology for quantification of enteric CH_4 emission. The thorough understanding of these will in turn pave way for the formulation of effective mitigation strategies for minimizing enteric CH_4 emission in livestock.

1.3.2 Enteric Methane Emission Under Different Feeding System

Since CH_4 production is negatively correlated with total VFA and proportion of propionate (Wang et al. 2009), improvements in ruminal fermentation that favor propionic acid may also allow a decrease in CH_4 production, because propionic acid contains more hydrogen than other volatile fatty acids (VFA). Hence, the pattern of ruminal fermentation may be changed by the use of different cereal sources that encourage effective utilization of the other feed ingredients (Danielsson et al. 2014). The degradation rate of cereal starch differs based on the source (cornstarch less degradable than barley) which in turn may modify ruminal fermentation pattern (Schimidely et al. 1999). A higher content of fibrous carbohydrates in diets of low feeding value increases the CH_4 emitted per unit feed digested (Moe and Tyrell 1979). A higher rate or ruminal starch digestion for barley than for corn has resulted in greater efficiency of microbial synthesis for dairy ruminants (McCarty et al. 1989). An increase in the concentrate ratio may improve the nutritional status of animals and will also increase the ratio of propionic to acetic acid. Concentrate supplementation at higher levels sometimes leads to metabolic disorders, but ruminants can learn the physiological consequences of ingestion of particular feeds and can recognize the limit of feed ingredients offered as free choice according to their post-ingestive effects (Yurtseven and Gorgulu 2004) and thus can consume high concentrate feed without suffering from metabolic disorders (Fedele et al. 2002). Further, free choice system of feeding has been reported to emit lower CH_4 and CO_2 as compared to total mixed ration in sheep (Sabri et al. 2009). CH_4 production (g per unit production) is generally higher for ruminant livestock in extensive grassland-based systems than in intensive systems where diets offered are typically higher quality. In contrast, CH_4 production (g per day) is typically lower in grassland-based systems due to low levels of productivity (Sere and Gronewold 1996).

1.3.3 Estimation Methodologies for Enteric Methane Emission

Knowledge about methods used in quantification of GHG is currently needed to curtail global warming and to execute the international commitments to reduce the emissions. In the agricultural sector, one important task is to reduce enteric CH_4 emissions from ruminants. Accurate CH_4 measurements are required for identifying mitigation strategies that can discriminate among treatments relevant to on-farm conditions (Lassey 2008). Different methods for quantifying these emissions are presently being used and others are under development, all with different conditions for application (Storm et al. 2012; Bhatta et al. 2008). There are several methodologies available such as open-circuit respiration chambers, sulfur hexafluoride (SF6) tracer technique, inverse-dispersion technique, micrometeorological mass difference technique, and backward Lagrangian stochastic (bLS) dispersion technique (Sejian et al. 2011b). For researchers working with reduction of enteric methane emission, it is very important to understand the advantages and disadvantage of the different methods in use which will help them to quantify methane. Chapter 13 addresses in detail the different methodologies currently being employed and their significance in quantifying enteric CH_4 emission in ruminants.

1.3.4 GHG Emission from Livestock Manure

Livestock manure and its common use as fertilizer contribute to GHG emissions. Manure contains organic compounds such as carbohydrates and proteins. These relatively complex compounds are broken down naturally by bacteria. In the presence of oxygen (O_2), the action of aerobic bacteria results in the C being converted to CO_2, and, in the absence of O_2, anaerobic bacteria transform the C skeleton to CH_4. When livestock are in fields and their manure ends up being spread thinly on the ground, aerobic decomposition usually predominates. However, with modern intensive livestock practices, where animals are often housed or kept in confined spaces for at least part of the year, manure concentrations will be higher, and manure will often be stored in tanks or lagoons where anaerobic conditions generally predominate and CH_4 will be evolved. Animal wastes also contain N in the form of various complex compounds. The microbial processes of nitrification and denitrification of animal waste form N_2O. CH_4 and N_2O are the two major GHGs produced from livestock manure which has direct impact on global warming. Besides these GHG emissions, other emissions from livestock manure management systems are ammonia (NH_3), nitric oxide (NO), and non-CH_4 volatile organic compounds (NMVOC).

1.3.5 Significance of Metagenomics

Genetic and biological diversity of microorganisms is an important area of scientific research. Considering the importance of ruminants in livestock strategies, their ability to convert locally available feedstuff to animal products should be improved. Recent advances in the molecular biology and genomics now offer new opportunities to conduct a more holistic examination of the structure and function of rumen communities. To understand the complex microbial community function and how microbes interact within their niches represents a major challenge for rumen microbiologists today. Metagenomics has the potential for providing insight into the functional dimensions of the rumen genomic database and will help to achieve a major goal of rumen microbiology, the complexities of microbial community function and interaction among these microbes. This particular chapter in this volume will address in detail the molecular methods of culture-independent insight “metagenomics” and their recent application to study the rumen ecosystem for enhancing the livestock productivity.

1.3.6 Scope of Livestock Carbon Trading

IPCC undertook an initiative to tackle climate change issue and established international climate policy treaty Kyoto Protocol in 2005. The primary purpose of establishing KP is to frame rules and regulations for instructing countries with higher emission rate to curtail the reduction to a tune of 5.2 % below their 1990 levels over the commitment period 2008–2012. The cap set under the KP on the amount of GHGs that an Annex I country can produce is allocated (or auctioned) to the carbon-emitting entities in the country such as electric utilities, industrial units, etc., that is, the committed country, in turn, set quotas on the emissions of businesses. The quota permits are freely tradable and can be bought and sold in the form of carbon credits between businesses or in the international markets (Sirohi and Michaelowa 2008). The livestock sector offers huge scope for carbon trading. Based on the latest livestock census (2007) and the emission factors of bovine animals used by United Nations Framework Convention on Climate Change (UNFCCC), the current level of CH_4 emissions from bovine animals works out to be 8,832 Gg. Adding the emissions from the ovines (at 5 kg./annum from adult sheep and goat as per the IPCC default emission factors), the total CH_4 budget from enteric emissions is about 9,483 Gg at present, clearly indicating a large potential for carbon trading if the mitigation strategies can be effectively put in place (Sirohi et al. 2007).

1.4 Methane Mitigation Strategies in Livestock

Part IV of this volume covers CH_4 mitigation strategies in detail. The primary focus of this part would be to identify and discuss in detail the different strategies that are available to reduce livestock-related GHG emission. Various strategies such as manipulation of rumen microbial ecosystem, plant secondary metabolites, ration balancing, alternate hydrogen sinks, manure management, and significance of modeling in curtailing GHG emission will be covered in detail in six chapters.

There are many strategies that could be considered for the purpose of reducing CH_4 emissions from enteric fermentation in dairy farms. Although the reduction in GHG emissions from livestock industries is seen as a high priority, strategies for reducing emissions should not reduce the economic viability of enterprises if they are to find industry acceptability (Hascic et al. 2012). The reduction of enteric CH_4 emissions from livestock by selection for more feed-efficient animals based on their estimated breeding value offers a novel way of reducing the CH_4 production in livestock species without compromising the growth rate. Improved knowledge of quantitative nutrition provides powerful tools to develop concepts to undertake a wide range of problem-oriented research with the goal of curtailing CH_4 production by livestock farms. Many recommended on-farm practices, such as genetic selection for production traits, feed testing, and ration balancing, using CH_4 inhibitors can reduce enteric CH_4 emissions and reduce feed costs associated with higher animal production. Several other CH_4 reduction strategies are at various stages of investigation, such as the use of feed additives, ionophores, defaunation, and vaccination. With an improved understanding of how these mitigation strategies affect livestock responses in a whole-system context, there are grounds for optimism that in the medium term, new effective strategies may become available to supplement those presently available.

The metabolic pathways involved in hydrogen production and utilization, as well as the methanogenic community, are important factors that should be considered when developing strategies to control CH_4 emissions by ruminants. An integrated approach that considers the rumen microbiota, the animal, and the diet seems the best approach to find a long-term solution for reducing enteric CH_4 production by ruminants. It has been reported that enteric CH_4 is the most important GHG emitted (50–60 %) at the farm scale in ruminant production systems (Ogino et al. 2007). CH_4 represents also a significant energy loss to the animal ranging from 2 to 12 % of gross energy (GE) intake (Johnson and Johnson 1995). So, decreasing the production of enteric CH_4 from ruminants without altering animal production is desirable both as a strategy to reduce global GHG emissions and as a means of improving feed conversion efficiency. Any given strategy has to address one or more of the following goals: (1) reduction of hydrogen production that should be achieved without impairing feed digestion and (2) stimulation of hydrogen utilization toward pathways producing alternative end products beneficial for the animal and/or an inhibition of the methanogenic archaea (numbers and/or activity).

Responding to the challenges of global warming necessitates a paradigm shift in the practice of agriculture and in the role of livestock within the farming system. Science and technology are lacking in thematic issues, including those related to climatic adaptation, dissemination of new understandings in rangeland ecology, and a holistic understanding of pastoral resource management. There is a new need for further concerted research on methane emission by livestock and its mitigation. For instance, there are several new and more advanced CH_4 mitigation options, including the addition of probiotics, acetogens, bacteriocins, archaeal viruses, organic acids, and plant extracts to the diet, as well as immunization, and genetic selection of animals. Although these new strategies are promising, more research is needed for validation purposes and to assess in vivo their effectiveness in reducing CH_4 production in dairy animals. There is also a need to improve the efficacy of current strategies both economically for livestock production and increasing their capacity to limit emissions. Vaccine development against methanogens is promising and calls for concerted research efforts if this strategy is to become a reality. The development of biomarkers to identify low CH_4 emission animals or low CH_4-producing bacteria also merits further investigation.

1.4.1 Nutritional Interventions

Feeding management is one of the most important strategies for CH_4 mitigation in ruminants. Both the amount of digestible nutrients ingested and the composition of the diet are among major factors governing CH_4 production (Blaxter and Clapperton 1965; Bhatta et al. 2008). Increasing the level of concentrate in the diet leads to a reduction in CH_4 emissions as a proportion of energy intake or expressed by unit of animal product (milk and meat). Increasing energy density also increases productivity, thereby also contributing to decreased C per unit of product. Replacing structural carbohydrates from forages (cellulose, hemicellulose) in the diet with non-structural carbohydrates (starch and sugars) contained in most energy-rich concentrates is associated with increases in feed intake, higher rates of ruminal fermentation, and accelerated feed turnover, which results in large modifications of rumen physiochemical conditions and microbial populations. This results in a lower CH_4 production because the relative proportion of ruminal hydrogen sources declines, whereas that of hydrogen sinks increases.

Dietary fat seems a promising nutritional alternative to depress ruminal methanogenesis without affecting other ruminal parameters. The modes of action of lipids are multiple: a common effect for all lipid sources is that unlike other feed constituents such as forages and cereals, they are not fermented in the rumen, and thus the decrease in fermented organic matter leads to a decrease in CH_4. In addition, medium-chain FAs and polyunsaturated FAs also contribute to CH_4 decrease through a toxic effect on cellulolytic bacteria and protozoa (Doreau and Ferlay 1995; Nagaraja et al. 1997; Machmuller et al. 2003). These microbial changes favor a shift of ruminal fermentation toward propionate and thus to an increase in hydrogen utilization by this process. These multiple actions may impair digestion, if the number and activity of primary microbial fermenters are affected or if the negative effect on methanogens leads to an accumulation of hydrogen in the rumen. Methanogenesis tends to be lower when forages are ensiled than when they are dried, and when they are finely ground or pelleted than when coarsely chopped (Beauchemin et al. 2008).

1.4.2 Manipulation of Rumen Microbial Ecosystem

Hydrogen is the key element to consider for reducing CH_4 production (Joblin 1999). In the rumen ecosystem, the ubiquitous protozoa are large producers of this metabolic end product. In addition, a physical association between protozoal cells and methanogens exists in the rumen ecosystem that favors hydrogen transfer (Rose et al. 2014). The methanogens found both attached and inside ciliate protozoal cells have been estimated to contribute between 9 and 37 % of the rumen methanogenesis (Finlay et al. 1994; Newbold et al. 1995). Some lipids, saponins, tannins, and ionophores are toxic to protozoa. Ionophore antibiotics, such as monensin and lasalocid, are used to improve the efficiency of animal production and are known to decrease CH_4 production (Beauchemin et al. 2008). Their effect on other microbes associated with propionate production is the most likely mode of action. Ionophores also affect protozoa; the reduction and subsequent recovery in protozoal numbers perfectly matched CH_4 abatement up to 30 % and restoration to previous level in a cattle trial (Guan et al. 2006). For tannin-containing plants, the antimethanogenic activity has been attributed mainly to the group of condensed tannins. Two modes of action of tannins on methanogenesis have been proposed: a direct effect on ruminal methanogens and an indirect effect on hydrogen production due to lower feed degradation Tavendale et al. (2005). Saponins are glycosides found in many plants that have a direct effect on rumen microbes. Saponins decrease protein degradation and at the same time favor microbial protein and biomass synthesis (Makkar and Becker 1996): the two processes result in reduced availability of hydrogen for CH_4 production (Dijkstra et al. 2007). However, the mode of action of saponins seems to be mostly related to their antiprotozoal effect (Newbold and Rode 2006).

1.4.3 Secondary Plant Metabolites

The chemical composition of plants reveals that in addition to normal constituents like cellulose, hemicellulose, soluble sugars, proteins, fats, etc., there are also present some unique molecules. As these molecules are not synthesized as a result of primary metabolism of the plants, such compounds are known as plant secondary metabolites, which are usually meant for providing protection to the plants against predators, pathogens, invaders, etc. Several thousands of such metabolites have been identified. Majority of these compounds fall either in one of the category of lignins, tannins, saponins, terpenoids/volatile essential oils, alkaloids, etc. These plant secondary metabolites have antimicrobial activity, but their mechanism of action and inhibition of microbial growth is very specific, and therefore these are active against a specific group of microbes (Bhatta et al. 2012). This specificity of these plant secondary metabolites against microbial groups can be used for selective manipulation of rumen fermentation. The methanogens which are classified as archaea have a distinctly different chemical composition of the cell walls from that of the other true bacteria present in the rumen. Therefore, there is a possibility that any one of the plant secondary compounds might act as a selective inhibitor of methanogens and can be used as a feed additive for the manipulation of rumen fermentation (Bhatta et al. 2013a). The role of tannins, saponins, and essential oils has been proved in the inhibition of methanogens or the process of methanogenesis in the rumen (Hess et al. 2004; Agarwal et al. 2009; Bhatta et al. 2013b).

1.4.4 Ration Balancing Significance

A balanced ration is the amount of feed that will supply the proper amount and proportions of nutrients needed for an animal to perform a specific purpose such as growth, maintenance, lactation, or gestation. Ration balancing concept could be employed for enteric methane reduction. FAO (2012) signified the importance of ration balancing on enteric methane reduction in ruminants. Kannan and Garg (2009), apart from recording significant enteric methane reduction, also documented remarkable progress in animal performance utilizing a program to feed balanced rations to lactating cows ($n = 540$) and buffaloes ($n = 1,131$) in India. Evaluation of the nutritional status of animals showed that for 71 % of the animals, protein and energy intakes were higher, and for 65 %, Ca and P intakes were lower than the requirements. Balancing the rations significantly improved milk yield by 2–14 % and milk fat by 0.2–15 %. Feed conversion efficiency, milk N efficiency, and net daily income of farmers also increased as a result of the ration balancing. Thus, it is of paramount importance that science-based feeding systems and feed analysis are gradually introduced into developing countries with subsistence animal agriculture. This will not only have a measurable economic benefit for the farmer but will also help maximize production and feed utilization and consequently reduce GHG livestock emissions.

1.4.5 Alternate Hydrogen Sinks

Rumen fermentation results in the production of excess hydrogen, which needs to be removed from the rumen for the fermentation process and microbial growth to continue efficiently (Immig 1996). Several strategies for utilizing hydrogen in the rumen as alternatives to methanogenesis have been identified. Two approaches which could be promoted as alternative hydrogen sinks to methanogenesis are reductive acetogenesis and increased synthesis of propionate and butyrate through the provision of intermediates such as malate, fumarate, and crotonate. If we are to employ these strategies successfully, we need a more complete understanding of the physiology and ecology of the microorganisms underpinning these metabolic pathways. When methane reduction is attempted, it is therefore necessary to consider alternative hydrogen sinks to methanogenesis. The primary pathway for hydrogen utilization is through increased propionogenesis by addition of substrates (fumarate and malate) to the diet that support propionate production (Mitsumori and Sun 2008). In addition, propionate production can be increased by introducing bacteria expressing reductive acetogenesis into the rumen (Molano et al. 2008). Other reactions such as nitrate and nitrite reduction, reductive acetogenesis, and biohydrogenation of unsaturated fatty acid play a relatively minor role in hydrogen consumption within the rumen (Kobayashi 2010). The inhibition of methane production by nitrate is most likely attributable to the energetically more favorable use of hydrogen in the reduction of nitrate to ammonia. Sulfate reduction to hydrogen sulfide also consumes eight electrons and thus offers the same potential per mole to reduce methane emissions as nitrate (Ungerfeld and Kohn 2006).

1.4.6 Strategies to Reduce GHG Emission from Livestock Manure

There are two potential strategies for GHG reduction from animal manure. The first strategy is to capture the CH_4 and use it for energy, and the second strategy to reduce GHG emissions from animal manure is to eliminate the methane emissions by changing manure management. Composting animal manure has the potential to reduce emissions of N_2O and CH_4 from agriculture. Some of the common practices followed for reducing GHG from livestock manure are manure cooling, altering manure pH, compaction, frequent spreading, anaerobic digestion, covering manure storage, CH_4 use for energy, and manure aeration. The composition of livestock diets can also affect the amount and ratios of nitrogenous components excreted in manure (Paul et al. 1998), providing another route by which livestock feed can influence GHG emissions. Misselbrook et al. (2005) looked at the potential of increasing the tannin level in diets to decrease the rate of release of N_2O, but the net benefit is likely to depend on the composition of the manure and the ambient conditions. The mitigation potential and financial viability of these potentially significant management opportunities require further research before widespread implementation.

1.4.7 Modeling of GHG in Livestock Farm

In the wake of the current global climate crisis, it has become increasingly clear that there is an urgent need to not only better understand the magnitude of the livestock sector's overall contribution to GHG emissions but also to identify effective approaches to reduce emissions. Enteric fermentation, manure management, and farmland activities are the major sources of GHGs from farms. Since on-site measurement of GHG emissions from livestock production facilities requires complex and often expensive equipment, estimates of emissions from individual farms or from different farming systems may need to be made by means of prediction equations. Models of rumen function aim at an improved prediction of fermentation in the rumen for practical purposes, e.g., microbial representations in protein evaluation systems, or at an improved understanding and integration for research purposes. Such quantitative approaches may be broadly classified into empirical and mechanistic models. Broadly, there are two types of models present, viz., empirical/statistical and mechanistic/dynamic model. At present, among two models, mostly mechanistic models are used to estimate CH_4 emissions from enteric fermentation at a national and global level. Empirical models use experimental data to quantify relationships directly. In contrast, mechanistic models are constructed by examining the structure of a system and analyzing the behavior of the system in terms of its individual components and their interactions. The low prediction accuracy of empirical CH_4 prediction models in whole farm models may introduce substantial error into inventories of GHG emissions and lead to incorrect mitigation recommendations. Therefore, the impact of mitigation strategies to reduce CH_4 emissions has to be assessed holistically, and empirical models lack the biological basis for such an assessment. Various mechanistic models have been developed that account for the most important features of ruminal digestion and microbial metabolism (Ellis et al. 2007; Chianese et al. 2009).

Mechanistic models are important tools for assessing mitigation options and for directing experimental research toward options most likely to result in significant reduction of CH_4 emissions from enteric fermentation. Some models have been developed specifically to predict GHG emissions from animals, and others have either been modified or adapted to estimate GHG emission from the entire farm (Sejian et al. 2011c). Computer simulation provides a cost-effective and an efficient method of estimating GHG emissions from dairy farms, and data inputs from management scenarios may affect generated GHG emission results. The integrated farm system model (IFSM) has been used effectively in dairy farms to predict the whole farm GHG emissions (Rotz et al. 2009). IFSM predicts the effect of management scenarios on farm performance, profitability, and environmental pollution. Future developments in the area of modeling must accompany any improved understating of the underlying rumen biology. Furthermore, the need to develop simpler and more accurate models compatible with current trends in computer technology cannot be overemphasized.

1.5 Amelioration Strategies to Improve Livestock Production Under Changing Climate

Part V of this volume elaborates on ameliorative strategies that should be given due consideration to prevent economic losses incurred due to climate change on livestock productivity. This part comprises of five chapters covering in detail different adaptation, mitigation, and amelioration strategies. Efforts are made in this chapter to propose suitable shelter design for different livestock under the changing climate scenario. Special emphasis would be given to highlight those strategies that are essential to improve production and reproduction in livestock from climate change perspectives. Emphasis has also been given to identify different strategies pertaining to improving livestock genetic resources to target developing different livestock breeds of high thermotolerance.

Reducing heat stress in livestock requires multidisciplinary approaches which emphasize animal nutrition, housing, and animal health. It is important to understand the livestock responses to environment, analyze them, in order to design modifications of nutritional and environmental management thereby improving animal comfort and performance (Dunshea et al. 2013). Management alternatives, such as the strategic use of wind protection and bedding in the winter or sprinklers and shade in the summer, need to be considered to help livestock cope with adverse conditions. In addition to these changes, manipulation of diet energy density and intake may also be beneficial for livestock challenged by environmental conditions. Additionally, socioeconomical status, technological tools, and financial infrastructure have instrumental roles in modifying environment stress. The ameliorative measures, to be incorporated, are therefore driven by socioeconomical and environmental factors (Dhakal et al. 2013).

1.5.1 Ideal Shelter Design for Different Livestock

While new knowledge about animal responses to the environment continues to be developed, managing animal to reduce the impact of climate remains a challenge. Changing animal housing to reduce the magnitude of heat stress offers the most immediate and cost-effective approach. The main climatic factors from which protection is needed are high and low ambient temperatures, environmental humidity, solar radiation, wind, and rain. The basic requirement of good animal housing is that it should alter or modify the environment for the benefit of animals and also protect them from predation and theft. Animal housing should buffer the animal from climate extremes to reduce stress allowing optimal animal performance in terms of growth, health, and reproduction.

There are various housing and floor designs that can be used depending on the production system employed and local climate. Cost of construction, ease of cleaning, proper ventilation and drainage, and adequate lighting are important aspects to be considered in designing a house. For construction of farm buildings, selection of site is most important. Proper housing is conducive to good health, comfort, and protection from inclement weather and would enable the animals to utilize their genetic ability and feed for optimal production. Animal housing in tropical and semitropical regions should be kept to a minimum except for intensive production systems. In the arid tropics, no protection other than natural shade may be required. In humid climates, a simple thatched shelter will provide shade and protection from excessive rain. Adequate ventilation within the housing system is essential in maintaining animal health.

1.5.2 Strategies to Improve Livestock Reproduction

Under the climate change scenario, elevated temperature and relative humidity will definitely impose heat stress on all the species of livestock and will adversely affect their production and reproduction specially dairy cattle. Fortunately, proven strategies exist to mitigate some effects of heat stress on animal reproduction. These include housing animals in facilities that minimize heat stress, use of timed artificial insemination (AI) protocols to overcome poor estrus detection, and implementation of embryo transfer programs to bypass damage to the oocyte and early embryo caused by heat stress. There are also several promising avenues of research that may yield new approaches for enhancing reproduction during heat stress. These include administration of antioxidants and manipulation of the bovine somatotropin insulin-like growth factor-1 (bST-IGF-1) axis. Opportunities also exist for manipulating animal genetics to develop an animal that is more resistant to heat stress. Genes in animals exist for regulation of body temperature and for cellular resistance to elevated temperature, and identification and incorporation of these genes into heat-sensitive breeds in a manner that does not reduce production and reproduction would represent an important achievement.

1.5.3 Nutritional Interventions to Sustain Livestock Production

During hot dry summer, there is a decrease in dietary feed intake which is responsible for the reduced productivity. In this situation, the efficient practical approaches like frequent feeding, improved forage quality, use of palatable feeds, good nutrition balance, and greater nutrient density are required (Sejian et al. 2012b). Feeding more concentrate at the expense of fibrous ingredients increases ration energy density and reduces heat increment. Increased feeding of concentrates is a common practice during conditions conducive to heat stress, but maximal benefit from concentrates appears to be approximately 60–65 % of the diet. Feeding high-quality forages and balanced rations will decrease some of the effects of heat stress. Feeding a high-quality bypass fat provides an energy-dense diet at a time when cows are consuming little feed. The use of fat in diets could also lower the heat load because of high energy density and lower metabolic heat when compared with other ingredients such as fiber and carbohydrate. Nutritional tools such as antioxidant feeding (Vit-A, selenium, zinc, etc.) and ruminant-specific live yeast can help (Sejian et al. 2014a). Studies have shown that addition of antioxidant in diets of cows is able to reduce stress and is a good strategy to prevent mastitis, optimize feed intake, and reduce the negative impact of heat stress on milk production and quality. Moreover, the use of antioxidants such as Vit-E, Vit-A, selenium, and selenium-enriched yeast helps reduce the impact of heat stress on the oxidant balance, resulting in improved milk quality and cow health.

1.5.4 Strategies to Improve Livestock Genetic Resources

There are clear genetic differences in resistance to heat stress, with tropically adapted breeds experiencing lower body temperatures during heat stress than nonadapted breeds. Even in nonadapted breeds, it is probably possible to perform genetic selection for resistance to heat stress since the heritability estimate for rectal temperature in cattle is high (0.25–0.65). There are also specific genes that could be selected which confer increased thermoregulatory ability, including those for coat color and the slick gene identified in Senepol cattle that causes short hair length. It may be possible to identify genes that control cellular resistance to elevated temperature (Collier et al. 2008). The superior fertility of tropically adapted breeds during heat stress is a function in large part of the enhanced ability of animals from these breeds to regulate body temperature in response to heat stress. Identification of the genes responsible for enhanced cellular resistance to heat shock may allow these genes to be transferred into thermally sensitive breeds through conventional or transgenic breeding techniques to produce an animal whose oocytes and embryos have increased resistance to elevated temperature (Collier et al. 2008).

1.6 Climate Change and Livestock Production: Research and Development Priorities

Part VI is the last part of this volume which summarizes the opinion of different contributors. This part also signifies the importance of planning that is needed to develop strategies that will help to sustain livestock production under the changing climate scenario keeping in view the adverse impact of climate change by 2025. The primary focus of the part would be on the projected climate change impact on livestock production by 2025, and the ways that agricultural systems and the people that manage and govern them need to change in the next 10 years in order to achieve food security through livestock sector. The focal point of discussion in this part would be to signify the importance of minimizing climatic change on animal husbandry. While attempts to reduce the GHG emissions are an important response to the threat of climate change, adaptation to climate change in addition to mitigation will also form a necessary part of the response. The chapter on vision 2025 attempts to project strategies to sustain livestock production under the changing climate scenario. The chapter will highlight the significance of improving the adaptive and resilience capacity of livestock to climate change apart from discussing different approaches for curtailing methane emission from ruminant livestock. This chapter also highlights the several institutional measures that need to be taken to support the adaptation process and also focuses on the technological interventions that are needed to meet the climate change challenge. Efforts are being made in this chapter to signify the importance of developing breeds with high thermotolerance and the challenges associated while formulating such breeding programs under changing climate scenario.

References

Adams TE, Sakurai H, Adams BM (1999) Effect of stress like concentrations of cortisol on estradiol dependent expression of gonadotropin-releasing hormone receptor in orchidectomized sheep. Biol Reprod 60:164–168

Agarwal N, Chandra S, Kumar R, Chaudhary LC, Kamra DN (2009) Effect of peppermint (*Mentha piperita*) oil on *in vitro* methanogenesis and fermentation of feed with buffalo rumen liquor. Anim Feed Sci Technol 148:321–327

Amundson JL, Mader TL, Rasby RJ, Hu QS (2006) Environmental effects on pregnancy rate in beef cattle. J Anim Sci 84:3415–3420

Assan N (2014) Possible impact and adaptation to climate change in livestock production in Southern Africa. IOSR J Environ Sci Toxicol Food Technol 8(2):104–112

Baker B, Viglizzo JF (1998) Rangelands and livestock. In: Feenstra JF, Burton I, Smith JB, Tol RSJ (eds) Handbook of methods for climate change impact assessment and adaptation strategies. IVM/UNEP version 2.0. http://130.37.129.100/ivm/pdf/handbook_range.pdf. Accessed 22 Sept 2002

Baylis N, Githeko AK (2006) The effects of climate change on infectious diseases of animals. T7.3. Foresight. Infectious diseases: preparing for the future. Office and Science Innovation (www.foresight.gov.uk)

Beauchemin KA, Kreuzer M, O'Mara F, McAllister TA (2008) Nutritional management for enteric methane abatement: a review. Aust J Exp Agric 48:21–27

Bernabucci U, Calamari L (1998) Effect of heat stress on bovine milk yield and composition. Zootec Nutr Anim 24:247–257

Bernabucci U, Basiricò L, Morera P (2013) Impact of hot environment on colostrum and milk composition. Cell Mol Biol 59(1):67–83

Bhatta R, Enishi O, Takusari N, Higuchi K, Nonaka I, Kurihara M (2008) Diet effects on methane production by goats and a comparison between measurement methodologies. J Agric Sci (Camb) 146:705–715

Bhatta R, Saravanan M, Baruah L, Sampath KT (2012) Nutrient content, in vitro ruminal fermentation characteristics and methane reduction potential of tropical tannin-containing leaves. J Sci Food Agric 92:2929–2935

Bhatta R, Saravanan M, Baruah L, Sampath KT, Prasad CS (2013a) In vitro fermentation profile and methane reduction in ruminal cultures containing secondary plant compounds. J Appl Microbiol 115:455–465

Bhatta R, Baruah L, Saravanan M, Suresh KP, Sampath KT (2013b) Effect of tannins from medicinal and aromatic plants on rumen fermentation, protozoa population and methanogenesis in vitro. J Anim Physiol Anim Nutr 97:446–456

Blaxter KL, Clapperton JL (1965) Prediction of the amount of methane produced by ruminants. Br J Nutr 19:511–522

Boland MP, Lonergan P, O'Callaghan D (2001) Effect of nutrition on endocrine parameters, ovarian physiology, oocyte and embryo development. Theriogenology 55:1323–1340

Bouraoui R, Lahmar M, Majdoub A, Djemali M, Belyea R (2002) The relationship of temperature humidity index with milk production of dairy cows in a Mediterranean climate. Anim Res 51:479–491

Brooks DR, Hoberg EP (2007) How will global climate change affect parasite–host assemblages. Trends Parasitol 23(12):571–574

Chadio SE, Kotsampasi B, Papadomichelakis G, Deligeorgis S, Kalogiannis D, Menegatos D, Zerwas G (2007) Impact of maternal undernutrition on the hypothalamic –pituitary-adrenal axis responsiveness in the sheep at different ages postnatal. J Endocrinol 192:495–503

Chianese DS, Rotz CA, Richard TL (2009) Whole farm greenhouse gas emissions: a review with application to a Pennsylvania dairy farm. Appl Eng Agric 25(3):431–442

Cobon DH, Toombs NR (2007) Climate change impacts on the water resources of the Cooper Creek catchment. In: Proceedings of MODSIM Congress' Christchurch, pp 483–489

Collier RJ, Collier JL, Rhoads RP, Baumgard LH (2008) Invited review: genes involved in the bovine heat stress response. J Dairy Sci 91(2):445–454

Daley CD, Sakurai H, Adams BM, Adams TE (1999) Effect of stress like concentrations of cortisol on gonadotroph function in orchidectomized sheep. Biol Reprod 60:158–163

Danielsson R, Werner-Omazic A, Ramin M, Schnürer A, Griinari M, Dicksved J, Bertilsson J (2014) Effects on enteric methane production and bacterial and archaeal communities by the addition of cashew nut shell extract or glycerol—an in vitro evaluation. J Dairy Sci 97(9):5729–5741

Dawson IK, Carsan S, Franzel S, Kindt R, van Breugel P, Graudal L, Lillesø JPB, Orwa C, Jamnadass R (2014) Agroforestry, livestock, fodder production and climate change adaptation and mitigation in East Africa: issues and options. ICRAF working paper no. 178. World Agroforestry Centre, Nairobi

Day KA, Scattini WJ, Osborne JC (1997) Extending carrying capacity calculations to the central Burnett region of Queensland. Stafford Smith DM, Clewet JF, Moore AD, McKeon GM, Clark R (eds) Drought Plan working paper no. 10. CSIRO, Alice Springs

Dhakal CK, Regmi PP, Khanal B, Bhastta UK (2013) Perception, impact and adaptation to climate change: an analysis of livestock system in Nepal. J Anim Sci Adv 3(9):462–471

Dijkstra J, Bannink A, France J, Kebreab E (2007) Nutritional control to reduce environmental impacts of intensive dairy cattle systems. In: Meng QX, Ren LP, Cao ZJ (eds) Proceedings of the VII international symposium on the nutrition of herbivores. China Agricultural University Press, Beijing, pp 411–435

Doreau M, Ferlay A (1995) Effect of dietary lipids on nitrogen metabolism in the rumen: a review. Livest Prod Sci 43:97–110

Dunn RJH, Mead NE, Willett KM, Parker DE (2014) Analysis of heat stress in UK dairy cattle and impact on milk yields. Environ Res Lett 9:064006 (11 pp)

Dunshea FR, Leury BJ, Fahri F, DiGiacomo K, Hung A, Chauhan S, Clarke IJ, Collier R, Little S, Baumgard L, Gaughan JB (2013) Amelioration of thermal stress impacts in dairy cows. Anim Prod Sci 53(9):965–975

Eckard RJ, Grainger C, de Klein CAM (2010) Options for the abatement of methane and nitrous oxide from ruminant production: a review. Livest Sci 130:47–56

Ellis JL, Kebreab E, Odongo NE, McBride BW, Okine EK, France J (2007) Prediction of methane production from dairy and beef cattle. J Dairy Sci 90:3456–3467

Epstein P, Diaz H, Elias S, Grabherr G, Graham N, Martens W, Thompson EM, Susskind J (1998) Biological and physical signs of climate change, focus on mosquito borne diseases. Bull Am Meteorol Soc 79:409–417

FAO (2006) World agriculture: towards 2030/2050: prospects for food, nutrition, agriculture and major commodity groups. Interim report, Global Perspective Studies Unit, Food and Agriculture Organization of the United Nations, Rome

FAO (2012) Balanced feeding for improving livestock productivity – increase in milk production and nutrient use efficiency and decrease in methane emission. In: Garg MR (ed) FAO animal production and health paper no. 173. Food and Agriculture Organization of the United Nations, Rome

Fedele VS, Claps R, Rubino M, Calandrelli M, Pilla AM (2002) Effect of free choice and traditional feeding system on goat feeding behaviour and intake. Livest Prod Sci 74:19–31

Finlay BJ, Esteban G, Clarke KJ, Williams AG, Embley TM, Hirt RP (1994) Some rumen ciliates have endosymbiotic methanogens. FEMS Microbiol Lett 117:157–162

Forcada F, Albecia AJ (2006) The effect of nutrition on the seasonality of reproduction in ewes. Reprod Nutr Dev 46:355–365

Gaughan JB (2012) Basic principles involved in adaption of livestock to climate change. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GMbH Publisher, Germany, Berlin, Heidelberg, pp 245–261

Gaughan JG, Goopy J, Spark J (2002) Excessive heat load index for feedlot cattle. In: Meat and Livestock-Australia project report, FLOT.316. MLA Ltd, Sydney

Gougeon A (1996) Regulation of ovarian follicular development in primates: facts and hypotheses. Endocr Rev 17:121–155

Guan H, Wittenberg KM, Ominski KH, Krause DO (2006) Efficacy of ionophores in cattle diets for mitigation of enteric methane. J Anim Sci 84:1896–1906

Habeeb AA, Marai IFM, Kamal TH (1992) Heat stress. In: Philips C, Piggens D (eds) Farm animals and the environment. CAB International, Wallingford, pp 27–47

Hall WB, McKeon GM, Carter JO, Day KA, Howden SM, Scanlan JC, Johnston PW, Burrows WH (1998) Climate change in Queensland's grazing lands: II. An assessment of the impact on animal production from native pastures. Rangel J 20:177–205

Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS, Samuel MD (2002) Climate warming and disease risks for terrestrial and marine biota. Science 296:2158–2162

Hascic I, Watson F, Johnstone N, Kaminker C (2012) Recent trends in innovation in climate change mitigation technologies. In: Organisation for Economic Co-operation and Development (ed) Energy and climate policy: bending the technological trajectory. OECD Publishing, Paris, p 44

Hatfield J, Boote K, Fay P, Hahn LC, Izaurralde BA, Kimball T, Mader J, Morgan D, Ort W, Polley A, Thomson, Wolfe D (2008) Agriculture. In: The effects of climate change on agriculture, land resources, water resources, and biodiversity in the United States. A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Washington, DC, p 362

Havlík P, Valin H, Herrero M, Obersteiner M, Schmidd E, Rufino MC, Mosnier A, Thornton PK, Böttcher H, Conant RT, Frank S, Fritz S, Fuss S, Kraxner F, Notenbaert A (2014) Climate change mitigation through livestock system transitions. Proc Natl Acad Sci 111(10):3709–3714

Hess HD, Beuret RA, Lotscher M, Hindrichsen IK, Machmüller A, Carulla JE, Lascano CE, Kreuzer M (2004) Ruminal fermentation, methanogenesis and nitrogen utilization of sheep receiving tropical grass hay-concentrate diets offered with *Sapindus saponaria* fruits and *Cratylia argentea* foliage. Anim Sci 79:177–189

Immig I (1996) The rumen and hindgut as a source of ruminant methanogenesis. Environ Monit Assess 42:57–72

IPCC (Intergovernmental Panel on Climate Change) (2013) Impacts, adaptation and vulnerability. http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-TS_FGDall.pdf

Ismail E, Abdel-Latif H, Hassan GA, Salem MH (1995) Water metabolism and requirement of sheep as affected by breed and season. World Rev Anim Prod 30(1–2):95–105

Joblin KN (1999) Ruminal acetogens and their potential to lower ruminant methane emissions. Aust J Agric Res 50:1307–1313

Johnson HD (1987) Part II, chapter 3: Bioclimate effects on growth, reproduction and milk production. In: Bioclimatology and the adaptation of livestock. Elsevier, Amsterdam

Johnson KA, Johnson DE (1995) Methane emissions from cattle. J Anim Sci 73:2483–2492

Kannan A, Garg MR (2009) Effect of ration balancing on methane emission reduction in lactating animals under field conditions. Indian J Dairy Sci 62(4):292–296

Kiyma Z, Alexander BM, Van Kirk EA, Murdoch WJ, Hallford DM, Moss GE (2004) Effect of feed restriction on reproductive and metabolic hormones in ewes. J Anim Sci 82:2548–2557

Kobayashi Y (2010) Abatement of methane production from ruminants: trends in the manipulation of rumen fermentation. Asian-Australas J Anim Sci 23(3):410–416

Kornmatitsuk B, Chantaraprateep P, Kornmatitsuk S, Kindahl H (2008) Different types of postpartum luteal activity affected by the exposure of heat stress and subsequent reproductive performance in Holstein lactating cows. Reprod Domest Anim 43:515–519

Kume S, Takahashi S, Kurihara M, Aii T (1989) The effects of a hot environment on the major mineral content in milk. Jpn J Zootech Sci 60:341–345

Lassey KR (2008) Livestock methane emission and its perspective in the global methane cycle. Aust J Exp Agric 48:114–118

Machmuller A, Soliva CR, Kreuzer M (2003) Methane-suppressing effect of myristic acid in sheep as affected by dietary calcium and forage proportion. Br J Nutr 90:529–540

Magiakou MA, Mastorakos G, Webster E, Chrousos GP (1997) The hypothalamic-pituitary-adrenal axis and the female reproductive system. Ann N Y Acad Sci 816:42–56

Makkar HPS, Becker K (1996) Effect of pH, temperature, and time on inactivation of tannins and possible implications in detannification studies. J Agric Food Chem 44:1291–1295

Marai IFM, El-Darawany AA, Fadiel A, Abdel-Hafez MAM (2007) Physiological traits as affected by heat stress in sheep – a review. Small Rumin Res 71:1–12

Martin GB, Rogar J, Blache D (2004) Nutritional and environmental effects on reproduction in small ruminants. Reprod Fertil Dev 16:491–501

McAllister TA, Newbold CJ (2008) Redirecting rumen fermentation to reduce methanogenesis. Aust J Exp Agric 48:7–13

McCarty RD, Klusmeyer TH Jr, Vicini JL, Clark JH, Nelson DR (1989) Effect of source of protein and carbohydrate on ruminal fermentation and passage of nutrients to the small intestine of lactating cows. J Dairy Sci 72:2002–2016

Misselbrook TH, Powell JM, Broderick GA, Grabber JH (2005) Dietary manipulation in dairy cattle: laboratory experiments to assess the influence on ammonia emissions. J Dairy Sci 88:1765–1777

Mitsumori M, Sun W (2008) Control of rumen microbial fermentation for mitigating methane emissions from the rumen. Asian-Australas J Anim Sci 21:144–154

Moe PW, Tyrell HF (1979) Methane production in dairy cows. J Dairy Sci 62:1583–1586

Mohankumar SMJ, Balasubramanian P, Dharmaraj M, Mohankumar PS (2012) Neuroendocrine regulation of adaptive mechanisms in livestock. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GMbH Publisher, Germany, Berlin, Heidelberg, pp 263–298

Molano G, Knight TW, Clark H (2008) Fumaric acid supplements have no effect on methane emissions per unit of feed intake in wether lambs. Aust J Exp Agric Sci 48:165–168

Morgan ER, Wall R (2009) Climate change and parasitic disease, farmer mitigation? Trends Parasitol 25(7):308–313

Moss AR, Jounany JP, Neevbold J (2000) Methane production by ruminants: its contribution to global warming. Ann Zootech 49:231–253

Nagaraja TG, Newbold CJ, Van Nevel CJ, Demeyer DI (1997) Manipulation of ruminal fermentation. In: Hobson PN, Stewart CS (eds) The rumen microbial ecosystem. Blackie Academic and Professional, London, pp 523–632

Naqvi SMK, Maurya VP, Gulyani R, Joshi A, Mittal JP (2004) The effect of thermal stress on superovulatory response and embryo production in Bharat Merino ewes. Small Rumin Res 55:57–63

Nardone A, Lacetera N, Bernabucci U, Ronchi B (1997) Composition of colostrum from dairy heifers exposed to high air temperatures during late pregnancy and the early postpartum period. J Dairy Sci 80:838–844

Naskar S, Gowane GR, Chopra A, Paswan C, Prince LLL (2012) Genetic adaptability of livestock to environmental stresses. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GMbH Publisher, Germany, Berlin, Heidelberg, pp 317–378

Newbold CJ, Rode LM (2006) Dietary additives to control methanogenesis in the rumen. In: Soliva CR, Takahashi J, Kreuzer M (eds) Greenhouse gases and animal agriculture: an update Elsevier International Congress Series, 1293. Elsevier, Amsterdam, pp 138–147

Newbold CJ, Lassalas B, Jouany JP (1995) The importance of methanogens associated with ciliate protozoa in ruminal methane production in vitro. Lett Appl Microbiol 21:230–234

NRC (National Research Council) Committee on Animal Nutrition, Subcommittee on Environmental Stress (1981) Effect of environment on nutrient requirements of domestic animals. National Academy Press, Washington, DC

Ogino A, Orito H, Shimadad K, Hirooka H (2007) Evaluating environmental impacts of the Japanese beef cow–calf system by the life cycle assessment method. Anim Sci J 78:424–432

Ozrenk E, Inci SS (2008) The effect of seasonal variation on the composition of cow milk in Van Province. Pak J Nutr 7:161–164

Padua JT, Dasilva RG, Bottcher RW, Hoff SJ (1997) Effect of high environmental temperature on weight gain and food intake of Suffolk lambs reared in a tropical environment. In: Proceedings of 5th international symposium, Bloomington, Minnesota, USA, pp 809–815

Patz JA, Thaddeus K, Graczyk Geller N, Vittor AY (2000) Effects of environmental change on emerging parasitic diseases. Int J Parasitol 30:1395–1405

Paul JW, Dinn NE, Kannangara T, Fisher LJ (1998) Protein content in dairy cattle diets affects ammonia losses and fertilizer nitrogen value. J Environ Qual 27:528–534

Polkowska J (1996) Stress and nutritional influences on GnRH and somatostatin neuronal systems in the ewe. Acta Neurobiol Exp 56:797–806

Rogelj J, Meinshausen M, Knutti R (2012) Global warming under old and new scenarios using IPCC climate sensitivity range estimates. Nat Clim Chang 2(4):248–253

Rose H, Wall R (2011) Modelling the impact of climate change on spatial patterns of disease risk, Sheep blowfly strike by *Lucilia sericata* in Great Britain. Int J Parasitol 41(7):739–746

Rose H, Hoar B, Kutz SJ, Morgan ER (2014) Exploiting parallels between livestock and wildlife: predicting the impact of climate change on gastrointestinal nematodes in ruminants. Int J Parasitol Parasite Wildl 3:209–219

Rotz CA, Corson MS, Chianese DS, Coiner CU (2009) The integrated farm system model: reference manual. USDAARS Pasture Systems and Watershed Management Research Unit, University Park. www.ars.usda.gov/SP2UserFiles/Place/19020000/ifsmreference

Rust JM, Rust T (2013) Climate change and livestock production: a review with emphasis on Africa. S Afr J Anim Sci 43(3):255–267

Sabri Y, Mehmet C, Irfan O, Abdullah C, Mustafa B, Tekin S, Huseyin T (2009) Effect of different feeding method on methane and carbon dioxide emissions milk yield and composition of lactating Awassi sheep. Asian J Anim Vet Adv 4(6):278–287

Saxena VK, Krishnaswamy N (2012) Molecular mechanisms of livestock adaptation. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GMbH Publisher, Germany, Berlin, Heidelberg, pp 299–315

Scanlan JC, Hinton AW, McKeon GM, Day KA, Mott JJ (1994) Estimating safe carrying capacities of extensive cattle-grazing properties within tropical, semi-arid woodlands of north-eastern Australia. Rangel J 16:76

Schimidely P, Lloret M, Pujol P, Bas A, Ruozeau C, Sauvant D (1999) Influence of feed intake and sources of dietary carbohydrate on metabolic response to propionate and glucose challenges in lactating goats. J Dairy Sci 82:738–746

Sejian V (2013) Climate change: impact on production and reproduction, adaptation mechanisms and mitigation strategies in small ruminants: a review. Indian J Small Rumin 19(1):1–21

Sejian V, Maurya VP, Naqvi SMK (2010a) Adaptability and growth of Malpura ewes subjected to thermal and nutritional stress. Trop Anim Health Prod 42:1763–1770

Sejian V, Maurya VP, Naqvi SMK (2010b) Adaptive capability as indicated by endocrine and biochemical responses of Malpura ewes subjected to combined stresses (thermal and nutritional) under semi-arid tropical environment. Int J Biometeorol 54:653–661

Sejian V, Maurya VP, Naqvi SMK (2011a) Effect of thermal, nutritional and combined (thermal and nutritional) stresses on growth and reproductive performance of Malpura ewes under semi-arid tropical environment. J Anim Physiol Anim Nutr 95:252–258

Sejian V, Lal R, Lakritz J, Ezeji T (2011b) Measurement and prediction of enteric methane emission. Int J Biometeorol 55:1–16

Sejian V, Rotz A, Lakritz J, Ezeji T, Lal R (2011c) Modeling of green house gas emissions in dairy farms. J Anim Sci Adv 1(1):12–20

Sejian V, Indu S, Ujor V, Ezeji T, Lakritz J, Lal R (2012a) Global climate change: enteric methane reduction strategies in livestock. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GMbH Publisher, Germany, Berlin, Heidelberg, pp 469–502

Sejian V, Valtorta S, Gallardo M, Singh AK (2012b) Ameliorative measures to counteract environmental stresses. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GMbH Publisher, Germany, Berlin, Heidelberg, pp 153–180

Sejian V, Maurya VP, Kumar K, Naqvi SMK (2013) Effect of multiple stresses (thermal, nutritional and walking stress) on growth, physiological response, blood biochemical and endocrine responses in Malpura ewes under semi-arid tropical environment. Trop Anim Health Prod 45:107–116

Sejian V, Singh AK, Sahoo A, Naqvi SMK (2014a) Effect of mineral mixture and antioxidant supplementation on growth, reproductive performance and adaptive capability of Malpura ewes subjected to heat stress. J Anim Physiol Anim Nutr 98:72–83

Sejian V, Bahadur S, Naqvi SMK (2014b) Effect of nutritional restriction on growth, adaptation physiology and estrous responses in Malpura ewes. Anim Biol 64:189–205

Sere CH, Gronewold J (1996) World livestock production systems: current status, issues and trends. FAO animal production health paper, 127. FAO, Rome, p 84

Sirohi S, Michaelowa A (2008) Implementing CDM for Indian dairy sector: prospects and issues. Clim Policy 8(1):62–74

Sirohi S, Michaelowa A, Sirohi SK (2007) Mitigation options for enteric methane emissions from dairy animals: an evaluation for potential CDM projects in India. Mitig Adapt Strateg Glob Chang 12:259–274

Slenning BD (2010) Global climate change and implications for disease emergence. Vet Pathol 47(1):28–33

Storm IMLD, Hellwing LF, Nielsen NI, Madsen J (2012) Methods for measuring and estimating methane emission from ruminants. Animals 2(2):160–183

St. Pierre NR, Cobanov B, Schnitkey G (2003) Economic loss from heat stress by US livestock industries. J Dairy Sci 86(E Suppl.): E52–E77

Tabbaa MJ, Alnimer MA, Shboul M, Titi HH (2008) Reproductive characteristics of Awassi rams. Anim Reprod 5(1):23–29

Tavendale MH, Meagher LP, Pacheco D, Walker N, Attwood GT, Sivakumaran S (2005) Methane production from in vitro rumen incubations with Lotus pedunculatus and Medicago sativa, and effects of extractable condensed tannin fractions on methanogenesis. Anim Feed Sci Technol 123:403–419

Tubiello FN, Salvatore M, Rossi S, Ferrara A, Fitton N, Smith P (2013) The FAOSTAT database of greenhouse gas emissions from agriculture. Environ Res Lett 8(1):015009

Ungerfeld EM, Kohn RA (2006) The role of thermodynamics in the control of ruminal fermentation. In: Sejrsen K, Hvelplund T, Nielsen MO (eds) Ruminant physiology: digestion, metabolism and impact of nutrition on gene expression, immunology and stress. Wageningen Academic Publishers, Wageningen, pp 55–85

Vinoles C, Forsberg M, Martin GB, Cajarville C, Repetto J, Meikle A (2005) Short term nutritional supplementation of ewes in low condition affects follicle development due to an increase in glucose and metabolic hormones. Reproduction 129:299–309

Wang CJ, Wang SP, Zhou H (2009) Influences of flavomycin, ropadiar, and saponin on nutrient digestibility, rumen fermentation, and methane emission from sheep. Anim Feed Sci Technol 148:157–166

Wilkerson VA, Casper DP, Mertens DR (1995) Nutrition, feeding, and calves: the prediction of methane production of Holstein cows by several equations. J Dairy Sci 78:2402–2414

Yurtseven S, Gorgulu M (2004) Effects of grain sources and feeding methods, free choice vs. total mixed ration, on milk yield and composition of German Fawn × Hair crossbred goats in mid lactation. J Anim Feed Sci 13:417–428

Part I

Green House Gas Emission and Climate Change

Greenhouse Gas, Climate Change and Carbon Sequestration: Overview and General Principles

2

Samuel M. Otenyo

Abstract

This chapter is divided into two parts. The first part covers three major topics: (1) greenhouse gas emission sources at the organisation level, (2) what GHG inventory is and its importance and (3) principles governing GHG accounting and carbon stock accounting. The second part will provide researchers with necessary information on technical issues relating to the significance of trees that we grow in our farms and any forest that exists. People in the world over don't realise the importance of forests and therefore focus a lot on using timber, logs and wood fuel. The chapter takes through stages to quickly understand the gravity of science by applying mathematics. The reason is to quantify the carbon stocks that are sequestered over time. The basis will be understanding accounting and environmental science and their relationship with climate change. This provides the best solution to combat climate change.

Keywords

Carbon sequestration • Climate change • GHGs accounting and global warming

2.1 Introduction to Climate Change

Human activities are the major factors influencing the atmospheric changes since the beginning of industrial era. Climate change refers to long-term temperature fluctuations, wind, precipitation and other parameters. Natural processes like solar-irradiance variations and volcanic activities can produce variation in climate. Changes in the concentration of various gases in the atmosphere affect the earth's absorption of radiation. The outgoing terrestrial radiation emitted to the atmosphere is averagely balanced. Greenhouse gases (GHGs) absorb infrared radiation as it is reflected from the earth's surface acting like a blanket and keep the earth warm. Human activities are the major catalysts for changing and destabilisation

S.M. Otenyo (✉)
Department of Climate Change Technology & Training, Greenhouse Gas Projects Accounting Services (GHGPAS), P.O BOX 6456, 00200 Nairobi, Kenya
e-mail: sotenyo@yahoo.com

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*, DOI 10.1007/978-81-322-2265-1_2,

of the earth's natural systems as a result of GHGs emission. The concentrations of GHGs grew rapidly in the past two and a half centuries particularly due to the increasing usage of fossil fuels like oil, natural gas and coal as energy source.

2.2 Greenhouse Gases

The major greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (NO_2), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). The greenhouse effects are primarily the function of the concentration of water vapour. Carbon dioxide and other trace gases in the atmosphere absorb the terrestrial radiation leaving the surface of the earth (IPCC 1997), thereby holding everything else constant. Increase in the greenhouse gas concentrations in the atmosphere will produce a net increase in the absorption of energy in the form of heat. We have unequivocal empirical evidence that human activities have affected concentrations, distribution and life cycles of these gases (IPCC 1997). Overall, the most abundant and dominant greenhouse gas in the atmosphere is water vapour. Water vapour is neither long lived nor well mixed in the atmosphere, varying spatially from 0 to 2 % (IPCC 1997). Human activities are not believed to directly affect the average global concentration of water vapour, but the global warming by the increased concentration of other greenhouse gases may indirectly change the hydrologic cycle.

2.2.1 Global Greenhouse Gas Emission

GHG emission sources are classified in relation to boundaries stating whether direct (Scope 1), indirect (Scope 2) and other indirect (Scope 3), commonly referred to as fugitive emissions. This chapter will enable you to learn basically how to identify, calculate, account and report GHG emission. Climate change is an environmental, economic and social issue affecting all sectors of the economy including agriculture, transport and public works, energy, tourism, health and water resources. Human activities contribute to global warming and the climate change. GHG accounting which is the major focus of this chapter enables us to track down accurately the GHG types and take steps to manage it. You can't control that you can't measure, the saying goes. This principle works well in the GHG accounting concept.

2.2.2 Climate Change and Accounting

GHG accounting offers better solutions to climate change problem. In understanding GHG accounting, there are five principles that govern climate change accounting work. These are the principle of transparency, the principle of relevance, the principle of completeness, the principle of consistency and finally the principle of accuracy. There are similar principles laid down by the financial experts to provide road maps for financial accountants to speak the same language and reporting format. Based on the same concept, climate change experts have developed GHG accounting which is accepted internationally.

2.2.3 Where Do We Start from in Tackling Climate Change Causes?

The starting point of tracking down GHG emissions is by developing GHG inventory. Even financial managers have developed various inventories for decision making. The GHG inventory enables one to identify GHG emission reduction opportunities. Companies, institutions and governments can only control emissions through these inventories. Through inventories, one will know the emission sources and types of emission, and with an acceptable quantification methodology, you can arrive at what you want. This chapter guides you to deal with climate change and also make decisions for improved profit for shareholders in an investment.

2.2.4 Boundary Conditions

To be able to track down emissions, drawing boundary conditions is the way forward. Boundaries are imaginary lines. The creation of boundaries will help us in addressing climate change but with specific focus to organisations. There are two types of boundary conditions:

2.2.4.1 Organisational Boundary Conditions

This defines the breadth of the GHG inventory. It enables the organisation to know where it can assume responsibility for its GHG emission. Organisation's boundary can either be defined by the amount of equity an organisation has in an operation (equity approach) or be based on the organisation operational control (control approach). Selection of the type of organisational boundary must be one that best accurately reflects the activities of the organisation on a day-to-day business practice. Companies may choose their organisational boundaries of the GHG inventory according to "control approach". Consistent with the approach, the organisation is responsible to account for GHG emission from its location for which it has direct control on operations. This can extend to locations leased by the organisation or company.

2.2.4.2 Operational Boundary Conditions

This operational boundary provides the depth to company's inventory by identifying which emission sources are to be accounted for within the organisational boundaries. This work is done in line with the GHG Protocol. The GHG Protocol outlines three emission sources referred to as *Scopes*. The three Scopes are Scope 1 (direct emissions), Scope 2 (indirect emission) and Scope 3 (other indirect emissions). Scope 1 is emissions that occur directly on sites and mobile emission sources owned by the company. Scope 2 refers to indirect emissions that occur off-site to produce electricity or steam purchased for use at the company site or location. Scope 3 refers to fugitive emission from activities down- or upstream from a companies' core business as product use, commuting, waste disposal and business travel. Scopes 1 and 2 are mandatorily to be reported by the organisation or companies, while Scope 3 emission is optional. However, it is very important for organisations to track down Scope 3 for a complete understanding of their emission level for decision making. Scope 3 has been found to contribute significantly to emissions to the atmosphere. For easy learning, Scope 1 emissions include all on-site fuel combustion and all mobile fuel combustion, from all leased and owned vehicles and refrigerants. Scopes 2 are emissions identified as those from purchased electricity and steam at some facilities. Scope 3 emission sources include air travel but are only included if found to contribute significant portion of the companies' GHG emissions and is cost effective in quantifying.

2.2.5 Understanding Emission Quantification

It is important to know from the outset that quantification of GHG emission is technical and very scientific in nature. This task calls for quality data (QD), sufficient enough to be used; therefore, correction of data is a must. It must be emphasised that data collection process is very critical as quality data gives better analytical results. The GHG inventory benefits are many including providing GHG emission sources contained within the defined boundaries. Quantification methodologies are based on guidance from the GHG Protocol with emission factors taken from international organisations and government. Such important sources include the US Environmental Protection Agency (EPA), the Intergovernmental Panel on Climate Change (IPCC) and the World Resources Institute (WRI).

2.2.6 Quantification Enablers

It is possible to directly measure emissions from some sources, but in most cases, you can estimate emissions based on activity data and emission factors. The following equation is generally used for quantification of emissions:

$$Y * X = K$$

where Y is an activity data, X is emission factor and K is emission. Activity data quantifies an activity. Activity may be represented in units that can help to calculate litres or gallons of heating oil, litres of jet fuel, miles travelled, etc. Emission factor changes activity to emission values. Emission factors are published locally, internationally and even regionally. Emission factors are on specific units like pounds of CO_2 per kWh of electricity.

2.2.7 How to Find Activity Data

Direct activity data are from fuel combustion sources owned by a company or institution. In this case, data source is purchased fuel records or invoices. More details can be found in *GHG Protocol Calculation Tools*. Indirect activity data are purchased electricity and can be had from the electricity bill units. However, collecting data for indirect emission can be challenging. The best advice that we can give in that situation is that consider consulting third party for information or one can use the estimates. Electricity data is a bit straight to obtain. The approach to collect emission information on electricity more or less is the same as the one applied by financial accountants when apportioning electricity consumption bills in shared property offices. For example, *(area occupied by your office) * (total building electricity used)/(total building area) = estimated electricity used by your office space*. This approach enables organisations sharing office space to distribute their emission accurately and profile their emissions.

2.2.8 How to Collect Emission Factors (EF)

It is important to know emission factors used to quantify activity data. These are typically published by government-owned agencies and are regularly updated. One must remember to do some research to use the updated records. Researchers must refer to emission factor sources which can be found in the *GHG Protocol Calculation Tools* (Ranganathan et al. 2004) and other upcoming credible sources like Otcarborn Solution Systems which is under development and expected soon to be in the market. Therefore, with the availability of activity data and emission factors, calculation of emission is found to be simple by the application of methods or formulae.

2.2.9 How Important Is Data and Collection Procedure in This Work?

This chapter helps the researchers to have a clear insight and understanding of climate change to take appropriate ameliorative measures. Data quality is very critical for better results. The process of collecting data for the quantification of GHG emissions is equally critical. A well-established data collection process can improve the quality of data collected and such data will be more efficient. Further, the quality of data collected depends on (1) which data to be collected, (2) sources of data, (3) who collects the data, (4) how do we maintain information or data and (5) quality of staff handling the job. The sources of data vary as information is collected from different places or locations depending on its relevance. Maintaining data quality is important, and this can best be achieved through elaborate internal systems. Like all systems in large organisations, processing of information takes several stages before the approval stage. This will check and eliminate some common mistakes when entering data for processing. Large organisation may develop complex systems, even web-based systems to check on their collection of data and quantifications for accurate results.

2.2.10 Tracking GHG Emissions

At the organisation or company level, companies undergo tremendous changes. Such changes include acquisitions, mergers and divestments. These changes can significantly alter the companies' historical emission profile making comparison of emission difficult over a period of time. Therefore, in order to make comparisons of figures possible and relevant, recalculation of historic emission data should be done. Climate change is a result of GHG emission from various sources, and hence, there is a need to track down GHG emissions from companies too. Reasons for companies to track down emission include establishing GHG targets, controlling or managing risks and opportunities, public reporting and also addressing the needs of investors and stakeholders. Effective GHG monitoring therefore calls for companies to keep records for comparisons, similar to the way in which financial records are kept. The best point to be identified in the process is to find a base year. The base year helps to compare the changes. Companies choose a base year when data is available, and they must explain why they choose that particular year.

2.2.11 What Are the Steps for Identifying and Calculating GHG Emissions?

Once inventory boundaries are established, companies calculate emission using the following strategies: (1) identify greenhouse gas emission sources; (2) select a greenhouse gas emission calculation approach; (3) collect activity data and choose emission factors to be used; (4) apply calculation tools; and (5) roll up greenhouse gas emissions data to corporate level.

2.3 Overview on Carbon Sequestration and Climate Change

Carbon sequestration refers to the uptake of CO_2 and storage of carbon in biological sink. During photosynthesis, plants take in carbon as CO_2 from the atmosphere and store it in their tissues. Until this carbon is cycled back into the atmosphere, it resides in any of the carbon pools. Pools include above-ground biomass, e.g. in a forest, farmland and other terrestrial environments; below-ground biomass, e.g. roots; and biomass-based products, e.g. wood products during use and even in landfills. Carbon can remain in some of these pools for a very long time. If carbon stocks stored in these pools increase, it translates to a net removal of carbon from the atmosphere and, in reverse case, a net addition of carbon to the atmosphere, leading to global warming.

2.3.1 Accounting for Forest Carbon Stocks (AFCS)

Investors of forests or companies investing in forests need to know how well the forests have performed in withdrawing CO_2 from the atmosphere. They will get to know this by doing calculations to lay claim for compensation. However, national government inventories are important and recognise measures of tracking carbon stocks. That is the reason as to why inventories for GHG emissions are prepared. It is recognised that changes in stocks of sequestered carbon and the associated exchanges of carbon with atmosphere are the subject of GHG inventories. There are also companies in biomass-based industries such as forest product industries. The most significant aspect of a company's role in the atmospheric CO_2 level is the result of impacts on sequestered carbon in their operations as well as their value chain. Those companies, who care, have to track their GHG emission footprint (GHGF). Companies who collect their data on GHGF find it useful for decision making and for educating their shareholders and other stakeholders. The information helps the companies to identify reduction opportunities and potentially increase their profitability as well as profiles. Researchers need to know that for accounting of sequestered carbon, consensus methodology is not yet developed. However, the critical aspects that need to be addressed when evaluating biologically sequestered carbon under a GHG inventory must include tracking removal over time, setting operational boundaries, setting organisational boundaries, identifying and calculating GHG removals and reporting GHG removals.

2.3.2 Organisational Boundaries for Sequestered Carbon

The organisational boundaries include two steps: (1) consider applying equity share approach or the control approach to emissions directly or removal associated with sequestered atmospheric carbon; and (2) interrogate ownership of sequestered carbon under contractual arrangements or obligation that commonly touches on land management, harvesting rights and wood ownership.

2.3.3 Operational Boundaries

The operational boundary emphasises on the need to provide for value chain description to bring important areas to the notice of policy and decision makers in the organisation or governments. This will include pools in the analysis and the reasons for the selection of the pool.

2.3.4 Tracking Sequestered Carbon Over Time

The question to be addressed in this includes land acquisition, adjustments and recalculation of base year and also divesture, land use changes and land-related activities. The inventory data on carbon sequestered may need to be averaged over years to accommodate year to year changes (IPCC 2000).

2.3.5 Calculation: Sequestered Carbon

In other cases, quantification methods for national inventories (IPCC methodologies) or project level accounting may be used for corporate level quantification. There are no widely accepted calculation tools for sequestered carbon (IPCC 2003).

2.3.6 Reporting Sequestered Carbon

There is no consensus yet on reporting methods, but information is best reported in the “Optional Information” part of the report. To conclude, sequestered carbon, biofuel emissions and GHG offsets are well handled by special GHG accounting and reporting rules. Carbon sequestered should be reported under Optional Information, while biofuels should be reported as a Memo Item, separate from the scope (GHG Protocol Initiative 2006).

2.3.7 Enhancing Better Understanding on GHG Accounting for Forestry Inventory

These are some of the very technical parts of tracking causes which are very critical for controlling global warming and the climate change. To understand these subjects well, researchers must know what “a sink” is. A sink is defined as any process or activity that removes a greenhouse gas, an aerosol or a precursor of a greenhouse gas from the atmosphere. With this understanding, one is better equipped to run and discover many steps that follow. Learners need to know also about emission sources. What is “emission source”? This can be defined as any process or activity that releases a greenhouse gas, an aerosol or precursor of a greenhouse into the atmosphere. Emission is also defined as the release of greenhouse gases and/or their precursors into the atmosphere over a specified area and period of time. Sometimes, one could ask whether all forests are carbon sinks. All forests are not necessarily carbon sinks. The net balance of emissions and removals determines if a forest is a source or sink. Carbon in the form of CO_2 is both removed and emitted in forests. This is a very important point to note.

Forests are sinks because they remove CO_2 from the atmosphere through photosynthesis. When removals are greater than emissions which occur from combustion, harvesting and respiration, then the forest is a net sink. The reason that forests can be a source of CO_2 is relevant to the net balance of CO_2 emission removals in a forest, but it is not the process that makes forests uniquely able to be net sink of CO_2. Carbon is stored in forest carbon pools, e.g. living biomass, dead organic matter, wood products and soils. As a basic rule, organisations who prepare a forest GHG inventory either own land or manage forestland. The organisational boundaries of forest greenhouse gas inventory should include forestland. However, some but not all organisation preparing a forest GHG inventory would also harvest wood from these forests, actively plant forests on land that was previously non-forest or own or control wood-processing facilities.

A forest GHG inventory will by all standards include forests within the operational boundaries of the organisation, and the objectives of such an inventory would be to determine whether and by how much the forest is a net source or sink of CO_2. This is done by estimating the yearly net flux of CO_2 in forests. Net forest carbon emissions or removals in a given year are determined by estimating annual carbon flux or the change in carbon stocks from 1 year to the next. If a forest is a net source or sink in a given year, you compare carbon stocks from the most recent year's data with that of previous year's.

2.3.8 Recalculating Base Year Forest Carbon Stocks

Recalculating base year can be done after selling or acquiring a new forestland. If the amount of land included in the organisational boundaries changes, then this is a structural change in an organisation that impacts base year carbon stocks. To ensure you are comparing "like with like" when you assess cumulative changes in carbon stocks over a time within your organisation, you need to recalculate a base year to include carbon stocks from a newly acquired land. If you harvest some portion of your forests or you convert some of your forests to another land use, those changes can only impact carbon stocks on currently owned land but do not change the structure of an organisation. The principle of conservativeness is emphasised when estimating CO_2 emissions in a forest. The most conservative option for estimating net CO_2 flux in harvested wood product (HWP) after a forest stand is harvested is that you ensure that eventually all the carbon stored in harvested wood products will be emitted back to the atmosphere and record these emissions as occurring in the year the wood is harvested. This means underestimations of removals.

Here is the question researchers need to answer to increase their understanding. Do we need to consider CH_4 and NO_2 emission in forest GHG inventory preparations? Methane and NO_2 emissions occur from biomass combustion and NO_2 emissions can occur from nitrogen additions. These emission sources are typically small when compared to CO_2 emissions and removals in forest carbon pools. Forest GHG inventory guidelines do not explicitly demand or provide specific calculation methods for their estimation. That notwithstanding, these gases have a relatively greater impact on global warming per unit mass of gas emitted over a given time frame than CO_2, and basic methods including default emission factors for estimating emission from these sources are available in the IPCC guidelines. It is highly recommended therefore to calculate GHG emissions from these sources to ensure the forest GHG inventory is complete.

2.3.9 GHG Accounting and Reporting Principles

Like financial accounting, GHG accounting principles are intended to underpin and guide GHG accounting to ensure that the reported information represents a faithful, true and fair account of a company's GHG emissions. The principles listed below are derived in part from generally accepted financial accounting and reporting principles. They also reflect the outcome of a collaborative process involving stakeholders from a wide range of technical, environmental and accounting disciplines. Therefore, the following five principles for accounting and reporting for GHG are used:

2.3.9.1 Relevance

This ensures that the GHG inventory appropriately reflects the GHG emissions of the company and serves the decision-making needs of users, both internal and external, to the company.

2.3.9.2 Completeness

This demands that you account for and report all GHG emission sources and activities within the chosen inventory boundary. This also ensures disclosing and justifying any specific exclusion.

2.3.9.3 Consistency

This demands that you use a consistent methodology to allow meaningful comparisons of emissions over time. This also ensures transparency in documenting any changes to the data, inventory, methods or any other relevant factors in the time series.

2.3.9.4 Transparency

Address all relevant issues in a factual and coherent manner based on a clear audit trail. Disclose any relevant assumptions and make appropriate references to the accounting and calculation methodologies and data sources used.

2.3.9.5 Accuracy

Ensure that the quantification of GHG emission is systematic. The actual emissions are judged without bias and the uncertainties are reduced as far as practicable. Achieve sufficient accuracy to enable users to make decision with reasonable assurance as to the integrity of the reported information.

These principles are meant to address all matters of GHG accounting and reporting. Their application will ensure the GHG inventory condition of the company's GHG emissions.

For example, Nyandakwoga is the largest car maker in Kenya. While preparing its GHG inventory position, Nyandakwoga discovered that the structure of its GHG emission sources had undergone reasonable changes in 5 years. Emission from its production process, which initially was considered unnecessary at the entity level in 1998, today constitutes 30 % of its aggregated GHG emissions at the operation. The growing emission sources recently started operations for carrying out testing of equipments. This is an example that suggests that reassessing of operation sites from time to time is necessary to have a complete GHG inventory. This example is meant to teach learners of this chapter on the need to track down and account for emissions from organisation levels. The emission sources indeed contribute GHG to the atmosphere that finally causes climate to change.

2.3.10 Does the Company or Organisation Benefit from GHG Inventory Profiles?

This is a very important question. How do companies gain? The answer to the question is that organisations who undertake GHG inventories understand better the kind of decisions to make better planning. The understanding of your company's emission sources makes great business sense. This point is well brought out through the GHG Protocol Corporate Standard that has been designed as comprehensive GHG accounting and provides the information for business goals.

2.3.11 Business Objectives of Developing GHG Inventories

We do forget our activities around us that cause GHG emissions. The reason to put forth this chapter so much under scrutiny is to be able to understand the climate change causes in a compressive manner and bring all GHG emission sources into account. Therefore, the business objectives of developing GHG inventories are (a) helping in setting GHG reduction targets, (b) helping in taking part in GHG markets, (c) helping in voluntary GHG programme participation, (d) certifying GHG, (e) identifying GHG reduction opportunities, (f) helping to define cost-effective reduction opportunities, etc.

References

IPCC (1997) Revised 1996 Guidelines for national GHG inventories. Houghton JT, Maira LG, Lim B, Tranton K, Mamaty I, Bonduki Y, Grigg OJ, Callander B

IPCC (2000) Chapter 3: Afforestation, Reforestation, and deforestation (ARD) activities. In: Watson R, Noble IR, Bolin B, Ravindranath NH, Verardo DJ, Dokken DJ (eds) Land use, land-use change, and forestry: a special report. Cambridge University Press, Cambridge

IPCC (2003) Jim Penman, Tana Hiraishi, Thelma Krug, and Dina Kruger. Good practice guidance for land use, land use change and forestry (IGES) for IPCC

Ranganathan J, Cabier L, Bhatia P, Schmitz S, Gage P, Oren K (2004) Chapter 7: Managing inventory quality. In: The greenhouse gas protocol: a corporate accounting & reporting standard. World Resources Institute and World Business Council, Washington, DC, pp 48–57

GHG Protocol Initiative (2006) WRI/WBCSD. S. Russell, M. Sotos. The Land use, landuse change, and forestry (LULUCF) guidance for GHG project accounting

Contribution of Agriculture Sector to Climate Change

3

Sangeeta Lenka, N.K. Lenka, Veerasamy Sejian, and M. Mohanty

Abstract

Agriculture sector is a potential contributor to the total green house gas (GHG) emission with a share of about 24 % (IPCC, AR5 to be released) of the total anthropogenic emission, and a growing global population means that agricultural production will remain high if food demands are to be met. At the same time, there is a huge carbon sink potential in this sector including land use, land-use change, and forestry sector. For over four decades, evidence has been growing that the accumulation of GHGs in the upper atmosphere is leading to changes in climate, particularly increases in temperature. Average global surface temperature increased by 0.6 ± 0.2 °C over the twentieth century and is projected to rise by 0.3–2.5 °C in the next 50 years and 1.4–5.8 °C in the next century (IPCC, Climate change: synthesis report; summary for policymakers. Available: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf, 2007). In the recent report of IPCC AR5 (yet to be released), it has been observed that warming will continue beyond 2100 under all representative concentration pathways (RCP) scenarios except RCP 2.6. Temperature increase is likely to exceed 1.5 °C relative to 1850–1900 for all RCP scenarios except RCP 2.6. It is likely to exceed 2 °C for RCP 6.0 and RCP 8.5 (Pachauri, Conclusions of the IPCC working group I fifth assessment report, AR4, SREX and SRREN, Warsaw, 11 November 2013). Agriculture is a potential source and sink to GHGs in the atmosphere. It is a source for three primary GHGs: CO_2, N_2O, and CH_4 and sink for atmospheric CO_2. The two broad anthropogenic sources of GHG emission from agriculture are the energy use in agriculture (manufacture and use of agricultural inputs and farm machinery) and the management of agricultural land. Mitigation methods to reduce emissions from this sector are thus required,

---

S. Lenka (✉) • N.K. Lenka • M. Mohanty
Indian Institute of Soil Science,
Indian Council of Agricultural Research,
Nabibagh, Bhopal 462038, India
e-mail: sangeeta_2@rediffmail.com

V. Sejian
Animal Physiology Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_3, © Springer India 2015

along with identification and quantification of emission sources, so that the agricultural community can act and measure its progress. This chapter focuses on different sources of GHG emission from agriculture sector and their key mitigation strategies.

Keywords
GHG emission • Agriculture sector • Livestock • Mitigation strategies

3.1 Introduction

A continued rise in concentration of the greenhouse gases (GHGs) has led to enhanced greenhouse effect resulting in global warming and global climate change. Globally, GHG emission has increased by about 75 % since 1970. Looking at the total source of GHGs at present CO_2 contributes 76 %; CH_4 about 16 %, N_2O about 6 %, and the combined F-gases about 2 % (IPCC AR5, yet to be released). The impact of human activities on GHG emission through fossil fuel burning, agriculture, and industrial processes is important and familiar to people. The effects of GHG emissions on the ecological and socioeconomic vulnerability have already been noticed and will continue to grow regionally and globally in the years to come (IPCC 2007; Pachauri 2013). Carbon dioxide (CO_2), methane (CH_4), nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are the important GHGs that are monitored by the United Nations Framework Convention on Climate Change (UNFCCC 2008). Global GHG emissions due to human activities (anthropogenic) have grown since the beginning of the industrial revolution with an increase of 70 % between 1970 and 2004 (IPCC 2007). The radiative forcing of CO_2, CH_4, and N_2O is very likely (>90 % probability) increasing at a faster rate during the current era than any other time in the last 10,000 years. This is because of the increase in the global abundance of the three key GHGs, namely, carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), in the atmosphere. The concentrations of CO_2, CH_4, and N_2O have increased markedly by 30 %, 145 %, and 15 %, respectively, as a result of human activity since the period of industrial revolution (IPCC 2007). Management of agricultural land, land-use change, and forestry has a profound influence on atmospheric GHG concentration. The two broad anthropogenic sources of GHG emission from agriculture are the energy use in agriculture (manufacture and use of agricultural inputs and farm machinery) and the management of agricultural land. In the agriculture sector, besides the CO_2 emissions due to burning of crop and animal waste, the world's livestock population and rice fields are significant contributors to CH_4 emissions. An understanding of GHG emissions by sources and removal by sinks in agriculture is important to take appropriate mitigation and adaptation strategies and to estimate and create inventory of GHGs.

It is clear that the agriculture sector is increasing in size, but exactly how this is impacting on GHG emissions remains uncertain, as do the opportunities for mitigation. Within the scientific community there is increasing recognition that agriculture in general, and livestock production in particular, contribute significantly to GHG emissions (Bell et al. 2014; Bellarby et al. 2013; Galloway et al. 2007). As a result, the global agricultural community is committed to reducing emissions to safeguard the environment; however, it must simultaneously meet the demands of a growing human population and their increasing requirements for food high in quality and quantity. There is a need to improve the efficiency of agricultural production if we are to meet global food supply demands and decrease agriculture's impact on climate change. Quantification of the impacts that agriculture is having on the environment is thus of major importance. This chapter illustrates the different sources and sinks of GHG from agriculture sector including forestry and land-use changes and their mitigation potential.

3.2 Sources and Sinks of GHG from Agriculture

Sectoral distribution of GHG emission comparing the emission levels at 2004 (AR4) and 2010 (AR5) is given in Fig. 3.1. By sector, the largest sources of GHGs were the sectors of energy production (mainly CO_2 from fossil fuel combustion) and agriculture, forestry, and other land use (AFOLU) (mainly CH_4 and N_2O). The contribution of AFOLU (agriculture, forestry, and other land use) to total emission has come down from 31 % (2004) to 24 % (2010). Identification of GHG sources and quantification of GHG emission from agriculture sector has passed through many phases of refinement. The 1996 IPCC inventory guidelines require emission reporting from the following six categories: energy, industrial processes, solvent and other product use, agriculture, land-use change and forestry (LUCF), and waste (Crosson et al. 2011). These categories were revised in the 1996 revised guidelines, where LUCF was expanded to include

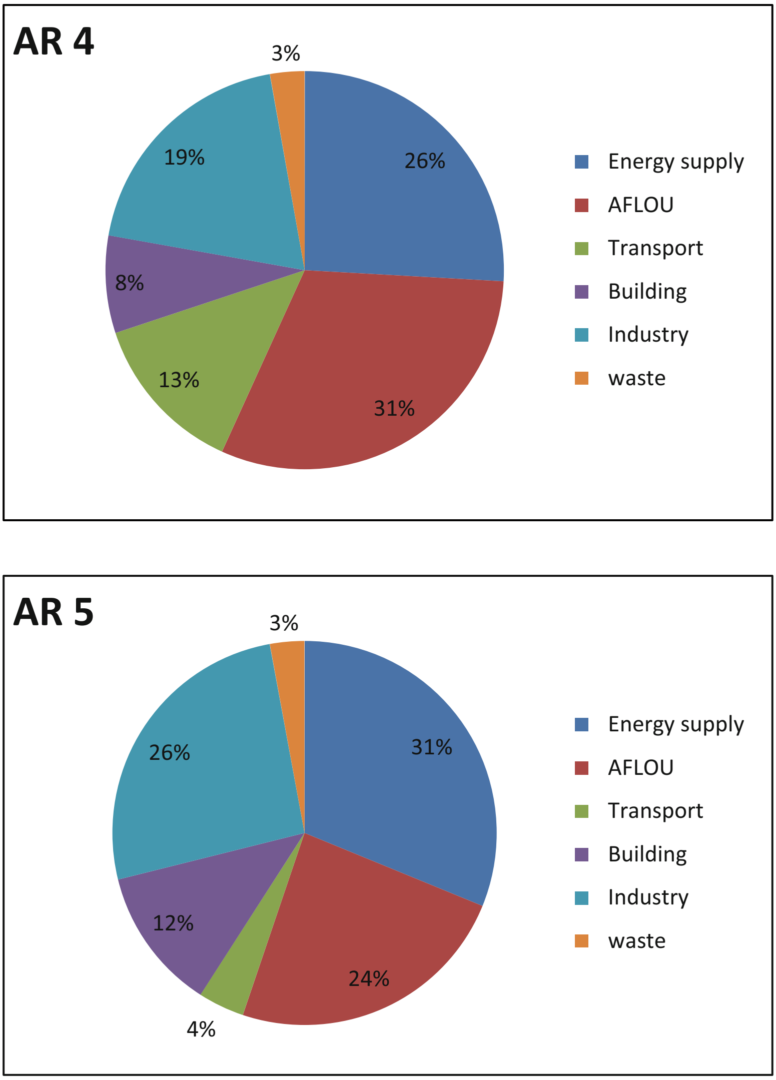


Fig. 3.1 Comparing AR_4 and AR_5 the sectoral distribution of GHG emissions showing the percentage of emission with respect to the total. AR_4 represent emission level at 2004 and AR_5 2010

emissions/sequestration from land under continuous use. The new category land use, land-use change, and forestry (LULUCF) was thus created (Paustian et al. 2006). In the 2006 IPCC guidelines, the categories have been altered and amalgamated, with only four sectors to which GHG emissions are now attributed. The agriculture and LULUCF sectors were combined to produce the sector agriculture, forestry, and other land use (AFOLU) (Crosson et al. 2011). Figure 3.2 gives a schematic presentation of emission by sources and removals by sinks in agriculture. And their detailed discussion is given in following section.

In agriculture the non-CO_2 sources (CH_4 and N_2O) are reported as anthropogenic GHG emissions, however. The CO_2 emitted is considered neutral, being associated to annual cycles of carbon fixation and oxidation through photosynthesis (IPCC 2007). Soil respiration is roughly

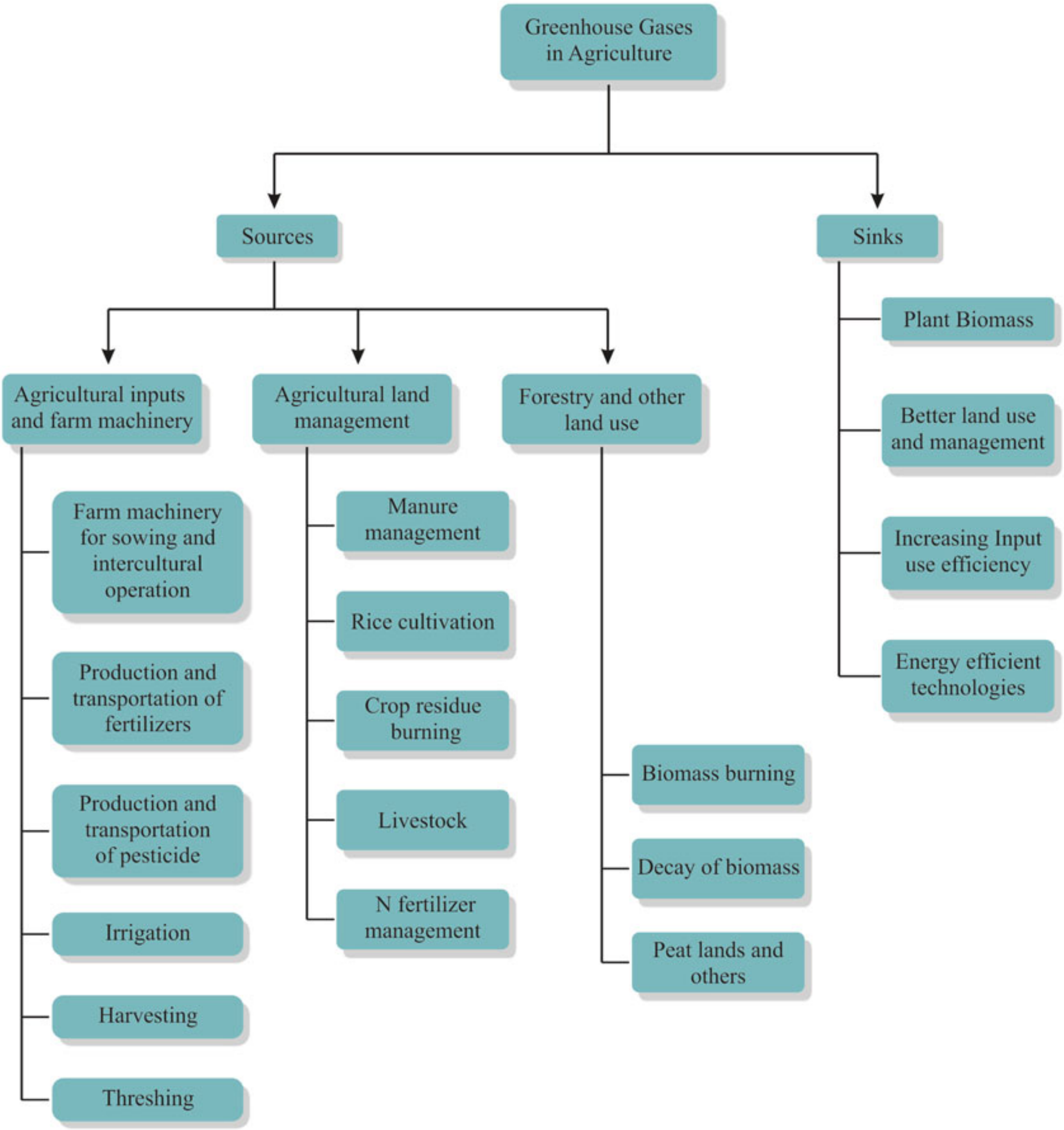


Fig. 3.2 Schematic presentation of sources and sinks of GHGs in agriculture, forestry, and other land use (AFOLU)

balanced by the net uptake of CO_2 through plant photosynthesis. Carbon inputs to the soil are determined by the quantity, quality, and distribution of primary productivity. The organic matter decomposition and microbial respiration are influenced by soil physicochemical and biological soil properties controlling the activity of soil microorganisms and fauna. Also there is growing consensus on soil respiration and hence CO_2 evolution is higher when any organic material is added to soil. Similarly soils with higher soil organic carbon (SOC) content emit more CO_2 than soil with low SOC, thereby increasing concentration of CO_2 in the atmosphere. On the other hand, higher concentrations of atmospheric CO_2 also will stimulate the growth of most plants, especially C_3 agricultural crops. Increased productivity can supply more plant residues to the soil, possibly increasing storage of SOM. But, higher level of atmospheric CO_2 is also coupled with temperature rise which would have both positive and negative effects on plant productivity. If the productivity decreases it would have a negative effect on soil carbon storage. Thus, accounting CO_2 emission and removal in agriculture should be considered in creating GHG inventory from agriculture. Further, the link between agriculture and climate change must be assessed and presented accurately and consistently. Flaws in the assessment of agriculture's contribution will lead to dispute, failure to trust the science, and, consequently, failure to act. Global recognition of the extent of agriculture's contribution to GHG emissions is required, as is quantification of how its contribution compares to that of other emission sources.

3.2.1 Rice Cultivation

The four decades since 1961 have seen an increase in area, production, and productivity of rice of 31.2, 174.9, and 109.7 %, respectively. The acreage under rice cultivation in the world is estimated at about 151.54 million hectares, mostly planted in wet monsoon or irrigated systems by flooding and puddling fields. These rice fields are a major source of emission of GHGs like CH_4 and N_2O. From 1961 to 2010, global emissions increased with average annual growth rates of 0.4 %/year (FAOSTAT 2013) from 0.37 to 0.52 $GtCO_2$ eq/year. The growth in global emissions has slowed in recent decades, consistent with the trends in rice-cultivated area. The developing countries are major producers of rice and also the largest share of methane emission approximately 94 % came from them. Researchers have attempted to model and estimate GHG emissions from rice fields under varying growing conditions. However, there are uncertainties in the estimation of GHG from rice fields due to diverse soil and climatic conditions and crop management practices. Flooded paddy soils have a high potential to produce CH_4, but part of produced CH_4 is consumed by CH_4 oxidizing bacteria, or methanotrophs. It is known that microbial-mediated CH_4 oxidation, in particular aerobic CH_4 oxidation, ubiquitously occurs in soil and aquatic environment, where it modulates CH_4 emission. In rice fields, it is possible that a part of produced CH_4 in anaerobic soil layer is oxidized in aerobic layers such as surface soil-water interface and the rhizosphere of rice plants, and the net emission will be positive or negative depending on the relative magnitudes of methanogenesis and methanotrophy, respectively; the emission pathways of CH_4 which are accumulated in flooded paddy soils are diffusion into the flood water, loss through ebullition, and transport through the aerenchyma system of rice plants. Some promising mitigation options are (1) system of rice intensification (SRI), (2) water management, (3) adding organic material along with inorganic fertilizers, (4) reducing tillage operations before sowing, and (5) selecting suitable variety which emit less CH_4, and there is no reduction in yield.

3.2.2 Livestock Production

Livestock contribute both directly and indirectly to climate change through the emissions of GHGs such as carbon dioxide, methane, and nitrous oxide. Globally, the sector contributes 18 % (7.1 billion tonnes CO_2 equivalent) of global GHG emissions. Although it accounts for only 9 % of global CO_2, it generates 65 % of human-related nitrous oxide (N_2O) and 35 % of methane (CH_4), which has 310 times and 23 times the global-warming potential (GWP) of CO_2, respectively.

There are two sources of GHG emissions from livestock: (a) From the digestive process, methane is produced in herbivores as a by-product of "enteric fermentation," a digestive process of enzymatic degradation elaborated by symbiotic microbes inhabiting in rumen medium in which carbohydrates are broken down into simple molecules for absorption into the bloodstream. (b) From animal wastes, animal wastes contain organic compounds such as carbohydrates and proteins. During the decomposition of livestock wastes under moist, oxygen-free (anaerobic) environments, the anaerobic bacteria transform the carbon skeleton to methane. Animal wastes also contain nitrogen in the form of various complex compounds. The microbial processes of nitrification and denitrification of animal waste form nitrous oxide, which is emitted to the atmosphere.

The major global-warming potential (GWP) of livestock production worldwide comes from the natural life processes of the animals. Methane production appears to be a major issue although it presently contributes only 18 % of the overall warming. It is accumulating at a faster rate and is apparently responsible for a small proportion of the depletion of the protective ozone layer. Methane arises largely from natural anaerobic ecosystems, rice/paddy field, and fermentative digestion in ruminant animal (Sejian et al. 2011). In fact, CH_4 considered to be the largest potential contributor to the global-warming phenomenon is an important component of GHG in the atmosphere and is associated with animal husbandry. Much of the global GHG emissions currently arises from enteric fermentation and manure from grazing animals and traditional small-scale mixed farming in developing countries. The development of management strategies to mitigate CH_4 emissions from ruminant livestock is possible and desirable. Not only can the enhanced utilization of dietary "C" improve energy utilization and feed efficiency, hence animal productivity, but a decrease in CH_4 emissions can also reduce the contribution of ruminant livestock to the global CH_4 inventory.

3.2.2.1 Enteric Methane Emission from Livestock

Livestock are produced throughout the world and are an important agricultural product in virtually every country. CH_4 is emitted as a by-product of the normal livestock digestive process, in which microbes resident in the animal's digestive system ferment the feed consumed by the animal. This fermentation process, also known as enteric fermentation, produces CH_4 as a by-product. The CH_4 is then eructated or exhaled by the animal. Within livestock, ruminant livestock (cattle, buffalo, sheep, and goats) are the primary source of emissions. Other livestock (swine and horses) are of lesser importance in nearly all countries. The number of animals and the type and amount of feed consumed are the primary drivers affecting emissions. Consequently, improvements in management practices and changes in demand for livestock products (mainly meat and dairy products) will affect future CH_4 emissions (Sejian et al. 2012).

Among the livestock, cattle population contributes most towards enteric CH_4 production (Johnson and Johnson 1995). Enteric fermentation emissions for cattle are estimated by multiplying the emission factor for each species by the relevant cattle populations. The emission factors are an estimate of the amount of CH_4 produced (kg) per animal and are based on animal and feed characteristic data, average energy requirement of the animal, the average feed intake to satisfy the energy requirements, and the quality of the feed consumed. The district- or country-level emission from enteric fermentation is computed as a product of the livestock population under each category and its emission coefficient (Chhabra et al. 2009). The emission coefficients for CH_4 emissions from enteric fermentation are country specific, and these coefficients should conform to IPCC guidelines (IPCC 2007).

3.2.2.2 GHG Emission from Livestock Manure

Animal manures contain organic compounds such as carbohydrates and proteins. These relatively complex compounds are broken down naturally by bacteria. In the presence of oxygen, the action of aerobic bacteria results in the carbon being converted to carbon dioxide, and, in the absence of oxygen, anaerobic bacteria transform carbon to methane. When livestock are in fields and their manure ends up being spread thinly on the ground, aerobic decomposition usually predominates. However, with modern intensive livestock practices, where animals are often housed or kept in confined spaces for at least part of the year, manure concentrations will be higher, and manure will often be stored in tanks or lagoons where anaerobic conditions generally predominate and methane will be evolved. Methane emissions from manure depend on (1) the quantity of manure produced, which depends on number of animals, feed intake, and digestibility; (2) the methane-producing potential of the manure which varies by animal type and the quality of the feed consumed, e.g., slurry from swine emits more GHG than does slurry from cattle (Dinuccio et al. 2008); the way the manure is managed (e.g., whether it is stored as liquid or spread as solid); the climate as the warmer the climate the more biological activity takes place and the greater the potential for methane evolution and temperature and duration of storage as long-term storage at high temperature results in higher methane emissions.

Management decisions about manure disposal and storage affect emissions of CH_4 and N_2O, which are formed in decomposing manures as a by-product of methanogenesis and nitrification/denitrification, respectively. Livestock manure is principally composed of organic material. When this organic material decomposes under anaerobic environment, methanogenic bacteria produce methane. When manure is stored or treated as a liquid (e.g., in lagoons, ponds, tanks, or pits), it tends to decompose anaerobically and produce a significant quantity of methane. When manure is handled as solid (e.g., in stacks or pits) or deposited on pastures and rangelands, it tends to decompose aerobically and little or no methane is produced. Furthermore, volatilization losses of NH_3 and NO_x from manure management systems and soils lead to indirect GHG emissions. There are three potential sources of N_2O emissions related to livestock production (Swamy and Bhattacharya 2011). These are (a) animals themselves, (b) animal wastes during storage and treatment, and (c) dung and urine deposited by free-range grazing animals. Direct emission from animals is not reported. Only liquid systems (anaerobic lagoons and other liquid systems) qualify under manure management. Emissions from stable manure applied to agricultural soil (e.g., daily spread), from dung and urine deposited by range grazing animals, and from solid storage and dry lot are considered to be emissions from agricultural soil. Although CH_4 and N_2O emissions from manure management are minor, manure itself is an important contributor to emissions because it is either applied on cropland as organic fertilizer or directly deposited by grazing animals on pasture. Global emissions from manure, as either organic fertilizer on cropland or manure deposited on pasture, grew between 1961 and 2010 from 0.57 to 0.99 $GtCO_2$ eq/year. Emissions grew by 1.1 %/year on average (IPCC AR5). Also the GHG emissions are more from manure deposited on soil surface in pasture lands or the backyard of farm land compared to when applied to agricultural land before sowing.

3.3 Agricultural Soils

Direct and indirect emissions from agricultural soil are determined by a multitude of factors such as the rate of fertilizer and organic manure application, yield, and area under cultivation. Direct emission sources include N fertilizers, crop residues, and mineralization process of soil organic matter. Indirect sources comprise leaching, runoff, and atmospheric deposition. N_2O emitted from the soil represents some 50 % of the total agricultural emissions. Even when it is not being cultivated, the soil naturally releases GHGs. N_2O is generated as a by-product of microbial activities that convert ammonium into nitrate (nitrification) or nitrate into nitrogen gas N_2 (denitrification). Both processes are influenced and controlled by environmental conditions. They are independent of the origin of N, whether from organic or mineral fertilizers or soil organic matter. Emissions increase with agricultural activity, partly as a result of N input from manure, mineral fertilizers, or from symbiotic N fixation in legumes. Globally, use of synthetic fertilizers in agriculture has increased more than agricultural production, and emissions from synthetic N fertilizers are increasing more than ninefold, from 0.07 to 0.68 $GtCO_2$ eq/year from 1951 to 2010 (Tubiello et al. 2013). Considering current trends, synthetic fertilizers will become a larger source of emissions than manure deposited on pasture in less than 10 years and the second largest of all agricultural emission categories after enteric fermentation. Globally, agricultural sources contribute to 4–6 Tg N/year through N_2O, including both direct and indirect emissions (Sharma et al. 2011).

The Intergovernmental Panel on Climate Change (IPCC) assumes a default value of 1 % of N content of the substrate, emitted as N_2O. As these emissions are the consequences of natural processes, they are difficult to control. The best possible approach is to increase nitrogen use efficiency. In addition, emission during fertilizer manufacturing can be reduced with new cleaning technology which can enable N_2O emission reduction by about 70–90 % (Kongshaug 1998).

3.4 Burning of Agricultural Residues in Field

The contribution of crop residue burning is the lowest 0.5 % of the total agricultural emissions among different sources of GHG emission in the agriculture sector. In developing countries agricultural wastes are burnt in the field to clear the remaining straw and stubble after harvest and to prepare the field for the next cropping cycle. Farmers prefer crop residue burning as a quick and labor-saving process to dispose of the crop residues of rice, wheat, maize, and sugarcane. Emissions of CO_2 during burning of crop residues are considered neutral, as it is reabsorbed during the next growing season. However, biomass burning is one of the significant sources of atmospheric aerosols and trace gas emissions, which has a major impact on human health. In addition to aerosol particles, biomass burning due to forest fires and crop residue burning are considered a major source of carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), volatile organic compounds (VOC), nitrogen oxides, and halogen compounds. Carbon monoxide is a chemically active gas in the troposphere influencing the abundance of O_3 and the oxidizing capacity (OH) of the troposphere. Thus, an increase in concentration of CO, VOC, and NO_x also increases concentration of GHGs in the atmosphere. Biomass burning is one of the main causes for dense brown clouds. Smoke particles from biomass burning have direct radiative impact by scattering and absorbing shortwave radiation and indirect radiative impact by serving as cloud-condensation nuclei (CCN) and changing the cloud microphysical and optical properties.

3.5 Forestry and Other Land Use (FOLU) Changes

This section of agriculture sector encompasses anthropogenic emission from deforestation, cultivation of organic soils, peatland drainage for cultivation, forest fires, etc. Emissions from cultivation of organic soils have become important because when peatlands are drained and degraded there is change in absolute carbon stocks. The continued expansion of farmland has a major environmental impact. It decreases biodiversity through destruction of ecologically valuable natural environments, such as forests and natural grasslands. In addition, deforestation and depletion of the humus releases large quantities of CO_2 from the carbon bound in the trees and the soil organic matter (SOM). Furthermore, deforestation has an immediate impact on the natural water cycle, resulting in a greater likelihood of flooding or drought. Some 24 % of the total global GHG emissions can be currently attributed to agriculture. About 12 % of these are due to change in land use and, with extended agricultural production, this percentage would rise considerably (FAOSTAT 2013). Further extension of the agricultural land area, therefore, should be kept to the minimum. Changes in land use have negatively affected the net ability of ecosystems to sequester C from the atmosphere. For instance, the C-rich grasslands and forests in temperate zones have been replaced by crops with much lower capacity to sequester C. However, the estimates indicate that the FOLU sector is a net sink. It helps in sequestering CO_2 annually offsetting FOLU emissions. The sink capacity of FOLU is due to afforestation and forest protection.

3.6 Agricultural Inputs and Farm Machinery

3.6.1 Fuel and Electricity

Use of fossil fuels in agriculture results in CO_2 emissions, and there are additional emissions associated with production and delivery of fuels to the farm. Carbon emissions attributed to fossil fuels are estimated using existing C coefficients, higher heating values, fuel chemistry, and the energy consumed during production and transport of the fuels. Nontraditional fuels sometimes used in processing agricultural materials include scrap tires and biomass. The CO_2 emission attributed to electricity consumption is based on the fuels used in power generation.

3.6.2 Fertilizers and Agricultural Lime

The production of fertilizers demands much energy and generates considerable GHG emissions. Kongshaug (1998) estimates that fertilizer production consumes approximately 1.2 % of the world's energy and is responsible for approximately 1.2 % of the total GHG emissions. The fertilizer industry deals primarily with supplying N, P, and K, although chemical fertilizers are used to supply 13 essential plant nutrients. This analysis includes the three primary nutrients and agricultural lime ($CaCO_3$) in the form of crushed limestone. Carbon dioxide emissions result from the energy required for production of fertilizers plus the energy required for their transport and application. The energy required per tonne of N and phosphate (P_2O_5) varies considerably with the form in which the nutrient is supplied. Carbon emissions from fossil fuels used in the production of fertilizers include emissions from mineral extraction and fertilizer manufacture. Postproduction emissions can include those from packaging, transportation, and field application of fertilizers. Energy is also used during fertilizer application using farm machinery, thus the greater the fertilizer use, the greater are the emissions. Carbon emissions from agricultural lime are calculated from the fuel used for mining limestone and for grinding the stone into a usable product. Energy used in the transportation of fertilizers and lime should be included in estimating the total energy budget.

3.6.3 Pesticides

Modern pesticides are almost entirely produced from crude petroleum or natural gas products. The total energy input is thus both the material used as feedstock and the direct energy inputs. Carbon dioxide emissions from production of pesticides consist of both these contributions to manufacture the active ingredient. Postproduction emissions include those from formulation of the active ingredients into emulsifiable oils, wettable powders, or granules and those from packaging, transportation, and application of the pesticide formulation. Carbon dioxide emissions from pesticide use are estimated for specific pesticide classes by calculating average values of energy input for the production and application of individual pesticides.

3.6.4 Irrigation

The on-farm wells, on-farm surface reservoirs, and off-farm surface reservoirs are the major sources of irrigation water. Fossil fuels used to power pumps, which distribute irrigation water, were calculated using energy expenses for on-farm pumping and energy price estimates. The energy use and C emissions from pumping water were applied to both on-farm wells and off-farm surface reservoirs. It is assumed that the average energy and CO_2 cost of pumping water is the same per ha-m of water for the two sources. The energy cost of collecting and distributing on-farm surface water, powered primarily by gravitational forces, was considered to be negligible.

3.6.5 Harvesting and Threshing

Energy and CO_2 emissions during harvesting and threshing of agricultural produce are also important. The greater the productivity, the greater are the energy and emissions required for harvesting and threshing.

3.6.6 Farm Machinery

Energy and CO_2 emissions associated with different tillage practices are a consequence of the fuel used by farm machines and the energy consumed in manufacture, transportation, and repair of the machines. While CO_2 emissions associated with the application of fertilizers and pesticides were calculated along with other farm operations, they do not occur on all fields and in all years, as do other farm operations. Therefore, CO_2 emissions from the application of fertilizers and pesticides are weighted by their extent of application.

3.7 Key Mitigation Options in Agriculture, Forestry, and Other Land Use

To reduce the impact of climate change mitigation and adaptation are the two key options available. Mitigation options are focused at reducing the emissions of GHGs from agriculture sector and at the same time meeting the demands of food production by the growing population. Mitigation activities are traditionally employed as natural resources conservation measures, but they generally serve the dual purposes of reducing the emission of GHG from anthropogenetic sources and enhancing carbon "sink." Forestry sector holds the key to the success of mitigation efforts and has great potential to sequester carbon through reduced emissions from deforestation and degradation (REDD), afforestation and reforestation, and forest management (Lenka et al. 2013). A variety of options exists for mitigation of GHG emissions in agriculture. The most prominent options are improved crop and grazing land management (e.g., improved agronomic practices, nutrient use, tillage, and residue management), increasing partial factor productivity and input use efficiency, restoration of organic soils that are drained for crop production, and restoration of degraded lands. Lower but still significant mitigation is possible with improved water and rice management; set-asides, land-use change (e.g., conversion of cropland to grassland), and agroforestry or other perennial planting in agricultural lands; as well as improved livestock and manure management. Many mitigation opportunities use current technologies and can be implemented immediately, but technological development will be a key driver ensuring the efficacy of additional mitigation measures in the future. Also the suitability and recommendation of mitigation technology is site specific and need based. There are few constraints and challenges in transferring of these mitigation technologies to a farmer's field. There is a need to address the issues and constraints and devise ways in achieving the large-scale adoption of climate-friendly agricultural practices. The established linkage of GHG emission with climate change has led to international negotiations and the recognition of carbon (C) as a tradable commodity. Agriculture practices with low C footprint can be a triple win in form of enhanced adaptation, increased mitigation, and stability in the food security and sustainability in the country. The imposition of a CO_2 tax on agricultural activity would result in a reduction of agricultural production, particularly for GHG-intensive commodities. In contrast, if farmers were rewarded for carbon sequestration activities (specifically agroforestry), this would lead to intensification, as more inputs are applied to the land remaining in agriculture. Emissions per unit of agricultural land would increase but would decline per unit of output. They are also supportive of arguments made by others that if global agriculture is to meet the needs of an expanding world population while simultaneously contributing to mitigation of GHG emissions, changes in the structure of production and intensification will be required (Blandford et al. 2014). Carbon offset program can be successful in agriculture sector only if the carbon credits to be traded are in a bulk quantity, easily measurable, and there are buyers to buy the credits. Thus, measures at the government level to effectively integrate farmers into carbon trading processes are needed. For example, if conservation agriculture is considered as a tradable activity, then the scale of adoption should be sizable so that a pool of credits is generated. Similarly, degraded land restoration measures and soil health improvement programs can be brought into the C trading network.

3.8 Conclusion

Management of agricultural land, land-use change, and forestry has a profound influence on atmospheric GHG concentration. In the agriculture sector, besides the CO_2 emissions due to burning of crop and animal waste, the world's livestock population and rice fields are significant contributors to CH_4 emissions. The two broad anthropogenic sources of GHG emission from agriculture are the energy use in agriculture (manufacture and use of agricultural inputs and farm machinery) and the management of agricultural land. An understanding of GHG emissions by sources and removal by sinks in agriculture is important to take appropriate mitigation and adaptation strategies and to estimate and create inventory of GHGs. Within the scientific community there is increasing recognition that agriculture in general, and livestock production in particular, contributes significantly to GHG emissions. As a result, the global agricultural community is committed to reducing emissions to safeguard the environment; however, it must simultaneously meet the demands of a growing human population and their increasing requirements for food high in quality and quantity. There is a need to improve the efficiency of agricultural production if we are to meet global food supply demands and decrease agriculture's impact on climate change.

References

Bell MJ, Cloy JM, Rees RM (2014) The true extent of agriculture's contribution to national GHG emissions. Environ Sci Policy 39:1–12

Bellarby J, Tirado R, Leip A, Weiss F, Lesschen JP, Smith P (2013) Livestock GHG emissions and mitigation potential in Europe. Glob Chang Biol 19:3–18

Blandford D, Gaasland I, Vardal E (2014) The trade-off between food production and GHG mitigation in Norwegian agriculture. Agric Ecosyst Environ 184:59–66

Chhabra A, Manjunath KR, Panigrahy S, Parihar JS (2009) Spatial pattern of methane emissions from Indian livestock. Curr Sci 96(5):683–689

Crosson P, Shalloo L, O'Brien D, Lanigan GJ, Foley PA, Boland TM, Kenny DA (2011) A review of whole farm systems models of GHG emissions from beef and dairy cattle production systems. Anim Feed Sci Technol 166/167:29–45

Dinuccio E, Balsari P, Berg W (2008) GHG emissions during the storage of rough pig slurry and the fractions obtained by mechanical separation. Aust J Exp Agric 48:93–95

FAOSTAT (2013) FAOSTAT database. Food and Agriculture Organization of the United Nations. Available at: http://faostat.fao.org/

Galloway JN, Burke M, Bradford GE, Naylor R, Falcon W, Chapagain AK, Gaskell JC, McCullough E, Mooney HA, Oleson KLL, Steinfeld H, Wassenaar T, Smil V (2007) International trade in meat: the tip of the pork chop. Ambio 36:622–629

IPCC (Intergovernmental Panel on Climate Change) (2007) Climate change: synthesis report; summary for policymakers. Available: http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr_spm.pdf

Johnson KA, Johnson DE (1995) Methane emissions from cattle. J Anim Sci 73:2483–2492

Kongshaug G (1998) Energy consumption and GHG emissions in fertilizer production. IFA technical conference, Marrakech, p 18

Lenka S, Lenka NK, Kundu S, Subba Rao A (2013) Climate change and natural resource management. New India Publishing Agency, New Delhi-88, p 359

Paustian K, Antle M, Sheehan J, Eldor P (2006) Agriculture's role in greenhouse gas mitigation. Pew Center on Global Climate Change, Washington, DC

Pachauri R (2013) Conclusions of the IPCC working group I fifth assessment report, AR4, SREX and SRREN, Warsaw, 11 November 2013

Sejian V, Lal R, Lakritz J, Ezeji T (2011) Measurement and prediction of enteric methane emission. Int J Biometeorol 55:1–16

Sejian V, Indu S, Ujor V, Ezeji T, Lakritz J, Lal R (2012) Global climate change: enteric methane reduction strategies in livestock. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GMbH Publisher, Germany, Berlin, Heidelberg, pp 469–502

Sharma SK, Choudhary A, Sarkar P, Biswas S, Singh A, Dadhich PK, Singh AK, Majumdar S, Bhatia A, Mohini M, Kumar R, Jha CS, Murthy MSR, Ravindranath NH, Bhattacharaya JK, Karthik M, Bhattacharya S, Chauhan R (2011) Green house gas inventory estimates for India. Curr Sci 101:405–415

Swamy M, Bhattacharya S (2011) Budgeting anthropogenic green house gas emission from Indian livestock's using country-specific emission coefficients. Curr Sci 91:1340–1353

Tubiello FN, Salvatore M, Rossi S, Ferrara A, Fitton N, Smith P (2013) The FAOSTAT database of GHG emissions from agriculture. Environ Res Lett 8:1–11. doi:10.1088/1748-9326/8/1/015009, ISSN: 1748–9326

UNFCCC (2008) Report of the conference of the parties on its thirteenth session, held in Bali from 3 to 15 December 2007. United Nations framework convention on climate change, Bali. Available at: http://unfccc.int/resource/docs/2007/cop13/eng/06a01.pdf

Part II

Climate Change Impact on Livestock

Impact of Climate Change on Livestock Production and Reproduction

4

John Gaughan and A.J. Cawdell-Smith

Abstract

There is little doubt that climate change will have an impact on livestock performance in many regions and for most predictive models the impact will be detrimental. The real challenge is how do we mitigate and adapt livestock systems to a changing climate? Livestock production accounts for approximately 70 % of all agricultural land use, and livestock production systems occupy approximately 30 % of the world's ice-free surface area. Globally 1.3 billion people are employed in the livestock (including poultry) sector and more than 600 million smallholders in the developing world rely on livestock for food and financial security. The impact of climate change on livestock production systems especially in developing countries is not known, and although there may be some benefits arising from climate change, however, most livestock producers will face serious problems. Climate change may manifest itself as rapid changes in climate in the short term (a couple of years) or more subtle changes over decades. The ability of livestock to adapt to a climatic change is dependent on a number of factors. Acute challenges are very different to chronic long-term challenges, and in addition animal responses to acute or chronic stress are also very different. The extents to which animals are able to adapt are primarily limited by physiological and genetic constraints. Animal adaptation then becomes an important issue when trying to understand animal responses. The focus of animal response should be on adaptation and management. Adaptation to prolonged stressors will most likely be accompanied by a production loss, and input costs may also increase. Increasing or maintaining current production levels in an increasingly hostile environment is not a sustainable option.

J. Gaughan (✉) • A.J. Cawdell-Smith
Animal Science Group, School of Agriculture and
Food Sciences, The University of Queensland,
Gatton, QLD 4343, Australia
e-mail: j.gaughan@uq.edu.au

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_4, © Springer India 2015

Keywords
Livestock • Heat stress • Production • Reproduction • Adaptation

4.1 Introduction

It is somewhat misleading to focus our discussion on potential livestock production and reproductive losses due to climate change. For a start we do not really know what these losses will be in 20, 30 or 100 years due to the interrelationships between climate, the environment and the animal. Of course human intervention is also a complicating factor, and some animals will adapt. It is easy to model production losses. We know what the impact of high temperature will be on a Holstein dairy cow producing 40 L of milk per day and we know the impact on a cow producing 19 L of milk per day. Similarly, for many of the traditional farm animals, we know the effect of exposure to hot conditions (Nardone et al. 2010). In contrast, we know little about some of the indigenous breeds that are used in many developing countries. One area in which we have little knowledge is the responses to extreme events which are likely to be a feature of climate change. So what should we do? What we need to focus on is how to ameliorate the negative effects of climate change on livestock production. We need to focus on animal adaptation and focus on planning for extreme events – this includes pre, post and during the event.

Livestock production accounts for approximately 70 % of all agricultural land use, and livestock production systems occupy approximately 30 % of the world's ice-free surface area (Steinfeld et al. 2006). Globally 1.3 billion people are employed in the livestock (includes poultry) sector and more than 600 million smallholders in the developing world rely on livestock for food and financial security (Thornton et al. 2006). For many smallholders livestock not only provide food but also provide a source of income that gives livelihood. Meat and milk consumption is increasing especially throughout the developing world due to improved living standards of the middle class (Delgado 2003). In 1973, approximately 6 % of caloric intake in the developing countries was obtained from beef, pork, goats, sheep, milk and eggs (Delgado 2003). In 1997, this had risen to approximately 10 % (Delgado 2003). In 2009, livestock products contributed 17 % to kilocalorie consumption and 33 % to protein consumption globally, but there were large differences between rich and poor countries (Rosegrant et al. 2009).

It has been estimated that agricultural production will need to increase 60 % (based on 2005–2007 production values) just to meet the demand from an increasing world population (FAO 2013). Estimates of future demand for animal-based proteins vary, but based on current growth, and the potential negative impacts of climate change on the livestock sectors in many countries, it is unlikely that food from livestock and poultry will be able to meet demand. The impact of climate change on livestock production systems especially in developing countries is not known, and although there may be some benefits arising from climate change (e.g. in northern Europe there are potential increase in crop yields (Olesen and Bindi 2002)), most livestock producers will face serious problems (Thornton et al. 2009). Furthermore, there is a growing shift in livestock production away from temperate dry areas to warmer, more humid and potentially more disease-prone environments (Steinfeld 2004). Potentially, these are areas that are more vulnerable to climate change. On account of changes in land use, there are shifts in livestock production and also changes in crop production (Thornton et al. 2009; Nardone et al. 2010). Both of these complicate the debate on how climate change will impact livestock production.

Climate change will impact on livestock systems in many ways, some of which are direct effects, e.g. heat stress, water availability, water quality, feed availability, feed quality, disease/parasites and disease/parasite vectors. Indirect effects may include human health issues that are influenced by climate as well as non-climate factors (Thornton et al. 2009). Other indirect effects include land degradation (due to overstocking) and market access. The indirect effects although important are outside the scope of this chapter. The focus of this chapter will be on the impact of climate change on production and reproduction in livestock. The focus will not be on production losses per se but how we might reduce the impact of climate change on livestock.

4.2 Impact of Climate Change on Animal Production and Reproduction

4.2.1 General Response to Climate Change

Climate change may manifest itself as rapid changes in climate in the short term (a couple of years) or more subtle changes over decades. The ability of livestock to adapt to a climatic change is dependent on a number of factors. Acute challenges are very different to chronic long-term challenges, and in addition animal responses to acute or chronic stress are also very different. The extents to which animals are able to adapt are primarily limited by physiological and genetic constraints (Devendra 1987; Parsons 1994). Animal adaptation then becomes an important issue when trying to understand animal responses. For example, should we try to enhance adaptive capacity through selective animal breeding or use breeds that are already adapted? An adjunct to this question is: are we focused on increasing animal performance (and hence food production) or simply family survivability? Unfortunately increased 'genetic' performance often leads to an increase in input costs and an animal that is more susceptible to harsh conditions. The ability of animals to cope with climatic extremes (more on this later) is influenced by their level of production. For example, high production Holstein dairy cows (>30 kg milk/day) exposed to high heat load had a 13.7 % reduction in milk yield compared with low production cows (<19 kg milk/day) which had a 4.1 % reduction under the same climatic conditions (Gaughan and Lees 2010). Further to this, reproductive rates fell by more than 20 % in the high production cows. Placing high production cows into a hot environment is not sustainable, and if there is an increase in extreme events, then selection of animals that can cope with these events is critical. Angus steers have faster growth rates and are more efficient in turning grain-based diets into meat than Brahmans are when lot fed, but Angus are also more susceptible to heat stress (Fig. 4.1). The higher rumen temperature of the Angus is an indication that they are not adapted to hot conditions. However, other factors will need to be considered.

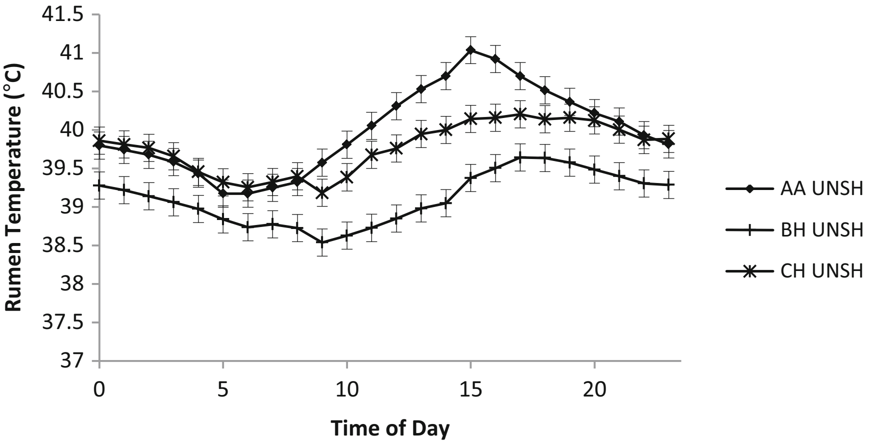


Fig. 4.1 Hourly rumen temperatures of unshaded Angus (AA), Charolais (CH) and Brahman (BH) steers in a feedlot over summer in Queensland, Australia (Gaughan unpublished)

4.2.2 Animal Adaptation

The introductory arguments suggest that livestock and poultry production will not meet the human demand for meat, milk and egg products due to the negative impacts of climate change. On this premise what can be done to improve animal performance when they are being challenged by a changing climate? Much has been said about the need to select animals that are adapted to certain climatic (or environmental) conditions or select those that have the capacity to adapt. However, adaptation is not necessarily a simple process and selection for this may be difficult.

Animal adaptation is a function of a number of intertwined factors, i.e. animal × human × resources. Animal adaptability in the face of a changing climate is as much about the animal as it is about the adaptability of humans and their use of the available resources (e.g. land, feed, water and money). Any discussion about animal adaptability needs to encompass all of the factors that will either enhance adaptability or reduce adaptability. There is another underling question. Should we be looking for adaptability in farm animals or should we focus on genotype, i.e. only use animals that are already adapted to the conditions? Or should we look for alternatives, e.g. changing from cattle to goats?

Furthermore, there are a number of issues facing livestock systems in much of the developing world and in parts of the developed world. These factors need to be addressed as prerequisites to animal adaptation. Some of these are:

- Low productivity (genetic)
- Low productivity (environment)
- Low productivity (G × E)
- Availability of land
- Availability of feed
- Availability of water
- Land degradation (natural, cropping, livestock)
- Capacity to adapt or change
- Cultural norms (prestige of owning livestock)
- Market access (and a fair price)

Effective management of livestock and nutrition under suboptimal conditions, rather than maximum production or selection for adaptability, may be a more realistic goal. Grazing livestock can improve soil fertility, reduce woody weeds and increase grass growth and reduce fire hazards. But only if the animals are managed correctly – overgrazing is a management issue not an animal issue.

The effects of climate change will be exacerbated where there is a lack of animal and resource management. Adaptation to climate change is more than adaptation to heat. Unfortunately, much of the focus has been on the potential for elevated heat in the future and in particular extreme heat events (which we will discuss below). It is difficult even with the most technologically advanced nations to select animals for climate extremes without a major reduction in the animals' performance. Therefore, there is a need to focus on the big picture. How will a changing climate impact on the animals' overall environment? Again a number of interacting factors need to be considered, and these include precipitation (variation and extremes), soil moisture, feed resources, parasite exposure, solar load, temperature (variation and extremes) and drinking water availability.

There is a growing need to select animals (and species) that are suited to the current climatic conditions, as well as the predicted future conditions. This is not an easy task. First, the future is largely unknown. Secondly there is a considerable breed variation, within and between breeds, for thermal tolerance and overall stress tolerance. The ability of livestock breeders to identify phenotypes, which carry specific genes, is difficult partly because phenotypic variance is due to the combined effects of genetic and environmental components. Therefore, there is a reliance on selecting animals from within the environment or from a similar environment in which they are expected to live. Livestock need to have 'adequate' performance in four key areas:

- Survivability (to reproductive age)
- Productivity (milk, wool, meat, egg production)
- Productivity
- Fertility

It can be argued that a reliance on 'natural' selection is fundamentally the correct approach (but it may not be quick enough). However, animals with adequate survival rates under harsh conditions may achieve this survivability at the expense of growth, production and fertility. Furthermore, the extent to which a location is likely to be favourable or unfavourable to the species or breed concerned at some point in the future needs to be considered. The time taken to fundamentally change the genetics of a breed is dependent upon the number of animals in a breeding programme, the fertility of the population, selection pressure (on the traits of interest), selection differential, the heritability of the trait concerned, and the generation interval. Reaching a desired goal may take 15–20 years (or longer). In a static environment this is probably not an issue, but if climate is changing, where do we head with a breeding programme? If predicted changes are wrong, a breeder may be 20 years into a breeding programme only to find they made the wrong decisions years ago.

In a further complication, livestock breeders are generally more concerned with local climatic conditions than regional or global change because the local changes have the biggest immediate impact on animal performance and it is this current performance that biases selection. It is unlikely that a smallholder will be able to do much to enhance genetic change in their animals without financial and technological assistance.

In the context of livestock production – what can be achieved? In the 2013/2014 drought in Queensland, Australia, cattle losses due to a lack of feed and water were high. However, the ability to move cattle (adjistment, feedlotting or selling) reduced mortality but was expensive. Even in a developed nation, a lack of financial resources will reduce options for short-term and long-term adjustment. Financial setbacks due to droughts, floods, fires and disease further reduce the capacity for livestock producers (large and small) to adapt to change. Furthermore, it is not possible for animals to adapt to no food and no water. Extreme events are likely to be more problematic in any selection programme for adaptation than the overall change in temperature. Nyong et al. (2007) studied the value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. In their conclusion, they made a salient comment that has application in both developed and developing nations: ‘Reducing vulnerability entails the strengthening of adaptive capacities of vulnerable individuals and groups. Capacity building should emphasize the need to build on what exists, to utilize and strengthen existing capacities.’ This statement applies broadly to the global livestock sector.

4.2.3 Heat Stress

Generally climate change is associated with an increasing global temperature. Various climate model projections suggest that by the year 2100, mean global temperature may be 1.1–6.4 °C warmer than in 2010 (Nardone et al. 2010). In many cases, animals and livestock systems will be able to adapt to an increased mean temperature (provided other factors such as feed and water remain available). The difficulty facing livestock is weather extremes, e.g. intense heat waves. In addition to production losses, extreme events also result in livestock death. There is little doubt that there has been an increase in extreme events since the 1990s. Documented heat wave mortalities for livestock include some 50,000 feedlot animals in North America between 1990 and 2014 and 12,000 feedlot steers in Australia between 1990 and 2014; 26,000 dairy cows died in California in July 2006; it was estimated that 700,000 poultry died during the July 2006 heat wave, and during a heat wave in India (2007), more than 800 peacocks died. It is likely that animal deaths are considerable in developing countries as well. Unfortunately data is mostly non-existent. Further to this, extreme events are often multifactorial, e.g. drought + heat, so categorising the cause of death as heat or drought is not easy. Livestock deaths are costly, not only is future income forgone, but past expenses are also not recovered. There is also a cost associated (in some countries) with carcass disposal. It should not be forgotten that major heat waves also kill humans. The 2003 heat wave that occurred in Europe left 35,000 dead, during the 2012 Russia event 15,000 died and a heat wave in

Andhra Pradesh killed more than 500 people in 2013. It is clear that extreme events are the problem and it is the uncertainty and irregular occurrence of these events which make management difficult.

Production/reproduction losses due to heat stress are well documented for sheep, pigs, poultry, beef cattle and dairy cows, although most of the research focuses on large-scale intensive production systems in developed countries. The proceeding few paragraphs will only discuss heat stress (generally) for dairy cows, poultry and beef cattle. This does not imply that the other species are not worth discussing. The reader is encouraged to look for the scientific literature to further their knowledge in this area.

4.2.3.1 Dairy Cows

Holstein-Friesian dairy cows are particularly vulnerable to heat stress (see West 2003). When ambient temperature exceeds 25 °C, dairy cows are subjected to heat stress (Staples and Thatcher 2011). The first manifestation of heat stress is an increase in body temperature and respiration rate (Fig. 4.2). As body temperature increases, there is a concurrent reduction in feed intake and a reduction in milk output (West 2003; Staples and Thatcher 2011). The magnitude of reduced production is, as mentioned earlier, a function of the degree of heat load and genetic merit of the cow. Staples and Thatcher (2011) reviewed a number of studies. They reported that when rectal temperature increased from 38.8 to 39.9 °C, there was a reduction in milk output from 22.4 to 19.2 kg/day. Dry matter intake also fell. Although data is limited, there is evidence that higher production cows are more susceptible to heat stress than are low production cows. A comparison of three studies (Staples and Thatcher 2011) shows that there is a difference in the heat stress response between high and low production cows with the high production cows (32.6 kg milk/day) having a 4.7 kg/day decrease in milk production compared with a 2.7 kg reduction in the low production cows (19.0 kg milk/day) (Table 4.1). Lower reductions were reported by Gaughan and Lees (2010). In a study, 150 Holstein-Friesian cows were studied over 120 days of summer. The cows were not housed and were subjected to natural Australian (Queensland) summer conditions. High production cows (34.4 kg milk/day) had a 2.3 kg per day reduction in milk yield compared with low production cows (<20 kg) where there was no change in milk yield. Reproductive performance of dairy cows also declines during heat stress. As with production losses, the impacts on reproduction are well documented (Jordan 2003; Hansen and Furquay 2011). There also appears to be a relationship between the level of production and fertility. Al Katanani et al. (1999) reported that during summer the fertility depression in Holstein cows was greater for high production cows (>9,072 kg milk) as compared to low production cows (<4,536 kg). Fertility depression was assessed by non-return rates (i.e. the number of cows that do not return to oestrus 21 days postinsemination). The non-return rate for the low

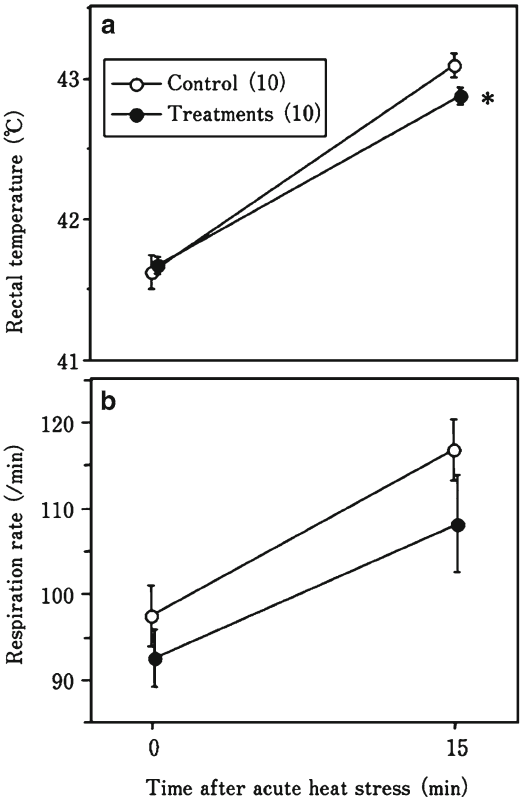


Fig. 4.2 Effect of environmental temperature on respiration rates and rectal temperatures of lactating dairy cows (Staples and Thatcher 2011)

Table 4.1 Differences in dry matter intake (DMI) and milk yield between low and high production dairy cows exposed to heat stress

	Low production cows (<25 kg milk/day)	High production cows (>30 kg milk/day)
Change in rectal temperature (°C)	38.9–39.9	38.5–39.8
Change in DMI (kg/day)	17.4–15.0	21.3–17.5
Change in milk yield (kg/day)	19.0–16.3	32.6–27.9
Reduction in milk output (kg) per 1 °C increase RT	2.7	3.6

Adapted from Staples and Thatcher (2011)

production cows was 44.9 % and for the high production cows the non-return rate was 5.3 %.

4.2.3.2 Poultry

Poultry production is expanding worldwide with much of the growth in developing countries in the tropics and sub-tropical zones. Heat stress is likely to be a major limiting factor in poultry production in many regions. Given that the optimum temperature for broilers is 18–22 °C (Lin et al. 2006), projected climate change scenarios are a major concern for the global poultry industry (Tanizawa et al. 2014). Because of this, more heat stress-related research has been undertaken for poultry than any other farm animal. Heat stress impacts on performance (reduced egg production, reduced growth rate), reduces product quality, decreases immune function and leads to an increase in mortalities (Sahin et al. 2013). Poultry (broilers) are probably more susceptible to heat stress than other farm animals due to their selection for rapid growth and feed efficiency (Lin et al. 2006). Selection for heat tolerance has not been a major consideration by breeding companies primarily because heat tolerance means reduced performance (Washburn et al. 1980). However, Yahav and Hurwitz (1996) demonstrated that thermotolerance could be induced in chickens by exposure to high temperatures at an early age. This is a continuing area of research and many researchers have demonstrated higher heat tolerance in poultry where embryos are exposed to high temperature for short periods (Fig. 4.3). Thermal conditioning resulted in significant ($P<0.05$) reductions in rectal temperature compared with non-treated birds (42.87 vs. 43.09 °C, respectively) and also for respiration rate (108.2 vs. 116.8 breaths/min) (Tanizawa et al. 2014).

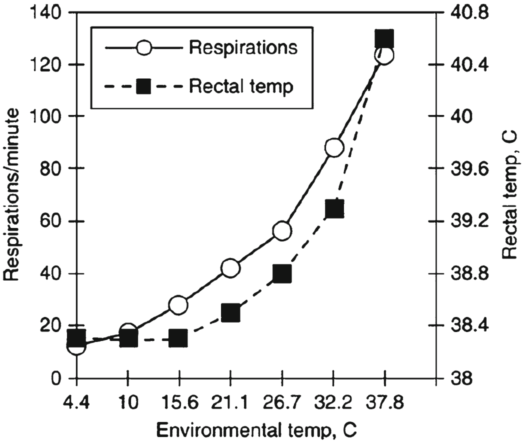


Fig. 4.3 Rectal temperature and respiration rate of chickens before and after thermal conditioning (From Tanizawa et al. 2014)

4.2.3.3 Beef Cattle

The effects of heat load on different breeds of cattle (*Bos indicus*, *Bos taurus* and various *Bos indicus* × *Bos taurus* crosses) have been reviewed by a number of authors, e.g. Blackshaw and Blackshaw (1994), Finch (1986), Hammond et al. (1996, 1998), Gaughan et al. (1999), and Beatty et al. (2006). *Bos indicus* breeds (e.g. Brahman), although having greater heat tolerance than *Bos taurus* breeds (Fig. 4.4), often have lower productivity (growth rate and reproductive efficiency) than the less heat-tolerant breeds (Gaughan et al. 2010). The normal respiration rate for *Bos taurus* cattle under thermoneutral conditions is 20–30 breaths per minute. Under extreme heat stress, respiration rate may exceed

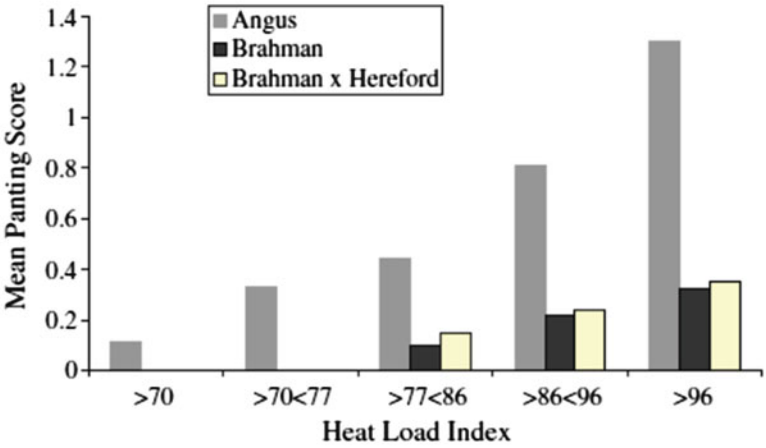


Fig. 4.4 Differences in panting score and heat load (the higher the value the greater the heat stress) for Angus, Brahman and Brahman × Hereford steers (Gaughan et al. 1999)

150 breaths per minute. Rectal temperatures may increase from 38.6 to 41.5 °C. When faced with hot ambient conditions, cattle (especially grain-fed cattle) reduce their feed intake. An inverse relationship between ambient temperature and feed intake exists for beef cattle. During periods of high heat load, dramatic drops in feed intake occur. A 17 % reduction in feed intake was reported by Brown-Brandl et al. (2005) for unshaded heifers when mean ambient temperature increased from 19.7 °C (maximum 21 °C) to 27.7 °C (maximum 35 °C). A depression in intake of 3–5 % has been reported to occur when ambient temperature increases from 25 to 35 °C; intake reductions go beyond 30 % when temperatures exceed 35 °C. Reduced production as a result of reduced feed intake is the major issue facing beef cattle exposed to chronic heat stress.

Reproductive performance of beef cattle is also affected by ambient conditions; however, there is little published data. In a US study, Amundson et al. (2006) reported that pregnancy rate decreased when the minimum night-time temperature exceeded 16.7 °C and temperature humidity index was greater than 72.9 units.

4.3 Can Livestock Adapt to Climate Change?

Returning to our original question – can livestock adapt? When environmental conditions change, an animal's ability to cope (or adapt) to the new conditions is determined by its ability to maintain essential functions and oxidative metabolism (Pörtner and Knust 2007). As we have discussed, environmental stressors brought about by climate change include reductions in available feed and water, changes in temperature and an increase in extreme events. The individual stress response to these challenges is influenced by a number of factors including species, breed, previous exposures to the stressor, health status, levels of performance, body condition, metabolic state (e.g. pregnant, lactating), mental state and age. To further complicate things, the stressors may be acute, sudden changes (usually short term, e.g. hours to days) in weather, or chronic, prolonged (weeks to months) exposure to stress. Animal responses to acute and chronic stressors may be very different. If we are looking for animals adapted to climate change do we select for acute or chronic stress? Given the earlier premise that selection for extremes is difficult, selection should probably focus on chronic environmental stress.

If an animal is not acclimated or adapted, then its physiological, behavioural and metabolic responses will most likely be different to when it is acclimated or in adapted. It is important therefore, while discussing animal adaptation, to understand that animal responses to a given set of stressors may change over time as the animal adjusts. It is possible that acclimatisation or adaptation may alleviate the stress response (Kassahn et al. 2009), but performance may not return to prestress levels. And this is the conundrum that livestock producers face. Adaptation is often at the expense of performance, and survivability is often better in 'low'-performance animals because their input needs (especially feed) are not high.

4.4 Conclusion

There is little doubt that climate change will have an impact on livestock performance in many regions and for most predictive models the impact will be detrimental. The real challenge is how do we mitigate and adapt livestock systems to a changing climate. Should the focus be on animal adaptation or an overall adaptation of the systems involved? Farmers need to adapt and invoke strategies that will reduce the impact of climate change. The capacity of animals to adapt in the short to medium term will be limited primarily by their genetics. However, financial resources and management capacity will have a major role. Adaptation to prolonged stressors will most likely be accompanied by a production loss, and input costs may also increase. Increasing or maintaining current production levels in an increasingly hostile environment is not a sustainable option. It may be wiser to look at using adapted animals, albeit with lower production levels (and also lower input costs), rather than try to infuse 'stress tolerance' genes into a non-adapted breed. This may be contrary to government policies and can be counter intuitive. It is not always easy to convince someone that they are better off with a cow that produces 9 L of milk per day versus one that produces 20 L. Perhaps a better solution is to change species, e.g. use goats instead of cattle. Animal adaptation is one part of the solution but it is not the solution to protect food resources in a changing climate.

References

Al Katanani YM, Webb DW, Hansen PJ (1999) Factors affecting seasonal variation in 90-d nonreturn rate to first service in lactating Holstein cows in a hot climate. J Dairy Sci 82:2611–2616

Amundson JL, Mader TL, Rasby RJ, Hu QS (2006) Environmental effects on pregnancy rate in beef cattle. J Anim Sci 84:3415–3420

Beatty DT, Barnes A, Taylor E, Pethick D, McCarthy M, Maloney SK (2006) Physiological responses of Bos taurus and Bos indicus cattle to prolonged, continuous heat and humidity. J Anim Sci 84:972–985

Blackshaw JK, Blackshaw AW (1994) Heat stress in cattle and the effect of shade on production and behaviour: a review. Aust J Exp Agric 34:285–295

Brown-Brandl TM, Eigenberg RA, Neinaber JA, Hahn GL (2005) Dynamic response indicators of heat stress in shaded and non-shaded feedlot cattle, Part 1: Analysis of indicators. Biosyst Eng 90:451–462

Delgado CL (2003) Rising consumption of meat and milk in developing countries has created a new food revolution. J Nutr 133:3907S–3910S

Devendra C (1987) Goats. In: Johnson HD (ed) Bioclimatology and the adaptation of livestock. Elsevier, Amsterdam

FAO (2013) Statistical year book 2013. World Food and Agriculture FAO, Rome

Finch VA (1986) Body temperature in beef cattle: its control and relevance to production in the tropics. J Anim Sci 62:531–542

Gaughan JB, Lees JC (2010) Categorising heat load on dairy cows. Proc Aust Soc Anim Prod 28:105

Gaughan JB, Mader TL, Holt SM, Josey MJ, Rowan KJ (1999) Heat tolerance of Boran and Tuli crossbred steers. J Anim Sci 77:2398–2405

Gaughan JB, Mader TL, Holt SM, Sullivan ML, Hahn GL (2010) Assessing heat tolerance of 17 beef cattle genotypes. Int J Biometeorol 54:629–635

Hammond AC, Olson TA, Chase CC, Bowers EJ, Randel CN, Murphy DW, Tewolde A (1996) Heat tolerance in two tropically adapted Bos taurus breeds, Senepol and Romosinuano, compared with Brahman, Angus and Hereford Cattle in Florida. J Anim Sci 74:295–303

Hammond AC, Chase CC, Bowers TA, Olson TA, Randal RD (1998) Heat tolerance in Tuli, Senepol and Brahman-sired F-1 Angus heifers in Florida. J Anim Sci 76:1568–1577

Hansen PJ, Furquay JW (2011) Heat stress: effects on reproduction. In: Encyclopedia of dairy sciences, 4 Vols., 2nd edn. Academic Press, Oxford, UK, pp 567–574

Jordan ER (2003) Effects of heat stress on reproduction. J Dairy Sci 86:E104–E114

Kassahn KS, Crozier RH, Pörtner HO, Caley MJ (2009) Animal performance and stress: responses and tolerance limits at different levels of biological organisation. Biol Rev 84:277–292

Lin H, Jiao HC, Buyse J, Decuypere E (2006) Strategies for preventing heat stress in poultry. Worlds Poult Sci J 62:71–85

Nardone A, Ronchi B, Lacetera N, Ranieri MS, Bernabucci U (2010) Effects of climate changes on animal production and sustainability of livestock systems. Livest Sci 130:57–69

Nyong A, Adesina F, Osman Elasha B (2007) The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. Mitig Adapt Strateg Glob Change 12:787–797

Olesen JE, Bindi M (2002) Consequences of climate change for European agricultural productivity, land use and policy. Eur J Agron 16:239–262

Parsons PA (1994) Habitats, stress, and evolutionary rates. J Evol Biol 7:387–397

Pörtner HO, Knust R (2007) Climate change affects marine fish through the oxygen limitation of thermal tolerance. Science 315:95–97

Rosegrant MW, Fernandez M, Sinha A, Alder J, Ahammad H, de Fraiture C, Eickhout C, Fonseca J, Huang B, Koyama J, Omezzine O, Pingali AM, Ramirez P, Ringler R, Robinson C, Thornton S, van Vuuren P, Yana-Shapiro D, Ebi H, Kruska K, Munjal R, Narrod P, Ray C, Sulser S, Tamagno T, van Oorschot M, Zhu T (2009) Chapter 5: Looking into the future for agriculture and AKST (Agricultural knowledge science and technology). In: McIntyre BD, Herren HR, Wakhungu J, Watson RT (eds) Agriculture at a crossroads. Island Press, Washington, DC, pp 307–376

Sahin K, Orhan C, Smith MO, Sahin N (2013) Molecular targets of dietary phytochemicals for the alleviation of heat stress in poultry. Worlds Poult Sci J 69:113–123

Staples CR, Thatcher WW (2011) Heat stress: effects on milk production and composition. In: Encyclopedia of dairy sciences, 4 Vols., 2nd edn. Academic Press, Oxford, UK, pp 561–566

Steinfeld H (2004) The livestock revolution – a global veterinary mission. Vet Parasitol 125:19–41

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow: environmental issues and options. FAO, Rome

Tanizawa H, Shiraishi J-I, Kawakami S-I, Tsudzuki M, Bungo T (2014) Effect of short-term thermal conditioning on physiological and behavioral responses to subsequent acute heat exposure in chicks. J Poult Sci 51:80–86

Thornton PK, Jones PG, Owiyo T, Kruska RL, Herrero M, Kristjanson P, Notenbaert A, Bekele N, Omolo A (2006) Mapping climate vulnerability and poverty in Africa: report to the Department for International Development. ILRI, Nairobi

Thornton PK, van de Steeg J, Notenbaert A, Herrero M (2009) The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agric Syst 101:113–127

Washburn KW, Peavey R, Renwick GM (1980) Relationship of strain variation and feed restriction to variation in blood pressure and response to heat stress. Poult Sci 59:2586–2588

West JW (2003) Effects of heat stress on production in dairy cows. J Dairy Sci 86:2131–2144

Yahav S, Hurwitz S (1996) Induction of thermotolerance in male broiler chickens by temperature conditioning at an early age. Poult Sci 75:402–406

Thermal Stress Alters Postabsorptive Metabolism During Pre- and Postnatal Development

5

J.S. Johnson, M. Abuajamieh, M.V. Sanz Fernandez, J.T. Seibert, S.K. Stoakes, J. Nteeba, A.F. Keating, J.W. Ross, R.P. Rhoads, and L. Baumgard

Abstract

Climate change, and thermal stress (i.e., heat and cold) in particular, is a key limiting factor to efficient animal production and negatively impacts health and development during postnatal life. In addition, thermal stress (especially heat stress) during in utero development can permanently alter postnatal phenotypes and negatively affect future animal performance. The global effects of thermal stress on animal agriculture will likely increase as climate models predict more extreme weather patterns in most animal-producing areas. While the ultimate consequence of heat and cold stress is similar (reduced productivity and compromised animal welfare), their mechanism(s) of action substantially differs. Predictably, many of the metabolic and physiological effects of heat and cold stress are biologically contrasting; however, both are homeorhetically orchestrated to prioritize survival at the cost of agriculturally productive purposes. Consequently, thermal stress threatens global food security and this is especially apparent in developing countries. There is an urgent need for the scientific community to develop mitigation strategies to increase production of high-quality animal protein for human consumption during the warm summer months.

Keywords

Heat stress • Cold stress • Epigenetics • Metabolism • Insulin

5.1 Introduction

Thermal stressors (i.e., heat stress, cold stress) negatively impact health and development in almost all livestock species. Typical animal responses to thermal stress include slower and inconsistent growth, altered metabolism and body composition, reduced milk synthesis, poor fertility, morbidity, and mortality (Young 1981;

J.S. Johnson • M. Abuajamieh • M.V. Sanz Fernandez
J.T. Seibert • S.K. Stoakes • J. Nteeba • A.F. Keating
J.W. Ross • L. Baumgard (✉)
Department of Animal Science, Iowa State University, Ames, IA 50011, USA
e-mail: baumgard@iastate.edu

R.P. Rhoads
Department of Animal and Poultry Sciences, Virginia Tech University, Blacksburg, VA 24061, USA

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_5, © Springer India 2015

Brown-Brandl et al. 2004; Baumgard and Rhoads 2013). As climate models predict an increase in extreme summer conditions for most global livestock-producing areas, the negative effects of heat stress (HS) will likely become more significant in the future (Luber and McGeehin 2008). Further, because increased basal heat production is an unintended consequence of most traditional genetic selection programs (Brown-Brandl et al. 2004), some suggest more productive animals have greater sensitivity to HS (Nienaber and Hahn 2007). In addition to its aforementioned postnatal effects, HS during gestation can impact a variety of fetal development parameters (Graham et al. 1998) and has the potential to adversely affect lifetime productivity. While cold stress (CS) does not pose a significant threat to animal homeothermy in modern agricultural systems (animals rarely die from CS in commercial operations), it can negatively impact productivity, especially in livestock species raised primarily outdoors (Young 1981). Consequently, there is an urgent need to better understand the mechanisms by which thermal stress compromises efficient production of high-quality animal protein for human consumption.

5.2 Global Impact of Thermal Stress

Thermal stress-induced suboptimal animal performance is already a considerable economic problem and food security issue. However, if climate change continues as expected (Bernabucci et al. 2010), the negative consequences of thermal stress could be an incredibly serious issue for global animal agriculture. Climate change affects ambient temperature, weather patterns, and sea levels and is thought that deforestation and greenhouse gas emissions are a significant contributor to the changing climate (U.S. EPA 2013). According to the US Environmental Protection Agency (2013), average global temperatures are expected to increase by 1.1–6.4 °C by 2100, doubling the increased experienced in the last 100 years. Further, an increase in average temperature worldwide would imply more frequent and intense extreme heat events with days over 32.2 °C expected to increase from 60 to 150 in the United States alone (U.S. EPA 2013). With increased heat wave frequency and periods of extreme temperature expected, incidences of thermal stress-related maladies in animals (and humans) are likely to increase. Therefore, there is an urgent need to better understand how thermal stress affects physiology and ultimately productivity of agriculturally important species in order to develop mitigation strategies.

5.3 Economic and Food Security Impacts of Heat Stress

The agriculture sector contributes $200 billion annually to the US economy (USGCRP 2009) and is likely more sensitive and vulnerable to climate change than any other sector (IPCC 2014). The economic impact of HS-related maladies is estimated to account for billions of dollars in lost revenue due to reduced production in almost every aspect of animal agriculture. In the United States alone, estimated economic losses due to HS range from $1.7 to $2.4 billion annually (St-Pierre et al. 2003). Despite improved management practices and cooling technology (shade, sprinklers, etc.), animal productivity remains compromised during the summer months (St-Pierre et al. 2003; Baumgard and Rhoads 2013).

Economic losses continue to occur because animals are being raised in regions where environmental conditions are outside the zone of thermal comfort during summer season (St-Pierre et al. 2003). During HS, efficiency is compromised because nutrients are diverted to maintain euthermia since preserving a safe core temperature becomes the highest biological priority and tissue synthesis is de-emphasized (Baumgard and Rhoads 2013). The effects of HS are especially evident in tropical and subtropical regions where many developing countries are located (Battisti and Naylor 2009; Muller et al. 2010). As a result, these regions may experience extended periods of HS compared with temperate climates, making HS a significant economic, food security, and humanitarian concern (Battisti and Naylor 2009). Further, because both the population and affluence of developing regions continue to rapidly grow (Godfray et al. 2010), the need for high-quality protein will also increase, and this will likely amplify the negative consequences of thermal stress on animal agriculture.

5.4 Thermal Stress and Animal Production

5.4.1 Heat Stress

Heat stress reduces feed intake, body weight gain, reproductive efficiency, and in severe cases may cause mortality in agriculturally important livestock species (Baumgard and Rhoads 2013; Table 5.1). Due to the aforementioned consequences, the efficiency of animal product synthesis is compromised during the summer heat, and it is estimated that a 1.0 °C increase in ambient temperature during summer months leads to a 4.5 % reduction in production output (Qi et al. 2014). Reduced feed intake is a highly conserved consequence of HS (Baumgard and Rhoads 2013) and is probably a strategy to reduce metabolic rate in an attempt to maintain the balance between heat production and heat loss. Although decreased feed intake was traditionally thought to be the primary contributor to reduced productivity (Beede and Collier 1986; Collin et al. 2001; West 2003), recent results challenge this dogma. These studies used controls that were pair fed to

Table 5.1 The effects of heat stress (HS) and cold stress (CS) on livestock production variables

Parameter	Species	HS	Reference (HS)	CS	Reference (CS)
Feed intake	Rodents	Decrease	6, 17	Increase	11, 13, 21
	Cattle	Decrease	16, 29, 38	Increase	8, 35, 38
	Pigs	Decrease	14, 15, 18, 19, 30	Increase	24, 28
	Sheep	Decrease	4, 25	Increase	2
	Poultry	Decrease	22, 23, 26	Increase	1
Body weight gain	Rodents	Decrease	3, 17	Decrease	11, 13
	Cattle	Decrease	16, 20, 36	Decrease	33, 35, 38
	Pigs	Decrease	14, 15, 18, 19	Decrease	24, 28
	Sheep	Decrease	4, 25	Decrease	2
	Poultry	Decrease	23, 26	Decrease	1, 34
Milk production	Rodents	Decrease	10	Increase	13
	Cattle	Decrease	20, 37, 37	Decrease	7, 12, 33
	Pigs	Decrease	5, 31	–	–
	Sheep	Decrease	9, 32	No change	27
Egg production	Poultry	Decrease	23, 26	Decrease	1

1. Alves et al. (2012)	14. Johnson et al. (2013a)	27. McBride and Christopherson (1984)
2. Ames and Brink (1977)	15. Johnson et al. (2013b)	28. Nyachoti et al. (2004)
3. Baumgard et al. (2012)	16. Johnson et al. (2015a)	29. O'Brien et al. (2010)
4. Bhattacharya and Hussain (1974)	17. Johnson et al. (2015b)	30. Pearce et al. (2013a)
5. Black et al. (1993)	18. Johnson et al. (2014a)	31. Renaudeau and Noblet (2001)
6. Brobeck (1948)	19. Johnson et al. (2014b)	32. Sevi and Caroprese (2012)
7. Broucek et al. (1991)	20. Kadzere et al. (2002)	33. Soren (2012)
8. Christopherson et al. (1979)	21. Klain and Hannon (1969)	34. Spinu and Degen (1993)
9. Finosshiaro et al. (2005)	22. Leeson (1986)	35. Webster (1974)
10. Halder and Bade (1981)	23. Lin et al. (2006)	36. West (2003)
11. Heroux (1969)	24. Lopez et al. (1991)	37. Wheelock et al. (2010)
12. Johnson (1976)	25. Marai et al. (2007)	38. Young (1981)
13. Johnson and Speakman (2001)	26. Marsden and Morris (1987)	

their HS counterparts but remained in thermal neutral conditions allowing for the evaluation of the direct effects of thermal stress while eliminating the confounding effects of dissimilar nutrient intake. Utilizing this model demonstrated that reduced feed intake only accounts for 35–50 % of decreased milk yield in dairy cattle during environmentally induced hyperthermia (Rhoads et al. 2009; Wheelock et al. 2010). In agreement, HS lambs do not gain as much body weight as pair-fed counterparts (Mahjoubi et al. 2014). However, there appears to be differences in how HS alters nutrient partitioning in pigs as HS pigs actually gain more weight than pair-fed counterparts (Pearce et al. 2013a). Regardless of species differences in the response to HS, these data indicate that HS directly alters nutrient partitioning and characterizing how and why this occurs is of practical interest.

5.4.2 Experimental Design Considerations

Although the pair-fed thermal neutral (PFTN) model attempts to separate the direct and indirect effects of HS, some limitations of this experimental design need consideration. The negative consequences of HS on productivity may be mediated by reduced intestinal integrity (Pearce et al. 2013b; Sanz Fernandez et al. 2014). During HS, blood flow is diverted to the skin in an attempt to increase heat dissipation, which results in decreased intestinal blood flow (Lambert 2009). Reduced blood flow leads to hypoxia at the intestinal epithelium, which can alter intestinal morphology, and may compromise the ability of tight junctions to maintain an effective barrier increasing the probability of bacterial translocation into the blood stream (Baumgart and Dignass 2002; Yan et al. 2006; Pearce et al. 2013b). The subsequent endotoxemia/septicemia and inflammation might be partially responsible for the negative effects of HS on productivity (Baumgard and Rhoads 2013). Further, HS-induced changes on villi morphology may decrease nutrient digestibility and absorption in heat-stressed animals as suggested by Pearce and colleagues (2013b), likely putting HS pigs at an even lower plane of nutrition than pair feeding can account for. However, it is important to note that nutrient restriction itself may also increase intestinal permeability (Ferraris and Carey 2000; Pearce et al. 2013b). In addition, voluntary reduced feed intake during HS is likely a strategy to reduce basal heat production (i.e., the thermic effect of feeding) in a concerted effort to acclimate to hyperthermia (Curtis 1983). However, limit-feeding pigs in thermo neutral (TN) conditions (i.e., an involuntary nutrient restriction) may initiate a stress response resulting in increased activity, abnormal behavior, and enhanced stress hormone secretion. Therefore, it is likely that PFTN animals are not only nutrient restricted, but may also be more psychologically stressed compared to their HS counterparts. A report by our group (Pearce et al. 2013a) indicated that pair feeding reduces core body temperature when compared to pigs fed ad libitum and raised in TN conditions. This core temperature decrease could result from reduced heat production from nutrient processing (i.e., the thermic effect of feeding), and in an attempt to maintain homeothermy, PFTN pigs may increase fasting heat production compared to HS pigs. Increased fasting heat production would imply greater maintenance costs, thus reducing energy efficiency in PFTN pigs compared to HS counterparts. Finally, because PFTN pigs lose more body weight when compared to heat-stressed counterparts (Pearce et al. 2013a), nutrient restriction in heat-stressed pigs may not be as metabolically stressful compared to PFTN pigs. Pair feeding as a percent of body weight can help mitigate nutrient intake differences due to altered rates of body weight gain. However, despite its limitations the PFTN model is currently the best method to minimize the confounding effects of dissimilar feed intake during HS experiments.

5.4.3 Heat Dissipation Limit Theory

A recently proposed theory for hyperthermia-induced production loss is the heat dissipation limit (HDL) theory (Speakman and Krol 2010), which states that the capacity of an animal to lose heat is the key variable controlling maximum energy expenditure (Speakman and Krol 2010). In other words, product synthesis (i.e., milk production, muscle synthesis, egg production) is not constrained by the capacity for animals to acquire energy (i.e., the feed intake differential), but the ability to dissipate thermal energy (Speakman and Krol 2010). Therefore, when animals are exposed to HS and their capacity for heat dissipation is reduced (Blatteis 1998), highly exergonic processes such as lactogenesis are constrained regardless of energy intake (Speakman and Krol 2010). This theory may have relevance when considering data published by our group comparing heat-stressed and pair-fed dairy cows (Rhoads et al. 2009). Despite similar energy intake, cows exposed to HS produced less milk compared to PFTN controls (Rhoads et al. 2009), ruling out the possibility that reduced feed intake is solely responsible for the well-documented decline in milk production. It is of interest, therefore, to determine how much the HDL contributes to reduced production in agriculturally important models.

5.4.4 Cold Stress

Two-thirds of all livestock in North America are raised in regions where the mean January temperature is below 0 °C; however, because of modern facilities, CS seldom represents an issue (Young 1981). Although swine and poultry species are particularly CS susceptible, they are often kept in heated housing when raised in colder regions (Young 1981). In addition, lactating or finishing cattle are highly cold tolerant due to larger body mass, hair cover, and metabolic heat production (i.e., fermentation, lactogenesis) and rarely experience ambient temperatures below their lower critical temperature (Young 1981). Despite the lack of hypothermia in cattle, production efficiency is often compromised due to cold temperatures (Table 5.1), especially in times of increased precipitation (Qi et al. 2014). This is primarily due to an increase in heat production (i.e., shivering and non-shivering thermogenesis) required to withstand thermal insults. When animals are first exposed to cold, heat production is increased to compensate for enhanced heat loss to their environment (Klain and Hannon 1969). Unable to balance their new caloric demands with the intake of feed, animals enter a period of negative energy balance where growth is arrested and weight loss occurs (Klain and Hannon 1969; Table 5.1). After this initial period of weight loss, animals will compensate for greater energy demands by increasing energy intake; however, production efficiency will remain compromised (Table 5.1) due to a reprioritization of nutrient partitioning as maximizing heat production becomes essential for survival (Young 1981).

5.5 Thermal Stress and Postabsorptive Metabolism

Thermal stress compromises animal production by directly altering metabolism and the hierarchy of nutrient utilization. A prerequisite to understanding thermal stress adaptation is an appreciation for the physiological and metabolic adjustments responsible for altered postabsorptive metabolism in livestock species during periods of inadequate nutrient intake. Collectively, changes in postabsorptive nutrient partitioning homeorhetically occur to support a dominant physiological state (i.e., milk and skeletal muscle synthesis; Bauman and Currie 1980). Defining the biology and mechanisms by which thermal stress governs animal metabolism may provide the foundation for developing future mitigation strategies.

5.5.1 Carbohydrate Metabolism

5.5.1.1 Heat Stress

During HS, carbohydrate utilization is enhanced (Streffer 1988), and we have demonstrated this in both pigs (Pearce et al. 2013a) and cattle (Wheelock et al. 2010). Acute HS was first reported to cause hypoglycemia in cats and originally thought to be responsible for reduced construction-worker productivity in summer months (Lee and Scott 1916; Table 5.2). Additionally, athletes exercising at high ambient temperatures have consistently elevated hepatic glucose production and enhanced whole-body carbohydrate oxidation at the expense of lipids (Fink et al. 1975; Febbraio 2001; Table 5.2). Moreover, exogenous glucose is unable to blunt hepatic glucose output (Angus et al. 2001), which is likely due to increased glycogenolysis (Febbraio 2001), and gluconeogenesis (Collins et al. 1980; Fig. 5.2). A proposed mechanism for the enhanced hepatic glucose output is increased pyruvate carboxylase expression (a rate-limiting enzyme that controls lactate and alanine entry into the gluconeogenic pathway) during times of HS (O'Brien et al. 2008; White et al. 2009), likely resulting from increased plasma lactate (presumably due to an increase in muscular lactate production; Hall et al. 1980; Elsasser et al. 2009).

Despite the well-documented reduction in nutrient intake and increased body weight loss (Baumgard and Rhoads 2013), heat-stressed animals are often hyperinsulinemic (Wheelock et al. 2010; O'Brien et al. 2010; Pearce et al. 2013a). This increase in insulin (a potent anabolic hormone) during a hypercatabolic condition as HS is a biological paradox, but an explanation may include insulin's key role in activating and upregulating heat shock proteins (Li et al. 2006). Regardless of the reason, HS is one of the few nondiabetic models where nutrient intake is markedly reduced but basal and stimulated insulin levels are increased (Baumgard and Rhoads 2013; Table 5.2; Fig. 5.2).

The mechanism(s) responsible for enhanced insulin action during HS is not clear. One possibility is heat-induced hyperprolactinemia (Iguchi et al. 2012; Fig. 5.2) described in multiple species (Alamer 2011) and recently confirmed in pigs (Sanz Fernandez et al. 2012). Although the role of prolactin during established ruminant lactation is not fully clear (Lacasse et al. 2012), its increase during HS is counterintuitive considering the marked reductions in milk yield (West 2003; Rhoads et al. 2009). Why prolactin is elevated during HS is unknown, but some have hypothesized its involvement in the sweating response (Kaufman and Mackay 1983), heat shock protein induction (Blake et al. 1995), water homeostasis (Collier et al. 1982), and pelage/molting (Foizik et al. 2009). We have hypothesized that prolactin may partially mediate HS-induced hyperinsulinemia as it increases in vitro pancreatic β-cell proliferation (Arumugam et al. 2010) and in vivo glucose-stimulated insulin secretion (Ben-Jonathan et al. 2006). In addition, the temporal pattern of HS-induced hyperprolactinemia precedes the increase in circulating insulin (3–4 days). Characterizing prolactin's role in HS-induced hyperinsulinemia is of interest, particularly in lactating agricultural species.

An additional cause of heat-induced hyperinsulinemia may be circulating endotoxin (e.g., lipopolysaccharide [LPS]). As mentioned earlier, heat-stressed animals redistribute blood to the periphery in an attempt to maximize radiant heat dissipation. To maintain blood pressure during HS, the gastrointestinal tract vasculature constricts (Lambert 2009), and blood flow to the splanchnic tissues can decrease up to 50 % (McGuire et al. 1989; Hall et al. 2001). Enterocytes are extremely sensitive to oxygen and nutrient restriction (Rollwagen et al. 2006), thus HS-induced vasoconstriction markedly changes gastrointestinal conformation and reduces intestinal barrier function (Lambert 2009; Hall et al. 2001; Fig. 5.1). We have demonstrated this in heat-stressed pigs (Pearce et al. 2013b), and presumably it also occurs in ruminants since HS causes rumen acidosis (Mishra et al. 1970; Kadzere et al. 2002), which, independent of HS, can compromise gastrointestinal tract barrier integrity (Plaizier et al. 2008). Therefore, ruminants may, in fact, be more prone to intestinal "leakiness" during HS than monogastrics (Baumgard and Rhoads 2013). Paracellular transport of LPS from the lumen into circulation causes a local inflammatory response, and if the liver's LPS detoxification becomes overwhelmed, systemic endotoxemia occurs (Bouchama and Knochel 2002; Mani et al. 2012; Fig. 5.1). This explains why heat stroke and severe endotoxemia

Table 5.2 The impact of heat stress (HS) and cold stress (CS) on serum parameters of postabsorptive metabolism

Parameter	Species	HS	Reference (HS)	CS	Reference (CS)
Glucose	Humans	Increase	1, 8, 9	Increase	22
	Rats	Increase	43	Increase	16
	Rats	Decrease	30, 31	–	–
	Pigs	Decrease	34	None	23
	Poultry	Decrease	14, 45	Decrease	6
	Cattle	Decrease	37, 41, 42	Increase	46
	Cats	Decrease	28	–	–
Insulin	Cattle	Increase	32, 44	Decrease	33
	Pigs	Increase	34	Decrease	4
	Rats	Increase	43	Decrease	16
	Humans	None	26	Decrease	22
	Buffalo	Decrease	21	–	–
Lactate	Pigs	Increase	19	Increase	5
	Cattle	Increase	7	Increase	33
	Humans	Increase	9, 29, 35	–	–
	Dogs	Increase	27	–	–
Nonesterified fatty acids	Cattle	Decrease	37, 38, 42, 44	Increase	17
	Rats	Decrease	3, 13, 14	Increase	16
	Poultry	Decrease	2	None	24
	Sheep	Decrease	39	–	–
	Pigs	Decrease	31	–	–
Cholesterol	Cattle	Decrease	15	Increase	33
	Humans	None	11	–	–
	Pigs	None	10	–	–
Plasma urea nitrogen	Cattle	Increase	25, 38, 40, 42, 44	Increase	33
	Humans	Increase	20	Increase	18
	Pigs	Increase	34	–	–
	Rats	Increase	12	–	–

1. Angus et al. (2001)
2. Bobek et al. (1997)
3. Burger et al. (1972)
4. Close et al. (1985)
5. Curtis 1983
6. Davison (1973)
7. Elsasser et al. (2009)
8. Febbraio et al. (1994)
9. Fink et al. (1975)
10. Fletcher et al. (1988)
11. Francesconi et al. (1976)
12. Francesconi and Hubbard (1986)
13. Frankel (1968)
14. Frascella et al. (1977)
15. Fuquay (1981)
16. Gasparetti et al. (2003)
17. Godfrey et al. (1991)
18. Goodenough et al. (1982)
19. Hall et al. (1980)
20. Hart et al. (1980)
21. Haque et al. (2012)
22. Hermanussen et al. (1995)
23. Hicks et al. (1998)
24. Hunter et al. (1999)
25. Kamiya et al. (2006)
26. Kappel et al. (1997)
27. Kozlowski et al. (1985)
28. Lee and Scott (1916)
29. Lorenzo et al. (2010)
30. Miova et al. (2013)
31. Mitev et al. (2005)
32. O'Brien et al. (2010)
33. Olson et al. (1983)
34. Pearce et al. (2013a)
35. Pettigrew et al. (1974)
36. Rhoads et al. (2009)
37. Ronchi et al. (1999)
38. Sano et al. (1983)
39. Settivari et al. (2007)
40. Shehab-El-Deen et al. (2010)
41. Shwartz et al. (2009)
42. Simon (1953)
43. Torlinska et al. (1987)
44. Wheelock et al. (2010)
45. Yalcin et al. (2009)
46. Young (1975)

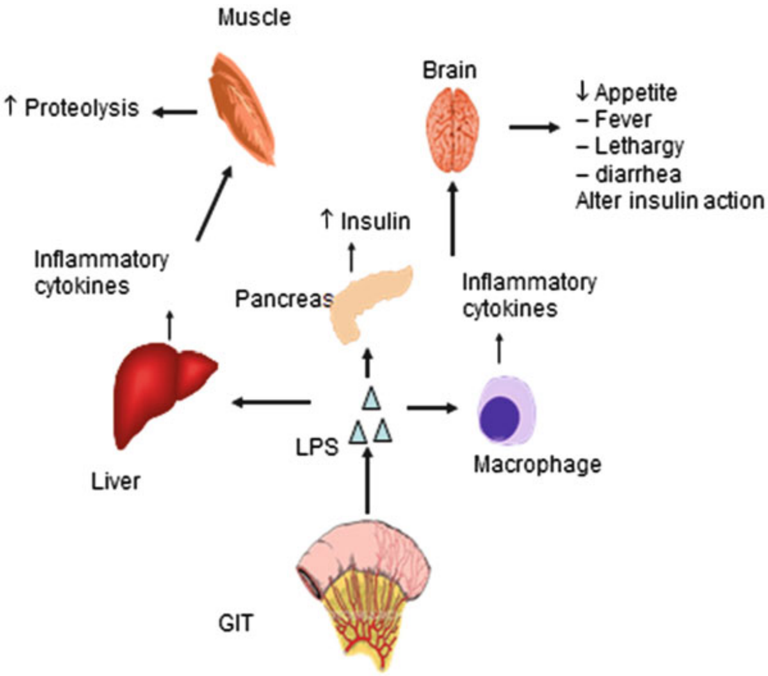


Fig. 5.1 Heat stress-induced LPS and subsequent metabolic and physiological changes

share many physiological and metabolic similarities (Lim et al. 2007; Baumgard and Rhoads 2013).

Differences in acid–base balance caused by hyperthermia (Bouchama and De Vol 2001) could result in the HS-induced hyperinsulinemia observed in various species (as reviewed by Baumgard and Rhoads 2013). In an attempt to dissipate heat, some HS-exposed animals will increase respiration rate and this hyperventilation can cause respiratory alkalosis (Bouchama and De Vol 2001). To counteract respiratory alkalosis, the kidneys retain hydrogen ions and compensatory metabolic acidosis occurs (Patience 1990). Metabolic acidosis impairs tissue sensitivity to both endogenous and exogenous insulin (DeFronzo and Beckles 1979) resulting in insulin resistance (Souto et al. 2011). As a result of whole-body insulin resistance, hyperinsulinemia can occur (Reaven 1988) and could contribute to the HS-induced hyperinsulinemia observed in various species (as reviewed by Baumgard and Rhoads 2013).

5.5.1.2 Cold Stress

During hypothermia, metabolism is markedly altered to provide energy for enhanced thermogenesis at the expense of tissue accretion and growth (Klain and Hannon 1969). Acute CS reduces glucose availability for normal tissue development and growth in multiple species (Baum et al. 1968; Benzing et al. 1983; Deavers and Musacchia 1979; Helman et al. 1984) and is accompanied by hypoinsulinemia (Benzing et al. 1983), reduced insulin secretion (Baum et al. 1968), and insulin resistance by peripheral tissues (Steffen 1988). Since CS is often associated with increased feed intake (Young 1981), the fact that circulating insulin is reduced is biologically difficult to explain. Hypothermia is also a potent activator of the sympathoadrenal system and elicits an increase in plasma catecholamines in rats (Jones et al. 1984), dogs (Warner et al. 1971), nonhuman primates (Chernow et al. 1983), and humans (Johnson et al. 1977). Increased plasma catecholamines increase hepatic glucose output (i.e., glycogenolysis) and gluconeogenesis (Klain

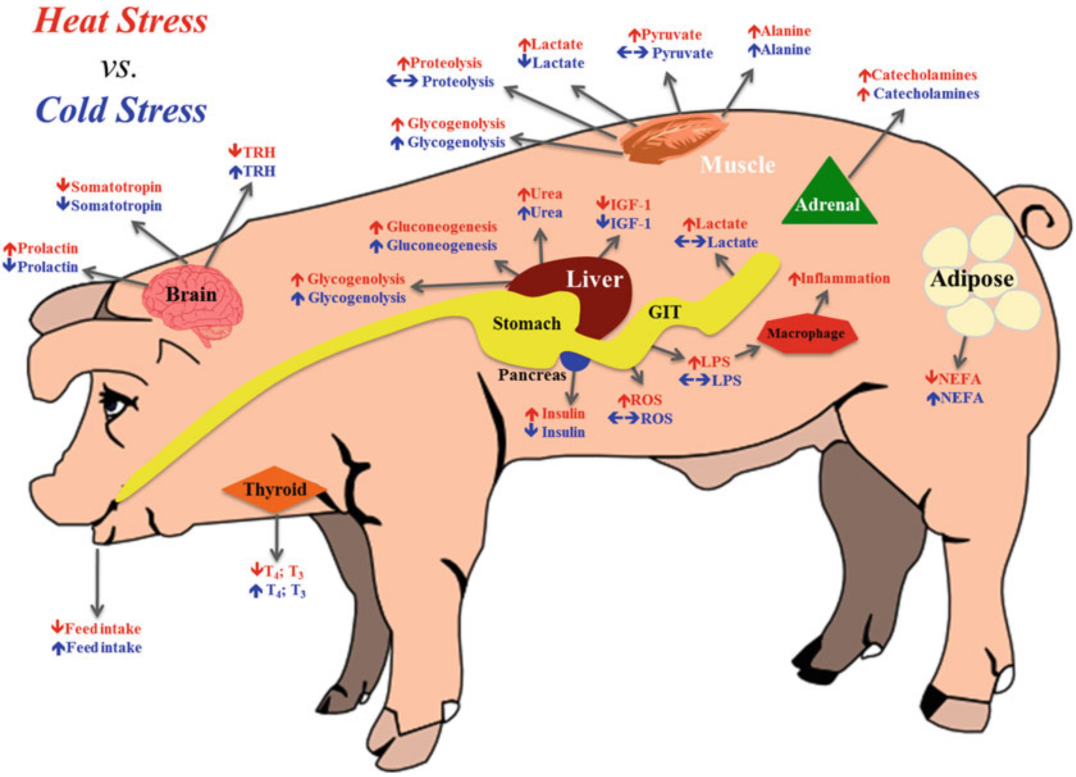


Fig. 5.2 Effects of heat stress and cold stress on metabolite and endocrine profiles in pigs

and Hannon 1969), which when combined with reduced peripheral glucose uptake and hypoinsulinemia contribute to the CS-induced hyperglycemia (Steffen 1988; Table 5.2; Fig. 5.2).

Despite whole-body hypoinsulinemia, plasma glucose clearance is enhanced during an insulin tolerance test in cold-stressed subjects (Vallerand et al. 1985), and this is likely because shivering thermogenesis requires a large amount of fuel (Steffen 1988). Since muscle contraction increases glucose uptake in the absence of insulin (Ploug et al. 1984), greater circulating glucose concentrations could provide substrate for energy metabolism in muscle, especially since whole-body glucose tolerance and oxidation are enhanced (Steffen 1988). Further, muscle tissue may rely primarily on glycolysis for ATP energy during acute CS (Seiyama et al. 1996), since the uncoupling of oxidative phosphorylation from ATP synthesis is increased due to enhanced heat production (Rousset et al. 2004).

5.5.2 Protein Metabolism

5.5.2.1 Heat Stress

During periods of inadequate nutrient intake or disease, skeletal muscle amino acids are mobilized to provide substrates to support energy metabolism and acute-phase protein synthesis limiting lean tissue accretion (Rhoads et al. 2013). Similarly, during HS muscle protein synthesizing machinery and RNA/DNA synthetic capacity are reduced (Streffer 1982), while skeletal muscle proteolysis is increased (Bianca 1965; Yunianto et al. 1997; Wheelock et al. 2010) resulting in decreased carcass lean tissue in growing livestock species (Collin et al. 2001; Brown-Brandl et al. 2004; Lu et al. 2007). Although it is known that protein breakdown is increased during HS, it is unclear if this is a result of enhanced rates of protein catabolism or a direct result of heat-induced muscle damage (Rhoads et al. 2013). It has been demonstrated that heat-stressed pigs (Pearce et al. 2013a), cows (Shwartz et al. 2009), and heifers (Ronchi et al. 1999) have increased plasma urea nitrogen concentrations compared to thermal neutral controls (Rhoads et al. 2013; Table 5.2; Fig. 5.2). More accurate indicators of muscle catabolism are circulating 3-methyl histidine or creatine, both of which are increased in heat-stressed poultry (Yunianto et al. 1997), rabbits (Marder et al. 1990), pigs (Pearce et al. 2013a), lactating cows (Schneider et al. 1988), and exercising men (Febbraio 2001). In addition, evidence indicates that HS directly alters protein metabolism by decreasing milk protein synthesis in dairy cattle compared to their pair-fed counterparts (Rhoads et al. 2009). The reduction in protein synthesis and subsequent increase in catabolism is perplexing since HS causes an increase in plasma insulin, a promoter of skeletal muscle synthesis and preventer of skeletal muscle catabolism (as reviewed by Baumgard and Rhoads 2013).

5.5.2.2 Cold Stress

Relatively little has been reported regarding the effects of hypothermia on protein metabolism. However, it is known that animals exposed to chronic CS have reduced muscle mass (Sagher 1975), likely due to the partitioning of energy toward shivering and non-shivering thermogenesis at the expense of tissue development and growth (Himms-Hagen 1984; Steffen 1988). In the case of non-shivering thermogenesis, energy sources (i.e., glucose, amino acids, free fatty acids) that would normally be converted to ATP by oxidative phosphorylation are partially converted to heat energy by uncoupling proteins (Rousset et al. 2004). Since the efficiency of ATP production by oxidative phosphorylation is compromised during CS, muscle increases its reliance on glycolysis as a source of ATP (Seiyama et al. 1996). In addition to energy losses through uncoupling protein activation, shivering thermogenesis results in enhanced muscle glycogen breakdown and a reduction in available energy for muscle growth (Steffen 1988). In order to counteract the effects of CS-induced losses in net energy, animals will often increase gross energy intake to enhance diet-induced thermogenesis (Himms-Hagen 1984) and increase available energy for growth (Young 1981). Despite this, losses in muscle mass, growth rate, and feed efficiency occur due to increased maintenance costs, heat production, and digestive inefficiency as a result of hypothermia (Young 1981).

5.5.3 Lipid Metabolism

5.5.3.1 Heat Stress

Production and observational data indicates that HS impacts lipid metabolism differently than would be expected based on calculated whole-body energy balance (Rhoads et al. 2013). Additionally, carcass data indicates that both chickens (Geraert et al. 1996) and pigs (Collin et al. 2001; Brown-Brandl et al. 2004) have increased lipid retention when reared in HS conditions and the effects in chickens are most pronounced in the abdominal fat depot (Yunianto et al. 1997). Interestingly, plasma nonesterified fatty acid (NEFA) concentrations are typically reduced in HS-exposed sheep and cattle, despite marked reductions in feed intake (Sano et al. 1983; Ronchi et al. 1999; Shwartz et al. 2009) and especially when compared to PFTN controls (Rhoads et al. 2009; Wheelock et al. 2010; Fig. 5.2). Alterations in carcass lipid composition and serum metabolites agree with rodent results indicating that HS reduces in vivo lipolytic rates and in vitro lipolytic enzyme activity (Torlinska et al. 1987). Considering that HS causes an increase in stress and catabolic hormones (i.e., epinephrine, cortisol, glucagon; Beede and Collier 1986), it is surprising that adipocyte lipolytic capacity is reduced (Baumgard and Rhoads 2013).

Changes in lipid metabolism during HS may result from increased insulin concentration and/or insulin sensitivity, as insulin is a potent antilipolytic and lipogenic hormone (Vernon 1992). In addition, reduced NEFA mobilization may allow for increased circulating insulin as excessive NEFAs cause pancreatic β-cell apoptosis (Nelson et al. 2002). Previous studies have demonstrated enhanced insulin sensitivity in heat-stressed rodents (DeSouza and Meier 1993), pigs (Hall et al. 1980), growing steers (O'Brien et al. 2010), and lactating cows (Wheelock et al. 2010). Moreover, HS increases adipose tissue lipoprotein lipase (Sanders et al. 2009), suggesting that adipose tissue of hyperthermic animals has an increased capacity to incorporate and store intestinal and hepatic derived free fatty acids (Baumgard and Rhoads 2013). Taken together, these studies suggest that heat-stressed animals have a limited ability to mobilize adipose tissue with a corresponding increased capacity for lipogenesis, resulting in greater adipose accretion.

5.5.3.2 Cold Stress

Hypothermia alters lipid metabolism by modifying the sympathoadrenal system and insulin homeostasis. Cold-stressed animals have increased catecholamine secretion, resulting in enhanced hepatic glucose output (Tamminga and Schrama 1988; Table 5.2; Fig. 5.2). Concurrently, insulin secretion is blunted and adipocyte insulin receptors are decreased causing hypoinsulinemia and reduced insulin action in adipose tissue (Steffen 1988; Torlinska et al. 1995). This results in greater rates of lipolysis and fatty acid oxidation (Kuroshima et al. 1978; Doi et al. 1982; Table 5.2; Fig. 5.2), which are mobilized in a coordinated effort to provide energy substrate for shivering and non-shivering thermogenesis and maintenance of homeothermy during times of CS. In addition to increasing lipid mobilization, CS also activates brown adipose tissue (BAT) for non-shivering thermogenesis (Steiner et al. 1969). In euthermic conditions, the functions of BAT appear similar to white adipose tissue (Steiner et al. 1968). However, during hypothermia, glucose oxidation by BAT is increased (tenfold) (Steiner et al. 1969). It is of interest to determine BAT's role in maintaining euthermia, and bioenergetics in general, in agriculturally important species.

5.6 Prenatal Impact of Thermal Stress

Prenatal insults can have lasting effects on offspring growth (Foxcroft et al. 2006, 2009; Tao et al. 2012), behavior (Shiota and Kayamura 1989), postabsorptive metabolism (Chen et al. 2010), and body composition (Pinney and Simmons 2010) and can be teratogenic (Graham et al. 1998). Hales and Barker (1992) first introduced the idea of a "thrifty phenotype" in response to fetal nutrient insufficiency, whereby fetal malnutrition causes maladaptive programming resulting in glucose-sparing mechanisms that persist after birth. In utero HS may also imprint future thermotolerance to a heat load, and this has been demonstrated in unicellular organisms (Estruch 2006), insects (Sorensen et al. 2001), and birds (Tzschentke 2007; Piestun et al. 2008). Although prenatal insults can result in negative postnatal phenotypes, they may also precondition offspring to harsh environmental conditions, and this "memory" may benefit future livestock production.

The mechanism(s) by which prenatal HS exposure impacts postnatal performance remains poorly understood, but likely results from epigenetic imprinting. Epigenetic programming is influenced by differences in DNA methylation of CpG islands (Klose and Bird 2006) that when altered during prenatal development can have lasting implications on gene expression (Bernal and Jirtle 2010) and can significantly impact lifetime production (Foxcroft et al. 2009). These epigenetic modifications in chromatin structure (which can last for short periods or be lifelong) influence the condensation of the DNA by reducing the recruitment and ability of DNA-binding proteins to interact with and transcribe genes from the genome. Intrauterine modifications via DNA methylation can also occur in temporal and tissue-specific patterns (Schneider et al. 2010), as numerous genes and quantitative trait loci associated with body composition and growth and development are subject to epigenetic regulation in mammals (Thomsen et al. 2004).

5.6.1 Heat Stress

Epigenetic programming and hormonal alterations in prenatally heat-stressed offspring resemble phenotypes of animals affected by intrauterine growth retardation (Baumgard et al. 2012; Table 5.3). Phenotypic changes are likely mediated by alterations to metabolism, uterine blood flow, and reproduction caused by maternal HS. Negative effects of maternal HS range from developmental defects (Graham et al. 1998) to altered HS response during future growth (Johnson et al. 2013a, b; Table 5.3). In some species, exposure to prenatal HS causes a reduction in birth weight, average daily gain, and brain weight that lasts into maturation (Jonson et al. 1976; Shiota and Kayamura 1989; Table 5.3). Although the specific cause of suboptimal performance in offspring exposed to prenatal HS is currently unknown, it is likely that epigenetic regulation plays a key role in the imprinting of future phenotypes.

Recent studies by our group have described multiple postnatal phenotypic changes due to in utero HS (Table 5.4). Previous reports indicate that prenatal exposure to HS in unicellular organisms (Estruch 2006), insects (Sorensen et al. 2001), and poultry species (Tzschentke 2007; Piestun et al. 2008) can infer increased postnatal thermal tolerance. However, we demonstrated in two studies that mammalian species (pigs) have a different postnatal thermoregulatory response to in utero HS (Johnson et al. 2013a, b). Specifically, pigs that experience in utero HS (especially during the first half of gestation) maintain a greater core body temperature (Table 5.4), regardless of the postnatal ambient temperature, and this increase is not influenced by a reduced ability to dissipate body heat (i.e., reduced skin temperature and respiration rate). Chronically increased core body temperature has obvious bioenergetic implications in both human health and animal agriculture, as maintaining this core body temperature differential throughout a lifetime requires a substantial amount of energy. In addition to altering core body temperature, we demonstrated that in utero HS alters porcine body composition during the early finishing phase by reducing protein and increasing adipose tissue deposition (Johnson et al. 2015a). While the specific mechanisms for this altered phenotype are unknown, it is potentially the result of a reduced

Table 5.3 The impact of in utero heat stress on postnatal phenotypes

Postnatal phenotype	Species	Response	Reference
Growth performance	Cattle	Decrease	13
	Rodent	Decrease	11
Teratogenicity	Pig	Increase	2
	Guinea pig	Increase	1, 6
	Rodent	Increase	4, 7, 11
	Monkey	Increase	5
	Human	Increase	8, 9
Thermal tolerance	Yeast	Increase	3
	Insects	Increase	12
	Poultry	Increase	10, 15
	Rodents	Increase	14

1. Edwards (1969)
2. Edwards et al. (2003)
3. Estruch (2006)
4. Germain et al. (1985)
5. Hendrickx et al. (1979)
6. Jonson et al. (1976)
7. Lary et al. (1983)
8. McDonald (1961)
9. Miller et al. (1978)
10. Piestun et al. (2008)
11. Shiota and Kayamura (1989)
12. Sorensen et al. (2001)
13. Tao et al. (2012)
14. Tetievsky and Horowitz (2010)
15. Tzschentke (2007)

Table 5.4 The biological consequences of pre- and postnatal heat stress[a]

	Timing of heat stress	
Phenotypic change	Prenatal	Postnatal
Insulin	Increase	Increase
Feed efficiency	Decrease	Decrease
Core body temperature	Increase	Increase
Body protein accretion	Decrease	Decrease
Body lipid accretion	Increase	Increase
Basal heat production	Increase	Decrease
Liver weight	Decrease	Decrease
Total viscera weight	No change	Decrease
Head size	Decrease	No change

[a]Adapted from Boddicker et al. (2014) and Johnson et al. (2013b; 2015a)

capacity to synthesize protein that diverts excess energy toward adipose tissue as we have previously suggested (Johnson et al. 2015a). These results have implications to the future performance and carcass quality of animals gestated in HS conditions and could compromise the efficiency of lean tissue production, especially in areas that experience prolonged periods of extremely high ambient temperatures.

5.6.2 Cold Stress

Although CS is not likely to impact homeothermy in modern agriculturally important mammalian species (Young 1981), prenatal hypothermia may negatively influence postnatal phenotypes in affected progeny. Despite the fact that very few studies have researched the effect of in utero CS, previous reports indicate that prenatal CS can reduce placental and fetal weight (Pan and Chen 2009) and may alter future behavioral responses (Tazumi et al. 2005). Interestingly, the reduction in placental and fetal mass is similar to the consequences of both intrauterine growth retardation (Foxcroft et al. 2006, 2009) and prenatal HS (Galan et al. 1999). While the implications of prenatal CS-induced reductions in placental and fetal weight on future phenotypes are unknown, it is tempting to speculate that those consequences could mimic that of intrauterine growth-restricted offspring.

5.7 Conclusion

Thermal stress limits efficient animal production and negatively impacts health and development during all life cycle stages. The impact of thermal stress will likely become more significant since climate models predict an increase in extreme weather patterns in most animal-producing areas, thereby undermining substantial advances made by the global animal agriculture industries. While the ultimate impacts of HS and CS are similar (reduced productivity), their modes of action differ significantly and as such different mitigation strategies need consideration. During HS exposure, animal productivity is compromised due to reduced FI, an altered metabolic profile, and gastrointestinal integrity perturbations. On the contrary, CS-induced performance reductions are primarily a result of enhanced thermogenesis required to maintain homeothermy. Not surprisingly, many of the metabolic effects of HS and CS are exactly opposite of each other, and both are homeorhetically orchestrated to prioritize survival at the cost of agriculturally productive purposes. Regardless of the mechanisms, thermal stress continues to threaten global food security (especially in developing countries), and the need for research to develop future mitigation strategies will continue into the foreseeable future.

References

Alamer M (2011) The role of prolactin in thermoregulation and water balance during heat stress in domestic ruminants. Asian J Anim Vet Adv 6:1153–1169

Alves FMS, Felix GA, Almeida Paz ICL, Naas IA, Souza GM, Caldara FR, Garcia RG (2012) Impact of exposure to cold on layer production. Braz J Poult Prod 14:159–232

Ames DR, Brink DR (1977) Effect of temperature on lamb performance and protein efficiency ratio. J Anim Sci 44:136–144

Angus DJ, Febbraio MA, Lasini D, Hargreaves M (2001) Effect of carbohydrate ingestion on glucose kinetics during exercise in the heat. J Appl Physiol 90:601–605

Arumugam R, Horowitz E, Noland RC, Lu D, Fleenor D, Freemark M (2010) Regulation of islet beta-cell pyruvate metabolism: interactions of prolactin, glucose, and dexamethasone. Endocrinology 149:5401–5414

Battisti DS, Naylor RL (2009) Historical warnings of future food insecurity with unprecedented seasonal heat. Science 323:240–244

Baum D, Dillard DH, Porte D Jr (1968) Inhibition of insulin release in infants undergoing deep hypothermic cardiovascular surgery. N Engl J Med 279:1309–1314

Bauman DE, Currie WB (1980) Partitioning of nutrients during pregnancy and lactation: a review of mechanisms involving homeostasis and homeorhesis. J Dairy Sci 63:1514–1529

Baumgard LH, Rhoads RP (2013) Effects of heat stress on post-absorptive metabolism and energetics. Annu Rev Anim Biosci 1:311–337

Baumgard LH, Rhoads RP, Rhoads ML, Gabler NK, Ross JW, Keating AF, Boddicker RL, Lenka S, Sejian V (2012) Impact of climate change on livestock production. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer, Berlin, pp 413–468

Baumgart DC, Dignass AU (2002) Intestinal barrier function. Curr Opin Clin Nutr Metab Care 5:685–694

Beede D, Collier R (1986) Potential nutritional strategies for intensively managed cattle during thermal stress. J Anim Sci 62:543–554

Ben-Jonathan N, Hugo ER, Brandebourg TD, LaPensee CR (2006) Focus on prolactin as a metabolic hormone. Trends Endocrinol Metab 17:110–116

Benzing G, Francis PD, Kaplan S, Helmsworth JA, Sperling MA (1983) Glucose and insulin changes in infants and children undergoing hypothermic open-heart surgery. Am J Cardiol 52:133–136

Bernabucci U, Lacetera N, Baumgard LH, Rhoads RP, Ronchi B, Nardone A (2010) Metabolic and hormonal acclimation to heat stress in domesticated ruminants. Animal 4:1167–1183

Bernal AJ, Jirtle RJ (2010) Epigenomic disruption: the effects of early developmental exposures. Birth Defects Res Part A Clin Mol Teratol 88:938–944

Bhattacharya AN, Hussain F (1974) Intake and utilization of nutrients in sheep fed different levels of roughage under heat stress. J Anim Sci 38:877–886

Bianca W (1965) Reviews of the progress of dairy science: physiology. Cattle in a hot environment. J Dairy Sci 32:291–328

Black JL, Mullan BP, Lorschy ML, Giles LR (1993) Lactation in the sow during heat stress. Livest Prod Sci 35:153–170

Blake MJ, Buckley AR, Zhang M, Buckley DJ, Lavoi KP (1995) A novel heat shock response in prolactin-dependent Nb2 node lymphoma cells. J Biol Chem 270:29614–29620

Blatteis CM (1998) Body temperature. In: Blatteis CM (ed) Physiology and pathophysiology of temperature regulation. World Scientific, Singapore, pp 13–22

Bobek S, Sechman A, Wieczorek E, Wronska-Fortuna D, Koziec K, Niezgoda J (1997) Reverse 3, 3', 5'-triiodothyronine (rT3) enhances hyperglycemia and lipemic effects of heat-stress in chickens. Horm Metab Res 29:252–254

Boddicker RL, Seibert JT, Johnson JS, Pearce SC, Selsby JT, Gabler NK, Lucy MC, Safranski TJ, Rhoads RP, Baumgard LH, Ross JW (2014) Gestational heat stress alters postnatal offspring body composition indices and metabolic parameters in pigs. PLoS One 9:e110859

Bouchama A, De Vol EB (2001) Acid-base alterations in heatstroke. Intensive Care Med 27:680–685

Bouchama A, Knochel JP (2002) Heat stroke. N Engl J Med 346:1978–1988

Brobeck JR (1948) Food intake as a mechanism of temperature regulation. Yale J Biol Med 20:545–552

Broucek J, Letkovicova M, Kovalcuj K (1991) Estimation of cold stress effect on dairy cows. Int J Biometeorol 35:29–32

Brown-Brandl TM, Nienaber JA, Xin H, Gates RS (2004) A literature review of swine production. Trans ASAE 47:259–270

Burger FJ, Du Plessis JP, Bieler EU, Lategan PJ (1972) Further studies on the chemical changes in the blood and tissues of rats during hyperthermia. S Afr Med J 41:718–721

Chen X, Fahy AL, Green AS, Anderson MJ, Rhoads RP, Limesand SW (2010) ß2-Adrenergic receptor desensitization in perirenal adipose tissue in fetuses and lambs with placental insufficiency-induced intrauterine growth restriction. Am J Physiol 588:3539–3549

Chernow B, Lake CR, Zaritsky A, Finton CK, Casey L, Rainey TG, Fletcher R (1983) Sympathetic nervous system "switch off" with severe hypothermia. Crit Care Med 11:677–680

Christopherson RJ, Gonyou HW, Thompson JR (1979) Effects of temperature and feed intake on plasma concentration of thyroid hormones in beef cattle. Can J Anim Sci 59:655–661

Close WH, Le Dividich J, Duee PH (1985) Influence of environmental temperature on glucose tolerance and insulin response in the new-born piglet. Biol Neonate 47:84–91

Collier RJ, Beede DK, Thatcher WW, Israel LA, Wilcox CJ (1982) Influences of environment and its modification on dairy animal health and production. J Dairy Sci 65:2213–2227

Collin A, van Milgen J, Dubois S, Noblet J (2001) Effect of high temperature on feeding behaviour and heat production in group-housed young pigs. Br J Nutr 86:63–70

Collins FG, Matros FA, Skibban JL (1980) Effect of palmitate on hepatic biosynthetic functions at hyperthermic temperatures. Metabolism 29:524–531

Curtis SE (1983) Environmental management in animal agriculture. Iowa State University Press, Ames

Davison TF (1973) Metabolite changes in the neonate fowl in response to cold stress. Comp Biochem Physiol 44:979–989

Deavers DR, Musacchia XJ (1979) The function of glucocorticoids in thermogenesis. Fed Proc 38:2177–2181

DeFronzo RA, Beckles AD (1979) Glucose intolerance following chronic metabolic acidosis in man. Am J Physiol 236:E328–E334

DeSouza CJ, Meier AH (1993) Alterations in body fat stores and plasma insulin levels with daily intervals of heat exposure in Holtzman rats. Am J Physiol 265:1109–1114

Doi K, Ohno T, Kuroshima A (1982) Role of endocrine pancreas in temperature acclimation. Life Sci 30:2253–2259

Edwards MJ (1969) Congenital defects in guinea pigs: retardation of brain growth of guinea pigs following hyperthermia during gestation. Teratology 2:329–336

Edwards MJ, Saunders RD, Shiota K (2003) Effects of heat on embryos and foetuses. Int J Hyperth 19:295–324

Elsasser T, Rhoads R, Kahl S, Collier R, Baumgard LH, Li C, Caperna T (2009) Heat stress augments plasma tyrosine-nitrated proteins and lactate-to-pyruvate ratio after repeated endotoxin (LPS) challenge in steers. J Anim Sci 87(E-Suppl. 2):9 (Abstr.)

Estruch F (2006) Stress-controlled transcription factors, stress-induced genes and stress tolerance in budding yeast. FEMS Microbiol Rev 24:469–486

Febbraio MA (2001) Alterations in energy metabolism during exercise and heat stress. Sports Med 31:47–59

Febbraio MA, Snow RJ, Stathis CG, Hargreaves M, Carey MF (1994) Effect of heat stress on muscle energy metabolism during exercise. J Appl Physiol 77:2827–2831

Ferraris RP, Carey HV (2000) Intestinal transport during fasting and malnutrition. Annu Rev Nutr 20:195–219

Fink WJ, Costill DL, Van Handel PJ (1975) Leg muscle metabolism during exercise in the heat and cold. Eur J Appl Physiol Occup Physiol 34:183–190

Finosshiaro R, van Kaam JB, Portolano B, Misztal I (2005) Effect of heat stress on production of Mediterranean dairy sheep. J Dairy Sci 88:1855–1864

Fletcher JE, Rosenberg H, Michaux K, Cheah KS, Cheah AM (1988) Lipid analysis of skeletal muscle from pigs susceptible to malignant hyperthermia. Biochem Cell Biol 66:917–921

Foizik K, Langan EA, Paus R (2009) Prolactin and the skin: a dermatological perspective on an ancient pleiotropic peptide hormone. J Investig Dermatol 129:141–147

Foxcroft GR, Dixon WT, Novak S, Putman CT, Town SC, Vinsky MDA (2006) The biological basis for prenatal programming of postnatal performance in pigs. J Anim Sci 84:E105–E112

Foxcroft GR, Dixon WT, Dyck MK, Novak S, Harding JC, Almeida FC (2009) Prenatal programming of postnatal development of the pig. Soc Reprod Fertil Suppl 66:213–231

Francesconi RP, Hubbard RW (1986) Dietary manipulation and exercise in the heat: thermoregulatory and metabolic effects in rats. Aviat Space Environ Med 57:31–35

Francesconi RP, Fine BJ, Kobrick JL (1976) Heat and simulated high altitude: effects on biochemical indices of stress and performance. Aviat Space Environ Med 47:548–552

Frankel HM (1968) Serum lipid changes during progressive hyperthermia. Life Sci 21:1203–1207

Frascella DW, Kampa IS, Francis BH (1977) Metabolic effect of high environmental temperature on nondiabetic and diabetic rats. Horm Metab Res 9:374–378

Fuquay JW (1981) Heat stress as it affects animal production. J Anim Sci 52:164–174

Galan HL, Hussey MJ, Barbera A, Ferrazzi E, Chung M, Hobbins JC, Battaglia FC (1999) Relationship of fetal growth to duration of heat stress in an ovine model of placental insufficiency. Am J Obstet Gynecol 180:1278–1282

Gasparetti AL, de Souza CT, de Silve MP, Oliveira RLGS, Saad MJA, Carneiro EM, Velloso LA (2003) Cold exposure induces tissue-specific modulation of the insulin-signaling pathway on Rattus norvegicus. J Physiol 552:149–162

Geraert PA, Padilha JC, Guillaumin S (1996) Metabolic and endocrine changes induced by chronic heat exposure in broiler chickens: growth performance, body composition and energy retention. Br J Nutr 75:195–204

Germain MA, Webster WS, Edwards MJ (1985) Hyperthermia as a teratogen: parameters determining hyperthermia-induced head defects in the rat. Teratology 31:265–272

Godfray HCJ, Crute IR, Haddad L, Lawerance D, Muir JF, Nisbett N, Pretty J, Robinson S, Toulmin C, Witeley R (2010) The future of the global food system. Philos Trans R Soc 365:2769–2777

Godfrey RW, Smith SD, Guthrie MJ, Stanko RL, Neuendorff DA, Randel RD (1991) Physiological responses of newborn Bos indicus x Bos taurus calves after exposure to cold. J Anim Sci 69:258–263

Goodenough RD, Royle GT, Nadel ER, Wolfe MH, Wolfe RR (1982) Leucine and urea metabolism in acute human cold exposure. J Appl Physiol Respir Environ Exerc Physiol 53:367–372

Graham JM, Edwards MJ, Edwards MJ (1998) Teratogen update: gestational effects of maternal hyperthermia due to febrile illnesses and resultant patterns of effects in humans. Teratology 58:209–221

Halder J, Bade V (1981) Involvement of opioid peptides in the inhibition of oxytocin release by heat stress in lactating mice. Exp Biol Med 168:10–14

Hales CN, Barker DJ (1992) Type 2 (non-insulin-dependent) diabetes mellitus: the thrifty phenotype hypothesis. Diabetologia 35:595–601

Hall GM, Lucke JN, Lovell R, Lister D (1980) Porcine malignant hyperthermia.VII: hepatic metabolism. Br J Anaesth 52:11–17

Hall DM, Buettner GR, Oberley LW, Xu L, Matthes RD, Gisolfi GV (2001) Mechanisms of circulatory and intestinal barrier dysfunction during whole body hyperthermia. Am J Physiol Heart Circ Physiol 280:H509–H521

Haque N, Ludri A, Hassain SA, Ashutosh M (2012) Alteration of metabolic profiles in young and adult Murrah buffaloes exposed to acute heat stress. Iran J Appl Anim Sci 1:23–29

Hart LE, Egier BP, Shimizu AG, Tandan PJ, Sutton JR (1980) External heat stroke: the runner's nemesis. Can Med Assoc J 122:1144–1150

Helman A, Gilbert M, Pfister-Jemaire N, Reach G, Assan R (1984) Glucagon and insulin secretion and their biological activities in hypothermic rats. Endocrinology 115:1722–1728

Hendrickx AG, Stone GW, Hendrickson RV, Matayoshi K (1979) Teratogenic effects of hyperthermia in the bonnet monkey (Macaca radiata). Teratology 19:177–182

Hermanussen M, Jensen F, Hirsch N, Friedel K, Kroger B, Lang R, Just S, Ulmer J, Schaff M, Ahnert P (1995) Acute and chronic effects of winter swimming on LH, FSh, prolactin, growth hormone, TSH, cortisol, serum glucose, and insulin. Arctic Med Res 54:45–51

Heroux O (1969) Diet and cold resistance. Fed Proc 28:955–959

Hicks TA, McGlone JJ, Whisnant CS, Kattesh HG, Norman RL (1998) Behavioral, endocrine, immune, and performance measures for pigs exposed to acute stress. J Anim Sci 76:474–483

Himms-Hagen J (1984) Nonshivering thermogenesis. Brain Res Bull 12:151–160

Hunter RR, Mitchell MA, Carlisle AJ (1999) Wetting of broilers during cold weather transport: a major source of physiological stress? Br Poult Sci 40:48–49

Iguchi M, Littmann AE, Chang SH, Wester LA, Knipper JS, Shields RK (2012) Heat stress and cardiovascular, hormonal and heat shock proteins in humans. J Athl Train 47:184–190

Intergovernmental panel on climate change (2014) Climate change 2014: impacts, adaptation, and vulnerability. Available at: http://www.ipcc.ch/report/ar5/wg2/. Accessed June 2014

Johnson HD (1976) Effects of temperature and humidity on lactation in cattle. In: Progress in animal biometeorology: the effect of weather and climate on animals, vol. 1. Part 1. Swets and Zeitlinger, Amsterdam

Johnson MS, Speakman JR (2001) Limits to sustained energy intake. V. Effect of cold-exposure during lactation in Mus musculus. J Exp Biol 204:1967–1977

Johnson DG, Hayward JS, Jacobs T, Collins ML, Eckerson JD, Williams RH (1977) Plasma norepinephrine response of man in cold water. J Appl Physiol 43:216–220

Johnson JS, Boddicker RL, Sanz Fernandez MV, Ross JW, Selsby JT, Lucy MC, Safranski TJ, Rhoads RP, Baumgard LH (2013a) Effects of mammalian *in utero* heat stress on adolescent thermoregulation. Int J Hyperth 29:696–702

Johnson JS, Sanz-Fernandez MV, Stoakes SK, Abuajamieh M, Ross JW, Lucy MC, Safranski TJ, Rhoads RP, Baumgard LH (2013b) Gestational heat stress alters postnatal thermoregulation. J Anim Sci 91:168 (Abstract)

Johnson JS, Bryant JK, Scharf B, Kishore DK, Coate EA, Eichen PA, Keisler D, Spiers DE (2014a) Regional differences in the fescue toxicosis response of Bos taurus cattle. Int J Biometeorol (Epub ahead of print). doi: 10.1007/s00484-014-0850-4

Johnson JS, Abuajamieh M, Keating AF, Ross JW, Selsby JT, Rhoads RP, Baumgard LH (2014b) The impact of heat stress and nutrient restriction on progeny body composition. J Anim Sci 1777 (Abstr.)

Johnson JS, Patience JF, Ross JW, Gabler NK, Lucy MC, Safranski TJ, Rhoads RP, Baumgard LH (2015a) Effects of *in utero* heat stress on postnatal body composition in pigs: II. Finishing phase. J Anim Sci 93: 82–92

Johnson JS, Patience JF, Ross JW, Gabler NK, Lucy MC, Safranski TJ, Rhoads RP, Baumgard LH (2015b) Effects of *in utero* heat stress on postnatal body composition in pigs: I. Growing phase. J Anim Sci 93: 71–81

Jones SB, Depocas F, Chan CC (1984) Plasma catecholamines in rats during rewarming from induced hypothermia. J Appl Physiol 57:808–814

Jonson KM, Lyle JG, Edwards MJ, Penny RH (1976) Effect of prenatal heat stress on brain growth and serial discrimination reversal learning in the guinea pig. Brain Res Bull 1:133–150

Kadzere CT, Murphy MR, Silanikove N, Maltz E (2002) Heat stress in lactating dairy cows: a review. Livest Prod Sci 77:59–91

Kamiya M, Kamiya Y, Tanaka M, Oki T, Nishiba Y, Shioya S (2006) Effects of high ambient temperature and restricted feed intake on urinary and plasma 3-methylhistidine in lactating Holstein cows. J Anim Sci 77:201–207

Kappel M, Gyhrs A, Galbo H, Pedersen K (1997) The response on glucoregulatory hormones of in vivo whole body hyperthermia. Int J Hyperth 13:413–421

Kaufman S, Mackay BJ (1983) Plasma prolactin levels and body fluid deficits in the rat: causal interactions and control of water intake. J Physiol 336:73–81

Klain GJ, Hannon JP (1969) Gluconeogenesis in cold-exposed rats. Fed Proc 28:965–968

Klose RJ, Bird AP (2006) Genomic DNA methylation: the mark and its mediators. Trends Biochem Sci 31:89–97

Kozlowski S, Brzezinska Z, Kruk B, Kaciuba-Uscilko H, Greenleaf JE, Nazar K (1985) Exercise hyperthermia as a factor limiting physical performance: temperature effect on muscle metabolism. J Appl Physiol 59:766–773

Kuroshima A, Doi K, Ohno T (1978) Role of glucagon in metabolic acclimation to cold and heat. Life Sci 23:1405–1409

Lacasse P, Lollivier V, Dessauge F, Bruckmaier RM, Ollier S, Boutinaud M (2012) New developments on the galactopoietic role of prolactin in dairy ruminants. Domest Anim Endocrinol 43:154–160

Lambert GP (2009) Stress-induced gastrointestinal barrier dysfunction and its inflammatory effects. J Anim Sci 87:E101–E108

Lary JM, Conover RDL, Johnson PH, Burg JA (1983) Teratogenicity of 27.12 MHz radiation in rats is related to duration of hyperthermic exposure. Bioelectromagnetics 4:249–255

Lee FS, Scott EL (1916) The action of temperature and humidity on the working power of muscles and on the sugar of the blood. Am J Phys 40:486–501

Leeson S (1986) Nutritional considerations of poultry during heat stress. Worlds Poult Sci J 42:69–81

Li G, Ali I, Currie RW (2006) Insulin induces myocardial protection and Hsp70 localization to plasma membranes in rat hearts. Am J Physiol Heart Circ Physiol 291:H1709–H1721

Lim CL, Wilson G, Brown L, Coombes JS, Mackinnon LT (2007) Pre-existing inflammatory state compromises heat tolerance in rats exposed to heat stress. Am J Physiol Regul Integr Comp Physiol 292:R186–R194

Lin H, Jiao HC, Buyse J, Decuypere E (2006) Strategies for preventing heat stress in poultry. Worlds Poult Sci J 62:71–86

Lopez J, Jesse GW, Becker BA, Elleersiek MR (1991) Effects of temperature on the performance of finishing swine: II. Effects of a cold, diurnal temperature on average daily gain, feed intake, and feed efficiency. J Anim Sci 69:1850–1855

Lorenzo S, Halliwill JR, Sawka MN, Minson CT (2010) Heat acclimation improves exercise performance. J Appl Physiol 109:1140–1147

Lu Q, Wen J, Zhang H (2007) Effect of chronic heat exposure on fat deposition and meat quality in two genetic types of chicken. Poult Sci 86:1059–1064

Luber G, McGeehin M (2008) Climate change and extreme heat events. Am J Prev Med 35:459–467

Mahjoubi E, Amanlou H, Mirzaie-Alamouti HR, Aghaziarati N, Hossein Yazdi M, Noori GR, Yuan K, Baumgard LH (2014) The effect of cyclical and mild heat stress on productivity and metabolism in Afshari lambs. J Anim Sci 92:1007–1014

Mani V, Weber TE, Baumgard LH, Gabler NK (2012) Invited review: endotoxin, inflammation and intestinal function. J Anim Sci 90:1452–1465

Marai IFM, El-Darawany A, Fadiel A, Abdel-Hafez MAM (2007) Physiological traits as affected by heat stress in sheep-a review. Small Rumin Res 71:1–12

Marder J, Eylath U, Moskovitz E, Sharir R (1990) The effect of heat exposure on blood chemistry of the hyperthermic rabbit. Comp Biochem Physiol A Comp Physiol 97:245–247

Marsden A, Morris TR (1987) Quantitative review of the effects of environmental temperature on feed intake, egg output and energy balance in laying pullet. Br Poult Sci 28:693–704

McBride GE, Christopherson RJ (1984) Effect of cold exposure on milk production and energy balance in the lactating ewe. Can J Anim Sci 64:379–389

McDonald AD (1961) Maternal health in early pregnancy and congenital defects: final report on a prospective inquiry. Br J Prev Soc Med 15:154–166

McGuire MA, Beede DK, DeLorenzo MA, Wilcox CJ, Huntington GB, Reynolds CK, Collier RJ (1989) Effects of thermal stress and level of feed intake on portal plasma flow and net fluxes of metabolites in lactating Holstein cows. J Anim Sci 67:1050–1060

Miller P, Smith DW, Shepard T (1978) Maternal hyperthermia as a possible cause of anencephaly. Lancet 1:519

Miova B, Dinevska-Kjovkarovska S, Cvetkovska F, Mitev S, Dzimrevska A, Dimitrovska M (2013) Liver carbohydrate metabolism in rats in the period of recovery after acute heat stress. Maced J Med Sci 6:16–23

Mishra M, Martz FA, Stanley RW, Johnson HD, Campbell JR, Hilderbrand E (1970) Effect of diet and ambient temperature humidity on ruminal pH, oxidation reduction potential, ammonia and lactic acid in lactating cows. J Anim Sci 30:1023–1028

Mitev S, Dinevska-Kovkarovska S, Miova B (2005) Effect of the acclimation to high environmental temperature on the activity of hepatic glycogen phosphorylase (a+b and a), liver glycogen content and blood glucose level in rat. J Therm Biol 30:563–568

Muller C, Cramer W, Hare WL, Lotze-Campen H (2010) Climate change risks for African agriculture. PIC 108:4313–4315

Nelson EAS, Wong Y, Yu LM, Fok TF, Li K (2002) Effects of hyperthermia and muramyl dipeptide on IL-Iβ, IL-6, and mortality in a neonatal rat model. Pediatr Res 52:886–891

Nienaber JA, Hahn GL (2007) Livestock production system management responses to thermal challenges. Int J Biometeorol 52:149–157

Nyachoti CM, Zijlstra RT, de Lange CFM, Patience JF (2004) Voluntary feed intake in growing-finishing pigs: a review of the main determining factors and potential approaches for accurate predictions. Can J Anim Sci 84:549–566

O'Brien MD, Cole LC, Wheelock JB, Sanders SR, Duff GC, Baumgard LH, Rhoads RP (2008) Thermal and nutritional regulation of hepatic gluconeogenic genes in growing beef cattle. J Anim Sci 86 (E-Suppl. 2):455 (Abstr.)

O'Brien MD, Rhoads RP, Sanders SR, Duff GC, Baumgard LH (2010) Metabolic adaptations to heat stress in growing cattle. Domest Anim Endocrinol 38:86–94

Olson DP, South PJ, Hendrix K (1983) Serum chemical values in hypothermic and rewarmed young calves. Am J Vet Med 44:577–582

Pan ZJ, Chen ZK (2009) Effects of cold-stress stimulation on filial growth and development of pregnant mice. Zhongguo Ying Yong Sheng Li Xue Za Zhi 25:162–165

Patience JF (1990) A review of the role of acid-base balance on amino acid nutrition. J Anim Sci 68:398–408

Pearce SC, Gabler NK, Ross JW, Escobar J, Patience JF, Rhoads RP, Baumgard LH (2013a) The effects of heat stress and plane of nutrition on metabolism in growing pigs. J Anim Sci 91:2108–2118

Pearce SC, Mani V, Boddicker RL, Johnson JS, Weber TE, Ross JW, Rhoads RP, Baumgard LH, Gabler NK (2013b) Heat stress reduces intestinal barrier integrity and favors intestinal glucose transport in growing pigs. PLoS One 8, E70215

Pettigrew RT, Galt JM, Ludgate CM, Horn DB, Smith AN (1974) Circulatory and biochemical effects of whole body hyperthermia. Br J Surg 61:727–730

Piestun Y, Schinder D, Ruzal M, Halevy O, Brake J, Yahav S (2008) Thermal manipulations during broiler embryogenesis: effect on the acquisition of thermotolerance. Poult Sci 87:1516–1525

Pinney SE, Simmons RA (2010) Epigenetic mechanisms in the development of type 2 diabetes. Trends Endocrinol Metab 21:223–229

Plaizier JC, Krause DO, Gozho GN, McBride BW (2008) Subacute ruminal acidosis in dairy cows: the physiological causes, incidence and consequences. Vet J 176:21–31

Ploug T, Galbo H, Richter EA (1984) Increased muscle glucose uptake during contractions: no need for insulin. Am J Physiol 247:E726–E731

Qi L, Bravo-Ureta BE, Cabrera VE (2014) From cold to hot: a preliminary analysis of climactic effects on the productivity of Wisconsin dairy farms. Agricultural and Applied Economics Association 2014 annual meeting, Minneapolis

Reaven GM (1988) Role of insulin resistance in human disease. Diabetes 37:1595–1607

Renaudeau D, Noblet J (2001) Effects of exposure to high ambient temperature and dietary protein level on sow milk production and performance of piglets. J Anim Sci 79:1540–1548

Rhoads ML, Rhoads RP, Van Baale MJ, Collier RJ, Sanders SR, Weber WJ, Crooker BA, Baumgard LH (2009) Effects of heat stress and plane of nutrition on lactating Holstein cows: I. production, metabolism and aspects of circulating somatotropin. J Dairy Sci 92:1986–1997

Rhoads RP, Baumgard LH, Suagee JK, Sanders SR (2013) Nutritional interventions to alleviate the negative consequences of heat stress. Adv Nutr 4:267–276

Rollwagen FM, Madhavan S, Singh A, Li YY, Wolcott K, Maheshwari R (2006) IL-6 protects enterocytes from hypoxia-induced apoptosis by induction of bcl-2 mRNA and reduction of fas mRNA. Biochem Biophys Res Commun 347:1094–1098

Ronchi B, Bernabucci U, Lacetera N, Supplizi AV, Nardone A (1999) Distinct and common effects of heat stress and restricted feeding on metabolic status of Holstein heifers. Zoot Nutr Anim 25:11–20

Rousset S, Alves-Guerra MC, Mozo J, Miroux B, Cassard-Doulcier AM, Bouillaud F, Ricquier D (2004) The biology of mitochondrial uncoupling proteins. Diabetes 53:S130–S135

Sagher BM (1975) The effect of cold stress on muscle growth in young chicks. Growth 39:281–288

Sanders SR, Cole LC, Flann KL, Baumgard LH, Rhoads RP (2009) Effects of acute heat stress on skeletal muscle gene expression associated with energy metabolism in rats. FASEB J 23:598.7 (Abstr.)

Sano H, Takahashi K, Ambo K, Tsuda T (1983) Turnover and oxidation rates of blood glucose and heat production in sheep exposed to heat. J Dairy Sci 66:856–861

Sanz Fernandez MV, Pearce SC, Upah NC, Long LR, Nayeri A, Sucu E, Gabler NK, Patience JF, Hsu WH, Rhoads RP, Baumgard LH (2012) Prolactin's role during acute and chronic heat stress in growing pigs. FASEB J 26:1079.7 (Abstr.)

Sanz Fernandez MV, Pearce SC, Gabler NK, Patience JF, Wilson ME, Socha MT, Torrison JL, Rhoads RP, Baumgard LH (2014) Effects of supplemental zinc amino acid complex on gut integrity in heat-stressed growing pigs. Animal 8:43–50

Schneider PL, Bede DK, Wilcox CJ (1988) Nycterohemeral patterns of acid-base status, mineral concentrations and digestive function of lactating cows in natural or chamber heat stress environments. J Anim Sci 66:112–125

Schneider E, Pliushch G, El Hajj N, Galetzka D, Puhl A, Schorsch M, Frauenknecht K, Riepert T, Tresch A, Muller AM, Coerdt W, Zechner U, Haaf T (2010) Spatial, temporal and interindividual epigenetic variation of functionally important DNA methylation patterns. Nucleic Acids Res 38:3880–3890

Seiyama A, Kosaka H, Maeda N, Shiga T (1996) Effect of hypothermia on skeletal muscle metabolism in perfused rat hindlimb. Cryobiology 33:338–346

Settivari RS, Spain JN, Ellersieck MR, Byatt JC, Collier RJ, Spiers DE (2007) Relationship of thermal status to productivity in heat-stressed dairy cows given recombinant bovine somatotropin. J Dairy Sci 90:1265–1280

Sevi A, Caroprese M (2012) Impact of heat stress on milk production, immunity and udder health in sheep: a critical review. Small Rumin Res 107:1–7

Shehab-El-Deen MAM, Leroy JL, Fadel MS, Saleh SY, Maes D, Van Soon A (2010) Biochemical changes in the follicular fluid of the dominant follicle of high producing dairy cows exposed to heat stress early postpartum. Anim Reprod Sci 117:189–200

Shiota K, Kayamura T (1989) Effects of prenatal heat stress on postnatal growth, behavior and learning capacity in mice. Biol Neonate 56:6–14

Shwartz G, Rhoads M, VanBaale M, Rhoads R, Baumgard L (2009) Effects of a supplemental yeast culture on heat-stressed lactating Holstein cows. J Dairy Sci 92:935–942

Simon JF (1953) Effects of hyperpyrexia on the human blood count, blood chemistry and urine. J Lab Clin Med 21:400–402

Soren NM (2012) Nutritional manipulations to optimize productivity during environmental stresses in livestock. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer, Berlin, pp 181–218

Sorensen JG, Dahlgaard J, Loeschcke V (2001) Genetic variation in thermal tolerance among natural populations of Drosophila buzzatii: down regulation of Hsp70 expression and variation in heat stress resistance traits. Funct Ecol 15:289–296

Souto G, Donapetry C, Calviño J, Adeva MM (2011) Metabolic acidosis-induced insulin resistance and cardiovascular risk. Metab Syndr Relat Disord 9:247–253

Speakman JR, Krol E (2010) Maximal heat dissipation capacity and hyperthermia risk: neglected key factors in the ecology of endotherms. J Anim Ecol 79:726–746

Spinu M, Degen AA (1993) Effect of cold stress on performance and immune responses of Bedouin and White Leghorn hens. Br Poult Sci 34:177–185

Steffen JM (1988) Glucose, glycogen, and insulin responses in the hypothermic rat. Cryobiology 25:94–101

Steiner G, Schonbaum E, Johnson GE, Sellers EA (1968) Lipid metabolism: effects of immunosympathectomy and acclimation to cold. Can J Physiol Pharmacol 46:453–561

Steiner G, Johnson GE, Sellers EA, Schonbaum E (1969) Nervous control of brown adipose tissue metabolism in normal and cold-acclimated rats. Fed Proc 28:1017–1022

St-Pierre N, Cobanov B, Schnitkey G (2003) Economic losses from heat stress by US livestock industries. J Dairy Sci 86:E52–E77

Streffer C (1982) Aspects of biochemical effects by hyperthermia. Natl Cancer Inst Monogr 61:11–17

Streffer C (1988) Aspects of metabolic change after hyperthermia. Recent Results Cancer Res 107:7–16

Tamminga S, Schrama JW (1988) Environmental effects on nutrient and energy metabolism in ruminants. Arch Anim Nutr 51:225–235

Tao S, Monteiro APA, Thompson IM, Haven MJ, Dahl GE (2012) Effect of late gestation maternal heat stress on growth and immune function of dairy calves. J Dairy Sci 95:7128–7136

Tazumi T, Hori E, Uwano T, Umeno K, Tanebe K, Tabuchi E, Ono T, Nishijo H (2005) Effects of prenatal maternal stress by repeated cold environment on behavioral and emotional development in the rat offspring. Behav Brain Res 162:153–160

Tetievsky A, Horowitz M (2010) Posttranslational modifications in histones underlie heat acclimation-mediated cytoprotective memory. J Appl Physiol 109:1552–1561

Thomsen H, Lee HK, Rothschild MF, Malek M, Dekkers JCM (2004) Characterization of quantitative trait loci for growth and meat quality in a cross between commercial breeds of swine. J Anim Sci 82:2213–2228

Torlinska T, Banach R, Paluszak J, Gryczka-Dziadecka A (1987) Hyperthermia effect on lipolytic processes in rat blood and adipose tissue. Acta Phys Polon 38:361–366

Torlinska T, Mackowiak P, Nogowski L, Kozlik J (1995) Effect of hypothermia on the insulin – receptor interaction in adipose plasma membranes. J Physiol Pharmacol 46:341–349

Tzschentke B (2007) Attainment of thermoregulation as affected by environmental factors. Poult Sci 86:1025–1036

United States Environmental Protection Agency (2013) www.epa.gov

USGCRP (2009) Global climate change impacts in the United States. In: Karl TR, Melillo JM, Peterson TC (eds) United States global change program. Cambridge University Press, New York

Vallerand AL, Zamecnik J, Jacobs I (1985) Plasma glucose turnover during cold stress in humans. J Appl Physiol 78:1296–1302

Vernon RG (1992) Effects of diet on lipolysis and its regulation. Proc Nutr Soc 51:397–408

Warner WA, Anton AH, Anderson TW, Swoffard LJ (1971) Ventricular fibrillation and catecholamine response during profound hypothermia in dogs. Anesthesiology 33:43–51

Webster AJF (1974) Heat loss from cattle with particular emphasis on the effects of cold. In: Monteithand JL, Mount LE (eds) Heat loss from animals and man. Butterworths, London

West JW (2003) Effects of heat-stress on production in dairy cattle. J Dairy Sci 86:2131–2144

Wheelock JB, Rhoads RP, VanBaale MJ, Sanders SR, Baumgard LH (2010) Effects of heat stress on energetic metabolism in lactating Holstein cows. J Dairy Sci 93:644–655

White HM, Koser SL, Donkin SS (2009) Regulation of bovine pyruvate carboxylase mRNA and promoter expression by heat stress. J Dairy Sci 92 (E-Suppl. 1):139 (Abstr.)

Yalcin S, Bruggeman V, Buyse J, Decuypere E, Cabuk M, Siegel PB (2009) Acclimation to heat during incubation: blood hormones and metabolites in broilers exposed to daily high temperatures. Poult Sci 88:2006–2013

Yan Y, Zhao Y, Wang H, Fan M (2006) Pathophysiological factors underlying heatstroke. Med Hypotheses 67:609–617

Young BA (1975) Temperature-induced changes in metabolism and body weight of cattle (*Bos taurus*). Can J Physiol Pharmacol 53:947–953

Young BA (1981) Cold stress as it affects animal production. J Anim Sci 52:154–163

Yunianto VD, Hayashi K, Kaneda S, Ohtsuka A, Tomita Y (1997) Effect of environmental temperature on muscle protein turnover and heat production in tube-fed broiler chickens. Br J Nutr 77:897–909

Climate Change and Water Availability for Livestock: Impact on Both Quality and Quantity

6

S.M.K. Naqvi, D. Kumar, Kalyan De,
and Veerasamy Sejian

Abstract

Water is an essential production factor in agriculture, both for crops and for livestock. Climate change will have a significant impact on agriculture in terms of affecting both water quantity and quality. It is known that changing climate will affect the water resource availability and global hydrological cycle. Livestock particularly in arid and semiarid region are mostly reared under extensive or traditional pastoral farming systems. The animals have different water requirements in different ambient temperatures. The requirement of water varies breed to breed according to their adaptability in a particular region and ambient temperature. Livestock of arid and semiarid region face the problem of water scarcity in most of the time of the year. So the animals need to take adaptive mechanism to overcome the water deprivation in different physiological stages. The animals exhibit several adaptive mechanisms to cope up to the less availability of water. These mechanisms include reduced plasma and urine volume, reduced faecal moisture, reduced body weight and reduced feed intake. The blood biochemical changes include increased haemoglobin, increased blood cholesterol and urea concentration, reduced protein concentration and increased sodium and potassium concentration. The endocrine changes include increased cortisol and reduced insulin, T_3, T_4 and leptin concentration in livestock. In addition, water deprivation in rumen also plays an important role in maintaining homeostasis in adapted animals. An adequate and safe water supply is essential for the normal and healthy production of livestock. Generally, surface or groundwater is supplied to the animals. This water source should be protected from microorganisms, chemicals and other pollutant contaminations. Keeping in view the adverse

---

S.M.K. Naqvi (✉) • D. Kumar • K. De
Division of Physiology and Biochemistry,
ICAR-Central Sheep and Wool Research Institute,
Avikanagar, Rajasthan 304501, India
e-mail: naqvismk@yahoo.co.in

V. Sejian
Animal Physiology Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_6, © Springer India 2015

water scarcity predicted in the future, strategies have to be developed to improve water-use efficiency and conservation for diversified production system in different locations. More research is needed into water resources' vulnerability to climate change and in order to support the development of adaptive strategies for agriculture.

Keywords

Climate change • Livestock • Water scarcity • Water quality • Water turnover

6.1 Introduction

Water is one of the most crucial component which depicts the climate change effects on the ecosystem, livelihood and various other productive aspects of the earth. Climate change influences the water demand, availability and quality. Changes in temperature and weather may affect the quality, quantity and distribution of rainfall, snowmelt, river flow and groundwater (IPCC 2007). Nowadays, many developing countries are facing water stress. So, if water management is inadequate, it will jeopardize the poverty alleviation program and sustainable development in economics, social and environment. Water scarcity and irregular rainfall are the common features in arid and semiarid environment. Along with the low water accessibility, the feed and fodder availability is also less in this region. Still livestock are the integral part of the ecosystem as well as livelihood of arid and semiarid environment. The ruminant animals of this region are well adapted to thrive in such harsh climatic conditions. Even they can survive up to 1 week with little or no water.

Water is an essential nutrient which is involved in all basic physiological functions of the body. Relative to other nutrients, water is consumed in considerably larger quantities. Therefore, water availability and quality are extremely important for animal health and productivity. The deprivation of water affects animal physiological homeostasis leading to loss of body weight, low reproductive rates and a decreased resistance to diseases (Barbour et al. 2005).

6.2 Climate Change, Water Availability and Agriculture

Water is an essential production factor in agriculture, both for crops and for livestock. Climate change will have a significant impact on agriculture in terms of affecting both water quantity and quality. This will be exacerbated by the increasing demand for food worldwide as population and real incomes increase. The production of biomass is inextricably linked to the need for fresh water, and livestock depends on water to drink. Just 3 % of the earth's water resources are fresh water and only 1 % of these are available for human activity, including agriculture. Imbalances between water availability and demand will most likely be exacerbated by climate change, and, like access to energy, water management is becoming one of the main geostrategic challenges of the twenty-first century. Water quality and quantity are closely interconnected and climate change will make this even more evident. Less water available makes management of its quality more difficult. More research is needed into water resources' vulnerability to climate change and in order to support the development of adaptive strategies for agriculture.

6.3 Water Availability

In this earth, freshwater availability is very less. Only 2.5 % of all water resource is fresh water. 96.5 % of water is in oceans and 1 % is brackish water. Out of this 2.5 % fresh water, 70 % is locked up in glaciers, permanent snow and atmosphere (Dompka et al. 2002; UNESCO 2005). Water availability was always reported to constrain human activities pertaining to agriculture. With increasing demand in agricultural products, water demand also increased. Continuous excessive withdrawal of groundwater and poor water management lowered groundwater (Rosegrant et al. 2002). Most of the fresh water is used in agriculture. In 2000, agriculture accounted for 70 % of water use and 93 % of water depletion worldwide (Turner et al. 2004). The growth of irrigated areas increased 5 times over the last century (FAO 2006). Along with that, the growth in the use of water in domestic and industrial purpose has been faster than agriculture (Rosegrant et al. 2002).

6.4 Water-Use Efficiency

Table 6.1 describes the current water usage for different purposes in different continents and India, and Table 6.2 describes the future water usage in India, China and the USA. The virtual water concept has gained wide acceptance recently. The virtual water is a broadscale, global water-use concept. It is developed to put all the industries and countries on equal basis in terms of water use as a part of global trading and environmental accounting system. The virtual water content of live animals is calculated on the basis of the virtual water content of their feed and amount of water used for drinking and services during their lifetime. The virtual water content is coined because the final water content in a finished product is significantly less than the water used to produce the product (Schlink et al. 2010). Table 6.3 describes the estimate of the amount of water used to produce different products.

Table 6.1 Water usage for different purposes in different continents and India

Usage (%)	World	Europe	Africa	India
Agriculture	69	33	88	83
Industry	23	54	5	12
Domestic	8	13	7	5

Table 6.2 Future water usage in India, China and the USA

	Agriculture	Industry	Domestic	Total	Per capita
Year	Billion l/day				l/day
India					
2000	1,658	115	93	1,866	88.9
2050	1,745	441	227	2,413	167.0
China					
2000	1,024	392	105	1,521	82.7
2050	1,151	822	219	2,192	155.4
USA					
2000	542	605	166	1,313	582.7
2050	315	665	187	1,167	484.6

Source: CITAAI (2005)

6.5 Climate Change Impact on Water

It is known that changing climate will affect the water resource availability and global hydrological cycle (IPCC 2008). Climate change can result in a higher intensity precipitation that leads to greater peak run-offs and less groundwater recharge. Longer dry periods may reduce groundwater recharge, reduce river flow and ultimately affect water availability, agriculture and drinking water supply. Global warming will increase water temperature that may result in algal bloom and may increase toxic cyanobacterial bloom and

Table 6.3 Average virtual water content of selected agricultural products in developed country production systems

Product	World average virtual water content (l/kg)
Paddy rice	2,291
Wheat	1,334
Soybean	1,789
Sorghum	2,853
Cotton lint	8,242
Coffee (roasted)	20,682
Beef	15,497
Pork	4,856
Goat meat	4,043
Sheep meat	6,143
Chicken meat	3,918
Eggs	3,340
Milk	990

Source: Hoekstra and Chapagain (2007)

diminished biodiversity. So, the consumption quality of water in rivers and lakes will be compromised. Climate change can directly affect water demand for agriculture and livestock. It is reported that, by 2055, 64 % of the world's population will be living in water-stressed basins and 33 % in areas of absolute water scarcity (Steinfeld et al. 2006). Figure 6.1 describes the impact of climate change on water sources for livestock in arid and semiarid regions of Rajasthan, India.

Climate change affects the water quality by:

(a) Increase in frequency of turbid water inflow into the reservoirs due to increase in the number of heavy rain days
(b) Stagnation of circulation in reservoir due to global warming
(c) Increased risk of toxic chemicals in raw water due to increase in vermin
(d) Increased production of trihalomethane due to water temperature rise
(e) Increased risk of pathogenic microorganisms in tap water due to water temperature rise

6.6 Water Requirement of Livestock

In livestock production system, water is required for drinking and servicing. 60–70 % of body weight is water. Livestock meet their water requirements through drinking water, water in feedstuff and metabolic water produced by oxidation of nutrients. Animals lost water from the body through respiration, evaporation, defecation and urination (NRC 1994). The water content of forage also varies; it remains 90 % during growing season whereas 10–15 % in dry season. Dry feed, concentrate and grain have 5–12 % water content. Metabolic water can provide up to 5–15 % of water requirement. Globally only 0.6 % of water is required for drinking and servicing of livestock. The drinking water requirement of different livestock species under different physiological conditions and air temperature is given in Table 6.4.

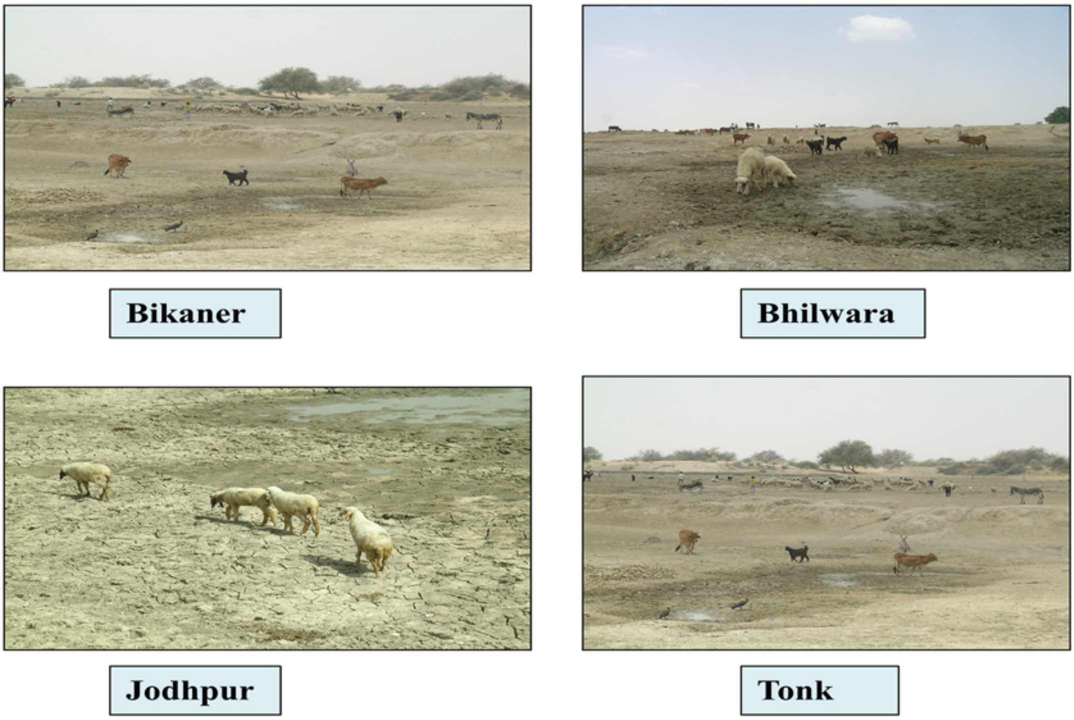


Fig. 6.1 Impact of climate change on water sources for livestock in arid and semiarid regions of Rajasthan, India

Table 6.4 Drinking water requirements (l/animal/day)

Species	Physiological condition	Average weight (kg)	Air temperature °C 15	 25	 35
			Water requirements		
Cattle	African pastoral system, lactating – 2 l milk/day	200	21.8	25	28.7
	Large breed, dry cow – 279 day pregnancy	680	44.1	73.2	102.3
	Large breed, lactating – 35 l milk/day	680	102.8	114.8	126.8
Goat	Lactating – 0.2 l milk/day	27	7.6	9.6	11.9
Sheep	Lactating – 0.4 l milk/day	36	8.7	12.9	20.1
Camel	Mid lactation – 4.5 l milk/day	350	31.5	41.8	52.2
Chicken	Adult broilers (100 animal)		17.7	33.1	62
	Laying eggs (100 animals)		13.2	25.8	50.5
Swine	Lactating daily weight gain of pigs 200 g	175	17.2	28.3	46.7

Source: Luke (1987), NRC (1985, 1987, 1994, 1998, 2000), Pallas (1986) and Ranjhan (1998)

Livestock in arid and semiarid region are mostly reared under extensive or traditional pastoral farming systems. The animals have different water requirements in different ambient temperatures. The requirement of water varies breed to breed according to their adaptability in a particular region and ambient temperature. Sheep is also not an exception in this aspect; sheep also showed different capacities to overcome water dearth. Awassi sheep can survive more than 1 month of watering every 2 days without much change (Jaber et al. 2004), while bighorn sheep withstand water deprivation up to 15 days (Farid et al. 1979; Turner 1979). The Australian Merino sheep survived 10 days without water (MacFarlane 1964).

6.7 Physiological Adaptation of Livestock to Water Deprivation

Breeds of arid and semiarid region took adaptive mechanisms to conserve water in times of heat and drought. Urine volume and faecal moisture content reduced in adapted breeds. The more concentrated urine is produced because of the length of Henle's loops located in the medulla of the kidney (McNab 2002). The thickness of the medulla is more in well-adapted breeds as compared to domestic breeds and able to produce more concentrated urine. The desert bighorn sheep produces highly concentrated urine of 3,900 mOsm/liter H_2O (Horst and Langworthy 1971; Turner 1973). The Awassi sheep demonstrated a similar ability to highly concentrate urine (up to 3,244 mOsm/Kg H_2O) under dehydration and to drink large volumes upon rehydration without disrupting their homeostasis (Laden et al. 1987). Table 6.5 describes the impact of water restriction on reproductive performance in Malpura ewes.

In dehydrated state blood urea concentration increased due to renal urea retention (Jaber et al. 2013). In water deprivation rumen also plays an important role in maintaining homeostasis in adapted animals. It acts as an important water reservoir because of its large volume. It also allows the intake of large volumes of water upon rehydration which is temporarily sequestered in the rumen. In the hottest part of the day, little body temperature increase was also observed, followed by body cooling at night through conduction and radiation. The capacity to tolerate this increase in temperature means that less water is needed for evaporative cooling (Kay 1997). The effects of water deprivation on various physiological attributes of livestock are as follows:

6.7.1 Body Weight

The most common physiological consequence of water restriction is weight loss. Previous reports showed that the weight loss ranges from 0.84 to

Table 6.5 Effect of water restriction on reproductive performance of Malpura ewes

Parameters		G-I	G-II	G-III	G-IV
First oestrous cycle	Oestrus %	100 (7/7)	100 (7/7)	85.7 (6/7)	85.7 (6/7)
	Oestrous duration (h)	34.3 ± 5.96	27.4 ± 5.96	28.0 ± 6.4	40.0 ± 6.4
Second oestrous cycle	Oestrus %	100 (7/7)	85.7 (6/7)	85.7 (6/7)	85.7 (6/7)
	Oestrus duration (h)	35.1 ± 6.94	32.0 ± 7.5	38.0 ± 7.5	50.0 ± 7.5
Oestrous cycle length (d)		17.0 ± 0.42	17.0 ± 0.45	17.0 ± 0.45	17.3 ± 0.45

26 % in dry and lactating Awassi ewes. It is clear that watering every 2 days did not cause a mentionable weight loss in Awassi ewes even if the temperature reached up to 32 °C. The highest weight loss (26.2 %) was recorded in young sheep (2-year-old ewes) and in lactating animals. Reported results lead to one conclusion that dry Awassi has a high adaptation to dehydration, and can tolerate 3-day water restriction regime, up to 1 month with losing only 16.8 % of their body weight. Both sheep and goat lose their weight subjected to feed and water stress (Silanikove 2000; MacFarlane et al. 1961). The weight loss may be due to body water loss and consequent mobilization of fat (and possibly muscle) used for energy metabolism to compensate the decrease in dietary intake (Jaber et al. 2004; Epstein 1985). Reports are available stating that water restriction causes more weight loss as compared to feed restriction alone (Ahmed Muna and El ShafeiAmmar 2001; Chedid 2009; Karnib 2009) although the difference was not always statistically significant. Figure 6.2 describes the intermittent water supply on the productive performance in Chokla ewes.

6.7.2 Feed Intake

A close correlation exists between water intake and feed intake. In normal feed intake process, hypovolaemia and hyperosmolality occur due to the salivation and gastric juice secretion. But during dehydrated state, salivary and gastric juice secretions are reduced due to water deprivation, which affects the feed intake (NRC 2007). Along with that an adequate level of water intake is necessary for proper digestive functions. Hyperosmolality of the ruminal fluid after taking a meal in water-restricted animals may also be the reason for reduced feed intake (Langhans et al. 1991). In Awassi sheep 3–4 days intermittent watering regime reduced their voluntary feed intake to approximately 60 % of the control (Jaber et al. 2004; Hamadeh et al. 2006). This reduction in feed intake is partially compensated for by a slower feed movement and longer retention time in the digestive tract. This is thought to lead to an increase in digestibility and nutrient utilization, as longer time is available for the microflora in the digestive tract to act on the feed (Hadjigeorgiou et al. 2000; Asplund and Pfander 1992; Musimba et al. 1987). Ahmed Muna and El Shafei Ammar (2001) reported an improvement in digestibility of lucerne hay under water restriction in desert goats.

At CSWRI, More and Sahni (1977, 1978, 1980) worked on Chokla sheep with intermittent water supply. The animals were supplied water for 24, 48 and 72 h interval for 6 months to see the effect on production performance. The results are presented in Fig. 6.2. Recently an experiment was carried out on Malpura ewes with water restriction to assess effect on endocrine response, body weight, feed intake and reproductive performances. This study was conducted for a period of 35 days covering two oestrous cycles. A total of 28 non-pregnant ewes were randomly and equally divided into four groups and offered adlib feed consisted of 70 % roughage and 30 % concentrate. Ewes in G-I (control, n = 7) were provided ad libitum water, in G-II 25 % less of adlib water, in G-III 50 % less of adlib water and in G-IV adlib water on alternate days. The results are presented in Table 6.5.

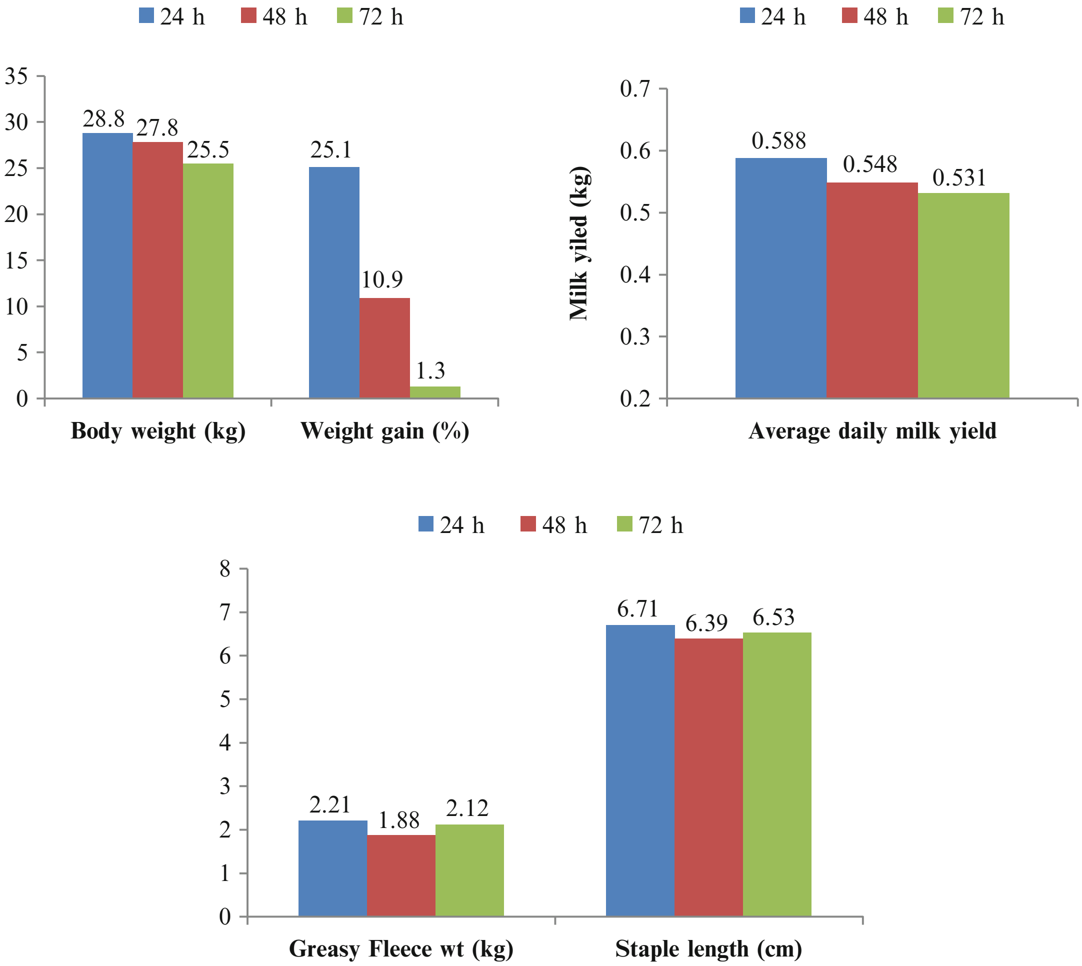


Fig. 6.2 Effect of intermittent water supply on production performance of Chokla ewes

6.7.3 Fat Metabolism

During water deprivation, fat mobilization also occurs in sheep. This fat mobilization increases the blood cholesterol levels (Silanikove 2000) and free fatty acid level. The increase in cholesterol level after water restriction is mainly due to fat metabolism because of low energy intake (Jaber et al. 2013). In Awassi sheep, fat-tail adipocyte diameter is reduced after intermittent watering regime (Jaber et al. 2011). Some reports stated that glucose metabolism decreases because of decreased propionate production in the rumen as feed intake reduces following water restriction.

6.7.4 Insulin and Leptin Levels

Intermittent watering (once in 4 days) decreases the insulin and leptin levels. It was reported that FFA is negatively correlated with insulin and leptin levels (Chedid 2009). During water-restricted period, insulin level decreased as feed intake reduced and insulin secretion is accelerated by feeding (Bassett 1975). Along with that, leptin levels also decreased in water and nutritional stress because of decreased metabolic status that inhibits the adipose tissue leptin secretion (Houseknecht and Portocarrero 1988).

6.7.5 PCV and Haematology

Plasma volume reduced in water stress as water is taken up by tissues (Schaefer et al. 1990). Although PCV and Hb values do not lead to a firm result, still haematocrit values were found to increase in water stress in some experiments. Contradictory results were also reported in Hb levels; the higher level of Hb may be due to decreased plasma volume because of less water availability (Jaber et al. 2013).

6.7.6 Protein

Some authors reported higher blood plasma albumin and globulin under water restriction (Jaber et al. 2004; Alamer 2005; Casamassima et al. 2008; Hamadeh et al. 2009). The possible reason may be due to reduced plasma volume in dehydration (Cork and Halliwell 2002). Other authors reported total protein and albumin reduction after water restriction. The reduction of plasma protein is attributed to low feed intake and use of the circulating protein to balance the dietary inadequacy (El-Sherif and Assad 2001). Generally it is suggested that a drop in serum albumin concentration is observed when the animal is under low dietary protein intake. The globulin concentration deceased later when the dietary inadequacy is prolonged (Sykes 1978; Caldeira et al. 2007). Serum albumin is required for maintaining body osmolarity, so, if changes occur in albumin levels, an animal has to maintain normal levels by transferring amino acids from skeletal muscle and other sources (Moorby et al. 2002).

6.7.7 Urea and Creatinine

Urea is the end product of protein catabolism. The kidney excretes urea from the body to eliminate excess N which is not used. Urea is recycled through saliva or by reabsorption into the rumen for utilization by rumen microflora (Jaber et al. 2013). Water stress reduces the urine output and produces dry faeces. This occurs under the influence of vasopressin, which increases water reabsorption (Olsson et al. 1997). Through the course of water deprivation, glomerular filtration slows down and reabsorption of urea is higher in kidneys (Jaber et al. 2013). It is reflected by higher urea concentration in blood. It was observed that urine volume diminishes by 75 % and faecal water output was 37 % lower in desert sheep when subjected to 5 days of water restriction (Li et al. 1982). The urea is recirculated from the blood system into the digestive tract. The urea conservation at the level of the kidney and recycling into the gut is increased when dietary nitrogen intake is low (Marini et al. 2004). After 5 days of water stress, creatinine concentration remained higher (Igbokwe 1993). Creatinine levels in lambs were not affected by 48 h water restriction (Jacob et al. 2006). Proteolysis and endogenous N sources influence the creatinine levels (Caldeira et al. 2007; Kataria and Kataria 2007). Another influencing factor is higher kidney retention because of reduced glomerular filtration. Actually, these factors are related to protein N intake deficiency along with level of dehydration (Jaber et al. 2013).

6.7.8 Electrolyte and Osmolarity

Electrolyte and osmolarity are affected by water stress. During water deprivation, hyperosmolarity occurs as plasma volume reduces. Sodium (Na^+) and chloride (Cl^-) electrolyte concentration mainly increased in water stress (Qinisa et al. 2011). To maintain Na^+ balance in the body, animal increased their retention of Na^+. Some workers reported that higher renal retention is because of aldosterone (Ashour and Benlamlih 2001), whereas others stated the effect of vasopressin (McKinley et al. 2000). Reports suggested that vasopressin increased in dehydrated state. Urinary vasopressin excretion rate is directly related to renal osmolarity and inversely related to urine flow rate. That is why lower urine volume and higher osmolarity and vasopressin levels were observed in dehydrated animals (Yesberg et al. 1970). In dehydrated animals, salivary secretion also reduced, but the osmolarity of the secretion is increased. During water stress the ruminants try to utilize the water present in the gut. They use the water across the rumen wall through active transport of Na^+. For this they need lower level of volatile fatty acid in the rumen, that is why feed intake is somewhat reduced in dehydration (Jaber et al. 2013).

A negative correlation exists between Na^+ and K^+ in plasma. So, blood K^+ level decreases in dehydrated animals (Jaber et al. 2004; MacFarlane et al. 1961). The possible reason behind this is the intra-erythrocytic diffusion of K^+ or loss of K^+ ions in urine in exchange of Na^+ reabsorption, although some contradictory results are also available because K^+ is not used as a reliable indicator of dehydration. In extracellular fluid, Cl^- is a major anion. During water stress, Cl^- level also increases in parallel with the Na^+ levels (Igbokwe 1993; Jaber et al. 2004; Hamadeh et al. 2006). Cl^- is passively distributed in relation to the electrical gradient established by active Na^+ transport (Tasker 1971). The increase may be due to increased haemoconcentration because of lower blood water level (Casamassima et al. 2008) and higher aldosterone and vasopressin concentrations which increase renal retention. Ca^+ does not vary under stress (Jaber et al. 2004; Casamassima et al. 2008).

Blood pH is important for normal metabolic and enzymatic functions. It remained unchanged in intermittent water supply, but pH increases with highly restricted water supply (once in 5 days) (Jaber et al. 2004). The possible reason behind increased pH may be that high dehydration and environmental heat cause hyperventilation that leads to respiratory alkalosis because of higher elimination of CO_2 (Srikandakumar et al. 2003).

6.7.9 Endocrine Profile

Cortisol is a major hormone. Cortisol is released because of the activation of the hypothalamic-pituitary-adrenal axis. Reports on Awassi sheep suggest that cortisol level does not change with water deprivation (Jaber et al. 2004; Ghanem 2005), whereas a report on Marwari sheep indicated higher level of cortisol in dehydrated state and remains higher up to 3 days of rehydration (Kataria and Kataria 2007).

Thyroid hormones, triiodothryronine (T_3) and thyronine (T_4), have important role in thermoregulation and maintaining metabolic homeostasis of energy and proteins (Huszenicza et al. 2002; Latimer et al. 2003; Thrall 2004). T_3 and T_4 level decreases in water-restricted animals (Jaber et al. 2011). The reason of reduced T_3 in water stress indicates lower metabolic state due to dehydration and decreased feed intake (Jaber et al. 2013). The possible reason behind decreased thyroid hormone activity is attributed to the animals' attempt to minimize water loss by declining metabolism (Olsson 2005).

6.7.10 Physiological Changes During Different Physiological Stages

Different physiological stages have different water demands. Livestock of arid and semiarid region face the problem of water scarcity in most of the time of the year. So the animals need to take adaptive mechanism to overcome the water deprivation in different physiological stages. Their physiological changes were observed according to the degree of water stress.

6.7.10.1 During Pregnancy

In semiarid region, higher haemoconcentration and reduced extracellular fluid were observed in pregnant Chokla sheep with intermittent watering (72 and 96 h) (More and Sahni 1980). Decreased glomerular filtration and increased plasma osmolarity and Na^+ concentration were found in pregnant 30 h dehydrated goats (Olsson et al. 1982). Pregnant sheep and goats have lower capacity to increase concentration of urine in dehydrated state (More and Sahni 1980; Olsson et al. 1982). It may be due to higher prostaglandin concentration which may decrease arginine-vasopressin sensitivity during late gestation. Twice-weekly watering for prolonged period did not affect the birth weight of well-adapted sheep breed of the desert, i.e. Magra and Marwari (Mittal and Ghosh 1986).

6.7.10.2 During Lactation

Lactating Awassi and Cornicana ewes showed significant weight loss during water loss. It may be due to that water stress causes reduced feed intake that forced the animal to depend on their body reserve for energy deficit (Sevi et al. 2002). Lower haemoglobin concentration was found in lactating ewes due to higher water content and plasma volume to increase water mobilization to the mammary glands (Jaber et al. 2013). Blood pH increased in lactating state because plasma Ca^{++} and K^{+} level reduced in plasma as they are required for milk production (Hamadeh et al. 2006). Along with that Na^{+} and Cl^{-} increase since Na^{+} is required for nutrient transport (Collier 1985).

Maximum water is needed in lactating state (Hossaini-Hilali et al. 1994). So, in dehydrated state, milk volume generally decreases (Hossaini-Hilali et al. 1994; Mengistu et al. 2007a, b), although well-adapted goats can maintain their milk production in water deprivation (Maltz et al. 1984). Reports stated that stress increases cortisol production which causes the plasmin system activation leading to protease peptone release with channel blocking activity from β-casein and interferes with lactose secretion into the lumen of the mammary gland and ultimately results in drop in milk production. Milk osmolarity and lactose density increase following 48 h of water restriction (Hossaini-Hilali et al. 1994; Laporte-Broux et al. 2011; Alamer 2009). The water content of milk is increased as an adaptive mechanism so that the offspring receives adequate quantity of water when water is not available (Mittal 1980; Yagil et al. 1986).

6.8 Water Turnover

Any living being has to maintain its body water pool homeostatically within a limit; for that, water loss has to be compensated. The amount of water utilized in a given unit of time is known as the water turnover. It varies according to the environment, adaptability of the animal, species, breed and physiological status of the body. In general, animals adapted to dry environments have lower turnover rates than species in temperate zones. But sometimes the heat load of animals increased, and at this time they need evaporative cooling by sweating which causes water loss; ultimately water turnover increases. Table 6.6 describes the different water turnover rates in livestock.

Table 6.6 Water turnover rates for different livestock species

Species	Water turnover (ml/kg/day)
Camel	38–76
Sheep	62–127
Goat	76–196
Zebu	63–178
Buffalo	108–203

Source: Macfarlane et al. (1963)

6.9 Water Quality for Livestock Drinking

An adequate and safe water supply is essential for the production of healthy livestock. Generally, surface or groundwater is supplied to the animals. So, this water should be protected from microorganisms, chemicals and other pollutant contaminations. However, scanty literature is available on the impact of water quality on livestock. Reduction of water consumption due to contamination causes mineral imbalance. If some particular salts and other elements remain in higher level, it may reduce growth and reproduction or may cause illness and death. Although animals are able to consume a wide variety of water because of their physiological adaptability. Commonly salinity, hardness, pH, sulphate and nitrate are analysed to evaluate water quality. Figure 6.3 depicts the different water sources for livestock and water collection from these sources for quality checking from different districts of arid and semiarid regions of Rajasthan, India.

Salinity indicates the salt dissolved in water. Salinity is measured as total dissolved solid (TDS) and expressed as parts per million (ppm). Table 6.7 describes the TDS and species variation between human and other livestock species. The anions that remained in water are carbonate, bicarbonate, sulphate, nitrate chloride, phosphate


Bikaner
Jalore
Jodhpur
Tonk

Fig. 6.3 Water collection for quality checking from different districts of arid and semiarid regions of Rajasthan, India

Table 6.7 Species variation for TDS between human and different livestock species

Species	Excellent	Good	Fair	Poor	Limit
Humans	0–800	800–1,600	1,600–2,500	2,500–4,000	5,000
Horses – working	0–1,000	1,000–2,000	2,000–3,000	3,000–5,000	6,000
Horses – others	0–1,000	1,000–2,000	2,000–4,000	4,000–6,000	10,000
Cattle	0–1,000	1,000–2,000	2,000–4,000	4,000–6,000	10,000
Sheep	0–1,000	1,000–3,000	3,000–6,000	6,000–10,000	15,000
Chickens and poultry	0–1,000	1,000–2,000	2,000–3,000	3,000–5,000	6,000

Source: Boyles et al. (1988)

and fluorides. The cations are calcium, magnesium, sodium and potassium. Sudden change in water salinity may affect the animal. Although animals can consume high-salinity water for few days without any effect, tolerance for salinity depends on age, species, requirement season and physiological condition. Excess of magnesium, calcium, sodium and chloride increases the salinity and may have toxic effects. Sulphate ion is the most common component of salinity. High level of sulphate in water may cause diarrhoea. Water having more than 1,500 mg sulphate/l reduces the copper status in cattle. Nitrate toxicity is rarely caused by water, but it may cause high nitrate in feed source. Nitrite (NO_2) is ten times more toxic than nitrate (NO_3). The bacteria of ruminants convert the nitrate to nitrite. When this process is fast, nitrate poisoning occurs. Table 6.8 depicts the guidelines for the use of saline waters for livestock and poultry.

The preferred pH for livestock is 5.5–8.3 but in cattle 6.0–8.0. Intake of highly alkaline water may cause digestive upsets, diarrhoea, reduced feed intake and feed conversion.

Table 6.8 A guide to the use of saline waters for livestock and poultry

Total soluble salt content of waters (mg/l or ppm)	Comment
Less than 1,000	These waters have a relatively low level of salinity and should present no serious burden to any livestock or poultry
1,000–2,999	These waters should be satisfactory for all classes of livestock and poultry. They may cause temporary and mild diarrhoea in livestock not accustomed to them or watery droppings in poultry but should not affect their health and performance
3,000–4,999	These waters should be satisfactory for livestock, although they may cause temporary diarrhoea or be refused at first by animals not accustomed to them. They are poor waters for poultry, often causing watery faeces and increased mortality and decreased growth
5,000–6,999	These waters can be used with reasonable safety for dairy and beef cattle, sheep, swine and horses. Avoid the use of those approaching the higher levels for pregnant animals. They are not acceptable waters for poultry, almost always causing some type of problem, especially near the upper limit, where reduced growth and production or increased mortality will probably occur
7,000–10,000	These waters are unfit for poultry and probably swine. Considerable risk may exist in using them for pregnant or lactating cows, horses, sheep, the young of these species or any animals subjected to heavy heat stress or water loss. In general, their use should be avoided, although older ruminants and horses or even poultry and swine may subsist on them for long periods of time under conditions of low stress
More than 10,000	The risk with these highly saline waters is so great that they cannot be recommended for use under any conditions

Source: NRC (1974)

6.10 Conclusion

The livestock sector contributes 1.4 % of the world's gross domestic product (GDP) with 2.2 % growth rate over ten years (1995–2005). Globally livestock contribute 40 % of the agricultural GDP, but water reserve in this globe is depleting day by day and prediction hints severe water scarcity in the near future. If the prediction becomes a reality, the livestock sector will also experience the misery like other sectors. Along with that, climate change, variability and distribution of water will force the livestock sector to compete with other farming in the near future. Keeping view on that, strategies have to be developed to improve water-use efficiency and conservation for a diversified production system in different locations. So, degradation of water reservoirs and land must be avoided through integrated soil-animal management system to provide continuous good quality water supply for sustainable livestock production system.

References

Ahmed Muna MM, El ShafeiAmmar I (2001) Effects of water and feed restriction on body weight change and nitrogen balance in desert goats fed high and low quality forages. Small Rumin Res 41:19–27

Alamer M (2005) Effect of deprivation and season on some biochemical constituents of blood in Awassi and Najdi sheep breeds in Saudi Arabia. J Anim Vet Adv 48:15–20

Alamer M (2009) Effect of water restriction on lactation performance of Aardi goats under heat stress conditions. Small Rumin Res 84:76–81

Ashour G, Benlamlih S (2001) Adaptation of Mediterranean breeds to heat stress and water deprivation. In: Guessous F, Rihani N, Ilham A (eds) Livestock production and climatic uncertainty in the Mediterranean: proceedings of the Joint ANPA-EAAPCIHEAM- FAO symposium. Wageningen Press, Wageningen

Asplund JM, Pfander WH (1992) Effects of water restriction on nutrient digestibility in sheep receiving fixed water: feed ratios. J Anim Sci 6:1271–1274

Barbour E, Rawda N, Banat G, Jaber L, Sleiman FT, Hamadeh S (2005) Comparison of immunosuppression in dry and lactating Awassi ewes due to water deprivation stress. Vet Res Commun 29:47–60

Bassett JM (1975) Dietary and gastro-intestinal control of hormones regulating carbohydrate metabolism in ruminants. In: MacDonald IW, Warner ACI (eds) Digestion and metabolism in the ruminants. University of New England Publishing Unit, Armidale, pp 383–398

Boyles S, Wohlgemuth K, Fisher G, Lundstrom D, Johnson L (1988) Livestock and water, AS- 954. North Dakota State University, Farg

Caldeira A, Belo C, Santos M, Vazques A, Portugal AV (2007) The effect of body condition score on blood metabolites and hormonal profiles in ewes. Small Rumin Res 68:233–241

Casamassima D, Pizzo R, Palazzo M, D'alessandro AG, Martemucci G (2008) Effect of water restriction on productive performance and blood parameters in Comisana sheep reared under intensive condition. Small Rumin Res 78:169–175

Chedid M (2009) Physiological responses of feed and water restricted dry Awassi ewes to aspirin administration. Master thesis, American University of Beirut, Riad El-Solh / Beirut 1107 2020 Lebanon, pp 1–64

CITAAI (Centre for International Trade in Agriculture & Agro-based Industries) (2005) Water scarcity and security in India. Sharad Krishi, Pune, pp 18–20

Collier RJ (1985) Nutritional, metabolic, and environmental aspects of lactation. In: Larson BL (ed) Lactation. Iowa State University Press, Ames, pp 102–107

Cork SC, Halliwell RW (2002) The veterinary laboratory and field manual: a guide for veterinary laboratory technicians and animal health advisors. Nottingham University Press, Nottingham

Dompka MV, Krchnak KM, Thorne N (2002) Summary of experts meeting on human population and freshwater resources. In: Krchnak DK (ed) Human population and freshwater resources: U.S. cases and international perspective. Yale University, New Haven, p 177

El-Sherif MMA, Assad F (2001) Changes in some blood constituents in Barki ewes during pregnancy and lactation under semi-arid conditions. Small Rumin Res 40:269–277

Epstein H (1985) The Awassi sheep with special reference to the improved dairy type, FAO animal production and health paper, 57. FAO, Rome, pp 34–38

FAO (2006) FAOSTAT. Rome (disponible à l'adresse http://faostat.fao.org/default.aspx?lang=fr)

Farid MF, Shawket SM, Abdel-Rahman MHA (1979) Observations on the nutrition of camels and sheep under stress. In: Proceedings of workshop on camels, International Foundation of Science, Kartoum, pp 126–170

Ghanem A (2005) The effect of vitamin C supplementation on some physiological and immunological indicators in water-deprived Awassi ewes. Master thesis, American University of Beirut, pp 1–89

Hadjigeorgiou I, Dardamani K, Goulas C, Zervas G (2000) The effect of water availability on feed intake and digestion in sheep. Small Rumin Res 37:147–150

Hamadeh SK, Rawda N, Jaber LS, Habre A, Abi Said M, Barbour EK (2006) Physiological responses to water restriction in dry and lactating Awassi ewes. Livest Sci 101:101–109

Hamadeh SK, Hanna N, Barbour EK, Abi Said M, Rawda N, Chedid M, Jaber LS (2009) Changes in physiological and blood parameters in water restricted Awassi ewes supplemented with different levels of Vitamin C. In: European Federation for Animal Science EAAP, 60th annual meeting, Barcelona. Session S.26 Abstract no. 3175. http://www.eaap.org/Previous_Annual_Meetings/2009Barcelona/Papers/26_Hamadeh.pdf

Hoekstra AY, Chapagain AK (2007) Water footprints of nations: water use by people as a function of their consumption pattern. Water Resour Manage 21:35–48

Horst R, Langworthy M (1971) Observations on the kidney of the desert bighorn sheep. Anat Rec 2:343

Hossaini-Hilali J, Benlamlih S, Dahlborn K (1994) Effects of dehydration, rehydration, and hyperhydration in the lactating and non-lactating black Moroccan goat. Comp Biochem Physiol 109:1017–1026

Houseknecht KL, Portocarrero CP (1988) Leptin and its receptors: regulators of whole body energy homeostasis. Domest Anim Endocrinol 15:457–475

Huszenicza GY, Kulcsar M, Rudas P (2002) Clinical endocrinology of thyroid gland functions in ruminant. Vet Med Czech 47:199–210

Igbokwe IO (1993) Haemoconcentration in Yankasa sheep exposed to prolonged water deprivation. Small Rumin Res 12:99–105

IPCC (2007) Climate change 2007: impacts, adaptation and vulnerability: contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Parry KL, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds). Cambridge University Press, Cambridge, p 976. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/contents.html

Intergovernmental Panel on Climate Change Secretariat (IPCC) (2008) Technical paper VI. In: Bates BC, Kundzewicz S, Wu ZW, Palutikof JP (eds) Climate change and water. IPCC Secretariat, Geneva, p 210. http://www.ipcc.ch/publications_and_data/publications_and_data_technical_papers_climate_change_and_water.htm

Jaber LS, Habre A, Rawda N, AbiSaid M, Barbour EK, Hamadeh SK (2004) The effect of water restriction on certain physiological parameters in Awassi sheep. Small Rumin Res 54:115–120

Jaber LS, Hanna N, Barbour EK, Abi Said M, Rawda N, Chedid M, Hamadeh SK (2011) Fat mobilization in water restricted Awassi ewes supplemented with vitamin C. J Arid Environ 75:625–628

Jaber L, Chedi M, Hamadeh S (2013) Water stress in small ruminants. INTECH open science. http://dx.doi.org/10.5772/53584. http://cdn.intechopen.com/pdfs-wm/41860.pdf

Jacob RH, Pethick DW, Clark P, D'Souza DN, Hopkins DL, White J (2006) Quantifying the hydration status of lambs in relation to carcass characteristics. Aust J Exp Agric 46:429–437

Karnib M (2009) The effect of vitamin C administration on some physiological parameters in water and feed restricted dry Awassi ewes. Master thesis, American University of Beirut, pp 1–48

Kataria N, Kataria AK (2007) Compartmental water management of Marwari sheep during dehydration and rehydration. Vet Arch 77:551–559

Kay RNB (1997) Responses of African livestock and wild herbivores to drought. J Arid Environ 37:683–694

Laden S, Nehmadi L, Yagil R (1987) Dehydration tolerance in Awassi fat-tailed sheep. Can J Zool 65:363–367

Langhans W, Scharre E, Meyer AH (1991) Changes in feeding behavior and plasma vasopressin concentration during water deprivation in goats. J Vet Med 38:11–20

Laporte-Broux B, Roussel S, Ponter AA, Perault J, Chavatte-Palmer P, Duvaux-Ponter C (2011) Short-term effects of maternal feed restriction during pregnancy on goat kid morphology, metabolism, and behaviour. J Anim Sci 89:2154–2163

Latimer KS, Mahaffy EA, Prasse KW (2003) Duncan and Prasses, veterinary laboratory medicine, clinical pathology, 4th edn. Iowa State Press, Ames

Li KE, Mousa HM, Hume JD (1982) Total body water and water economy in camels, desert goats and desert sheep during water restriction and deprivation. Iugosl Physiol Pharmacol Acta 18:229–236

Luke GJ (1987) Consumption of water by livestock. Resource management technical report no 60. Department of Agriculture, Western Australia, South Perth

MacFarlane WV (1964) Terrestrial animals in dry heat: ungulates. In: Dill DB, Adolph EFA, Wilberg CC (eds) Handbook of physiology, section 4: adaptation to the environment. American Physiological Society, Washington, DC, pp 509–539

MacFarlane WV, Morris RJH, Howard B, McDonald J, Budtz-Olsen OE (1961) Water and electrolyte changes in tropical Merino sheep exposed to dehydration during summer. Aust J Agric Res 12:889–912

Macfarlane WV, Morris RJH, Howard B (1963) Turnover and distribution of water in desert camels, sheep, cattle and kangaroos. Nature 197:270–271

Maltz E, Olsson K, Glick SM, Fyhrquist F, Shanikout N, Chosniak I, Shkolnik A (1984) Homeostatic responses to water deprivation or hemorrhage in lactating and non-lactating Bedouin goats. Comp Biochem Physiol A 77A:79–84

Marini JC, Klein JD, Sands JM, Van Amburgh ME (2004) Effect of nitrogen intake on nitrogen recycling and urea transporter abundance in lambs. J Anim Sci 82:1157–1164

McKinley MJ, Evered MD, Mathai ML (2000) Renal Na excretion in dehydrated and rehydrated adrenalectomized sheep maintained with aldosterone. Am J Physiol Regul Integr Comp Physiol 279:17–24

McNab BK (2002) The physiological ecology of vertebrates. Comstock Publishing Associates, Cornell University Press, Ithaca

Mengistu U, Dahlborn K, Olsson K (2007a) Mechanisms of water economy in lactating Ethiopian Somali goats during repeated cycles of intermittent watering. Animal 1:1009–1017

Mengistu UK, Dahlborn K, Olsson K (2007b) Effect of intermittent watering on water balance and feed intake in Male Ethiopian Somali goats. Small Rumin Res 67:45–54

Mittal SB (1980) Dairy development and seasonal variation in the quality of milk in the arid zone of western Rajasthan. In: Mann HS (ed) Arid zone research and development. Scientific Publishers, Jodhpur, pp 381–387

Mittal JP, Ghosh PK (1986) Effect of prolonged intermittent water restriction on the reproductive performance of ewes in the Indian desert. Anim Prod 43:255–260

Moorby JM, Dewhurst RJ, Evans RT, Fisher WJ (2002) Effects of level of concentrate feeding during the second gestation of Holstein–Friesian dairy cows. 2. Nitrogen balance and plasma metabolites. J Dairy Sci 85:178–189

More T, Sahni KL (1977) The effect of water deprivation on wool production of Chokla sheep under semi-arid conditions. Indian Vet J 54:818–822

More T, Sahni KL (1978) Effect of long-term water deprivation on body weights and water intake of breeding ewes under semi-arid conditions. J Agric Sci (Camb) 90:435–439

More T, Sahni KL (1980) Effect of intermittent watering on milk production and lamb growth in Chokla ewes under semi-arid conditions. Indian Vet J 57:464–466

Musimba NKR, Pieper RD, Wallace JD, Galyean ML (1987) Influence of watering frequency on forage consumption and steer performance in Southeastern Kenya. J Range Manag 40:412–415

National Research Council (1974) Nutrients and toxic substances in water for livestock and poultry. National Academy Press, Washington, DC

National Research Council (1985) Nutrient requirement of sheep- sixth rev edn, Subcommittee of sheep nutrition, Committee on Animal Nutrition, National Research Council. National Academy Press, Washington, DC, p 112

National Research Council (1987) Predicting feed intake of food-producing animals. Subcommittee on Feed Intake Committee on Animal Nutrition, National Research Council. National Academy Press, Washington, DC, p 248

National Research Council (1994) Nutrient requirements of poultry, rev. edn, Subcommittee on Poultry Nutrition, Committee on Animal Nutrition, National Research Council. National Academy Press, Washington, DC, p 176

National Research Council (1998) Nutrient requirements for swine, 10th edn. National Academy Press, Washington, DC

National Research Council (2000) Clean coastal waters: understanding and reducing the effects of nutrient pollution. National Academy Press, Washington, DC

National Research Council (2007) Nutrient requirements of small ruminants: sheep, goats, cervids, and New World camelids/Committee on Nutrient Requirements of Small Ruminants, Board on Agriculture and Natural Resources, Division on Earth and Life Studies, National Research Council of the National Academies, Northwest, Washington DC, US

Olsson K (2005) Fluid balance in ruminants: adaptation to external and internal challenges. Ann N Y Acad Sci 104:156–161

Olsson K, Benlamlih L, Dahlborn K, Fyhrquist F (1982) Effects of water deprivation and hyperhydration in pregnant and lactating goats. Acta Physiol Scand 115:361–367

Olsson K, Benlamlih S, Hossaini-Hilali J, Dahlborn K (1997) Regulation of fluid balance in goats and sheep from dry areas. In: Lindberg JE, Gonda HL, Ledin I (eds) Recent advances in small ruminant nutrition, Options Méditerranéennes: Série A. Séminaires Méditerranéens; n. 34, Proceedings of the seminar of the FAO-CIHEAM Network of Cooperative Research on Sheep and Goats, Rabat, 24–26 October 1996, pp 159–171

Pallas PH (1986) Water for animals. Division de la mise en valeur des terres et des eaux, FAO (disponible à l'adresse www.fao.org/docrep/R7488E/R7488E00.htm)

Qinisa MM, Boomker EA, Mokoboki HK (2011) Physiological responses of water-restricted tswana and boer goats. Life Sci J 8:106–111

Ranjhan SK (1998) Nutrient requirements of livestock and poultry, 2nd rev. edn. ICAR, New Delhi

Rosegrant MW, Cai X, Cline SA (2002) Global water outlook to 2025: averting an impending crisis, a report summary of the 2020 vision for food, agriculture and the environment initiative. International Food Policy Research Institute/International Water Management Institute, Washington, DC/Colombo

Schaefer AL, Jones SDM, Tong AKW, Lepage P, Murray NL (1990) The effects of withholding feed and water on selective blood metabolites in market-weight beef steers. Can J Anim Sci 70:1151–1158

Schlink AC, Nguyen ML, Viljo GJ (2010) Water requirements for livestock production: a global perspective. Rev Sci Tech 29:603–619

Sevi A, Albenzio M, Annicchiarco G, Caroprese M, Marino R, Taibi L (2002) Effects of ventilation regimen on the welfare and performance of lactating ewes in summer. J Anim Sci 8:2362–2372

Silanikove N (2000) The physiological basis of adaptation in goats to harsh environments. Small Rumin Res 35:181–193

Srikandakumar A, Johnson EH, Mahgoub O (2003) Effect of heat stress on respiratory rate, rectal temperature and blood chemistry in Omani and Australian Merino sheep. Small Rumin Res 49:193–198

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome, p 390

Sykes AR (1978) An assessment of the value of plasma urea nitrogen and albumin concentrations as monitors of the protein status of sheep. In: Lister D (ed) The use of blood metabolites in animal production. British Society of Animal Production occasional publication, 1. BSAP, Milton Keynes, pp 143–154

Tasker JB (1971) Fluids, electrolytes, and acid–base balance. In: Kaneko JJ, Cornelius CE (eds) Clinical biochemistry of domestic animals, 2nd edn. Academic Press Inc, London, pp 65–75

Thrall MA (2004) Veterinary hematology and clinical chemistry. Lippincott Williams and Wilkins, Philadelphia

Turner JC (1973) Water, energy and electrolyte balance in the desert bighorn sheep, Ovis Canadensis. PhD thesis, University of California, Riverside, pp 1–276

Turner JC (1979) Osmotic fragility of desert bighorn sheep red blood cells. Comp Biochem Physiol A 64:167–175

Turner K, Georgiou S, Clark R, Brouwer R, Burke J (2004) Economic valuation of water resources in agriculture: from the sectoral to a functional perspective of natural resource management. FAO water reports no 27. FAO, Rome (disponible àl'adresse http://www.fao.org/docrep/007/y5582e/y5582e00.htm)

UNESCO (2005) Portail de l'eau (disponible à l'adresse http://www.unesco.org/water/index_fr.shtml)

Yagil R, Amir H, Abu-Rabiya Y, Etzion Z (1986) Dilution of milk: a physiological adaptation of mammals to water stress? J Arid Environ 11:243–247

Yesberg N, Henderson M, Budtz-Olsen OE (1970) The excretion of vasopressin by normal and dehydrated sheep. Aust J Exp Biol Med Sci 48:115–127

Impact of Climate Change on Forage Availability for Livestock

7

Kandalam Giridhar and Anandan Samireddypalle

Abstract

Climate change has the potential to impact the quantity and reliability of forage production, quality of forage, water demand for cultivation of forage crops, as well as large-scale rangeland vegetation patterns. The most visible effect of climate change will be on the primary productivity of forage crops and rangelands. Developing countries are more vulnerable to climate change than developed countries because of the predominance of agriculture in their economies and their warmer baseline climates, besides their limited resources to adapt to newer technologies. In the coming decades, crops and forage plants will continue to be subjected to warmer temperatures, elevated carbon dioxide, as well as wildly fluctuating water availability due to changing precipitation patterns. The interplay among these factors will decide the actual impact on plant growth and yield. Elevated CO_2 levels are likely to promote dry matter production in C_3 plants more as compared to C_4 plants, and the quantum of response is dependent on the interactions among the nature of crop, soil moisture, and soil nutrient availability. Due to the wide fluctuations in distribution of rainfall in growing season in several regions of the world, the forage production will be greatly impacted. As the agricultural sector is the largest user of freshwater resources, the dwindling water supplies will adversely affect the forage crop production. With proper adaptation measures ably supported by suitable policies by the governments, it is possible to minimize the adverse impacts of climate change and ensure livestock productivity through optimum forage availability.

Keywords

Climate change • Forage yield • Forage quality • Livestock

K. Giridhar (✉)
ICAR-National Institute of Animal Nutrition
and Physiology, Adugodi, Hosur Road, Bangalore,
Karnataka 560030, India
e-mail: girikanu@gmail.com

A. Samireddypalle
International Livestock Research Institute, IITA
Ibadan, Oyo Road, Ibadan, Oyo 200001, Nigeria

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_7, © Springer India 2015

7.1 Introduction

The recently released fifth assessment report of IPCC has clearly shown through multiple lines of evidence that the climate is changing across the globe, largely as a result of human activities. The most compelling proof of climate change comes from observations of the atmosphere, land, oceans, and cryosphere. Unequivocal evidence from in situ observations and ice core records show that the atmospheric concentrations of important greenhouse gases such as carbon dioxide, methane, and nitrous oxide have increased over the last few centuries (Cubasch et al. 2013). Based on many studies covering a wide range of regions and crops, negative impacts of climate change on crop yields have been more common than positive impacts. The climate change impacts livestock productivity not only directly but also indirectly by its effect on the availability as well as quality of forage resources. Livestock production systems rely upon a wide variety of feed sources that include grazing of native forage and browse species, planted pasture, and feed products from arable land. Forage crops account for 60–90 % of feedstuff input in animal production systems (Barnes and Baylor 1994). One of the most evident and important effects of climate change on livestock production is mediated through changes in feed resources. Changes in the primary productivity of crops, forages, and rangelands are probably the most visible effect of climate change on feed resources for ruminants with the end result, for livestock production, a change in the quantity of grains, stovers, and rangelands available for dry season feeding (Thornton et al. 2007). Due to climate change, it is projected that in general, the length of the growing season and suitability for crops is likely to decline in all tropical farming systems due to the limitation of moisture availability or extreme heat.

Hopkins and Del Prado (2007) listed out a few major impacts on feed crops and grazing systems due to the climate change like:

- Changes in herbage growth brought about by changes in atmospheric carbon dioxide concentrations and temperature
- Changes in the composition of pastures, such as changes in the ratio of grasses to legumes
- Changes in herbage quality, with changing concentrations of water-soluble carbohydrates and N at given dry matter yields
- Greater incidences of drought, which may offset any dry matter yield increases
- Greater intensity of rainfall, which may increase nitrogen leaching in certain systems

A consensus has emerged that developing countries are more vulnerable to climate change than developed countries because of the predominance of agriculture in their economies, the scarcity of capital for adaptation measures, their warmer baseline climates, and their heightened exposure to the extreme events (Parry et al. 2001). Due to ever-increasing population pressure of human beings in the developing countries, arable land is mainly used for food and cash crops, and there is little chance of allocating good quality land for pasture production, creating perpetual shortage of green fodder for the livestock. The climate change will further accentuate production of sufficient quantum of forage to improve the productivity of livestock in these regions. By combining historical crop production and weather data into a panel analysis, a robust model of yield response to climate change for several key African crops was developed by Schlenker and Lobell (2010), and it has predicted negative impacts of warming and estimated that by midcentury, the mean declines in the production of major staple crops in sub-Saharan Africa could be 22 % for maize, 17 % each for sorghum as well as millet, and 18 % for groundnut. In all cases, there is a 95 % probability that damages exceed 7 %, and the countries with the highest average yields have the largest projected yield losses, suggesting that well-fertilized modern seed varieties are more susceptible to losses caused by global warming.

The combined and interacting influences of climate variability and change directly affect agriculture through crop and animal production and indirectly through changes in soils, water, pests, diseases, and biodiversity interactions. To assess the impact of climate change, crop growth models are extensively used to evaluate the response of crops in terms of development, growth, and yield. The future climate conditions, derived from General or Regional Circulation Models along with the simulation of carbon dioxide, obtained from crop experiments are utilized in these modeling studies.

7.1.1 Importance and Contribution of Pastures

Pasture-based production systems account for two thirds of the global dry areas. Extensive pastoralism supports around 200 million pastoral households and occurs on 1/4 of the global dry areas (Nori et al. 2005). Roughly 40 % of the land in Africa is dedicated to pastoralism, and the percentage of the total population relying on dry and subhumid lands for their livelihood is to the extent of 70 % (CBD/UNEP/IUCN 2007). In view of the large contribution of the pastures in livestock production and its role in supporting millions of small and marginal farmers, the impact of climate change on pastures and its likely impact on livestock productivity and food security need to be understood, and appropriate interventions and strategies need to be put in place to ensure that in coming years, the pastures would continue to play a useful role in supporting the livestock and the families relying on livestock as a major livelihood option. Livestock sector is the fastest-growing subsector in agriculture, and to sustain the present momentum, it has to be ensured that productivity and sustainability of pasture-based production systems is safeguarded against a wide range of factors like competition for land, desertification, droughts, widespread degradation, climate change, etc. As a result of overgrazing, salinization, alkalization, acidification, and other processes (FAO LEAD 2006), the grasslands are reported to be degraded to a great extent and this figure was around 71 % during early 1990s (Dregne et al. 1991) and the current percentage is likely to be much higher. Grasslands and rangelands in arid, semiarid, and subhumid areas are particularly affected (Safriel et al. 2005) through mismanagement, inappropriate habitat conversion, and, more recently, due to climate change. Fodders, grasslands, and rangelands are the primary inputs for dairy, meat, and wool production across a wide range of production systems, and like the food production, livestock production would be negatively affected by the climate changes across all the continents (IPCC AR5 2014).

7.2 Impact of Environmental Stresses on Crops

7.2.1 Elevated Carbon Dioxide

Among all global change factors, atmospheric CO_2 enrichment is least questioned and has little spatial variation. For the first time in the Holocene, the atmospheric CO_2 concentration exceeded 400 parts per million in the year 2013. Rising CO_2 concentrations are likely to have profound direct effects on the growth, physiology, and chemistry of plants, independent of any effects on climate (Ziska and Bunce 2007). Increased atmospheric CO_2 concentrations on plant growth are well studied. It causes partial closure of stomata, which reduces water loss by transpiration and thus improves water-use efficiency (Rötter and van de Geijn 1999) leading to improved crop yield, even in conditions of mild water stress. The effect is much larger for C_3 plants, but there is also a small effect for C_4 plants. Numerous studies conducted in the past four decades have clearly shown that plant biomass and yield tend to improve significantly with increase in carbon dioxide concentrations due to the higher photosynthetic rates. Species composition would be affected by the changes in temperature and CO_2 through changes in optimal growth ranges for different species, plant composition, and species competition. It is postulated that legume species in grasslands and the proportion of browse in rangelands are likely to increase with the rising CO_2 brought about by the climate change and the changes in herbage quality, with changing concentrations of water-soluble carbohydrates and N at given dry matter yields (Thornton et al. 2007). Between C_3 and C_4 species, in most cases C_3 have higher forage quality and it is predicted that the global warming due to climate change will favor C_4 species over temperate C_3 species (Howden et al. 2008), thereby leading to loss of forage quality and lowering of livestock productivity. Hatfield et al. (2011) carried out a meta-analysis of numerous greenhouse, growth chamber, and field studies to confirm a general positive response of plants to elevated carbon dioxide in terms of leaf photosynthesis, biomass, and yield. They also reported that on an average, a doubling of carbon dioxide increases reproductive yield by 30 % in C_3 species and by 10 % in C_4 species.

The plant responses to future CO_2 concentrations are obtained from the studies that have experimentally increased CO_2 and then compared with the performance of the plants grown under current ambient CO_2 conditions. Such studies are normally done in a wide variety of settings, including greenhouses and chambers of various sizes and designs. However, plants grown in chambers may not experience the effects of increasing CO_2 the same way as plants growing in more natural settings. To overcome such problems, the technique of Free-Air Carbon dioxide Enrichment (FACE) was developed to allow natural or agricultural ecosystems to be fumigated with elevated concentrations of CO_2 in the field without the use of chambers (Taub 2010). Hence, FACE studies provide the most reliable empirical results to estimate the response of crop production to CO_2 enrichment. Long et al. (2006) suggested that results from FACE studies, carried out under more realistic conditions, indicate that the CO_2 fertilization effect may be only half of the estimates made from enclosure studies. Across a range of FACE experiments, with a variety of plant species, growth of plants at elevated CO_2 concentrations of 475–600 ppm increased leaf photosynthetic rates by an average of 40 % and decreased stomatal conductance of water by an average of 22 % (Ainsworth and Rogers 2007).

Atmospheric CO_2 enrichment induces significant increase in the light-saturated CO_2 uptake, the diurnal photosynthetic rate, and the instantaneous transpiration efficiency. Ainsworth and Long (2005) made a meta-analysis of 15 years of FACE experiments, and when the results were averaged across all the experiments, the parameters mentioned above increased by 31 %, 28 %, and >50 %, respectively. They also pointed out that the increases in C_4 plants are much lower than in C_3 plants and the dry matter increase was 20 % for C_3 plants and nonsignificant for C_4 plants. The differential response of C_3 plants is due to the unsaturated photosynthesis at the current CO_2 concentration. C_4 plants include most tropical and subtropical grasses and several important crops, including maize (corn), sugarcane, sorghum, millets, etc. They use a biochemical pump to concentrate CO_2 at the locations within the leaf where the rubisco enzyme mediates incorporation of CO_2 by the Calvin-Benson photosynthetic cycle. As CO_2 concentrations are already high within the bundle sheath cells of C_4 plants, elevated atmospheric CO_2 concentrations have limited benefit on the photosynthetic rates for C_4 species. The dry matter production of legumes improved by 24 % and that of C_3 grasses by 10 % under elevated concentrations of CO_2 (Ainsworth and Long 2005). Legume crops, belonging to the botanical family Fabaceae, may respond well to elevated CO_2 with increased photosynthesis and growth (Rogers et al. 2009). Under elevated CO_2 conditions, legumes may be able to shunt excess carbon to root nodules where it can serve as a carbon and energy source for the bacterial symbionts. In effect, legumes may be able to exchange the excess carbon for nitrogen and thereby maximize the benefits. In FACE experiments, soybean, a legume crop, has shown a greater response to elevated CO_2 than wheat and rice for photosynthesis and overall growth (Long et al. 2006). The effects of elevated CO_2 on plants can vary depending on other environmental factors like nutrient supply from the soil. Across studies using all types of CO_2 fumigation technologies, there is a lower enhancement of biomass production by elevated CO_2 under low-nutrient conditions (Poorter and Navas 2003). This effect is best documented with nitrogen. Crop yield in FACE experiments appears to be enhanced by elevated CO_2 to a lesser extent under low nitrogen than under high nitrogen (Ainsworth 2008). Since elevated CO_2 levels improve the water-use efficiency of crops, it may offer an advantage for the crops in regions with limited precipitation. However, the quantum of plant production response to elevated CO_2 concentrations will be determined by interactions among pasture type, soil moisture, and soil nutrient availability (Stokes and Ash 2007).

7.2.2 Elevated Carbon Dioxide Interactions with Other Factors

The supposed beneficial effect of elevated carbon dioxide on water-use efficiency thought to be an advantage for the crops in areas with limited precipitation is likely to be offset by high temperatures by increasing the crop water demand. When forage crops are grown on the soils having limited water holding capacity, due to higher water requirements induced by warming, the crop failures can happen despite improved water-use efficiencies. In the coming decades, crops and forage plants will continue to be subjected to warmer temperatures, elevated carbon dioxide, as well as more variable water availability due to changing precipitation patterns, and the interplay among these factors will decide the final impact on plant growth and yield. It has been widely reported that other environmental variables such as temperature, soil N and water content, atmospheric humidity, and solar radiation may interact with the CO_2 effect on plant yield (Ainsworth and Long 2005). Among these parameters, nitrogen availability is a critical factor, limiting plant growth and decreasing plant response to elevated CO_2 when nitrogen is scarce. At elevated CO_2 concentrations, a low supply of soil N could limit photosynthesis (Luo et al. 2004).

7.2.3 High Temperature

The major physiological effects of higher temperatures on plant growth are not easy to isolate but generally are associated with higher radiation levels and increased water use. The impacts are clearly dependent on the location. Rising temperatures may have either positive or negative effects on plant productivity, depending on the current climate regime and the availability of soil resources (Hatfield et al. 2011). The review of model projections by IPCC indicated that moderate warming in the first half of this century is likely to benefit crop and pasture yields in temperate regions but would cause yield declines in semiarid and tropical regions. At higher latitudes, rising temperatures are likely to prolong the growing season. This beneficial impact may be partially offset by lower light intensity and workability problems of soils in early spring or late autumn. Projected increases in temperature and the lengthening of the growing season should extend forage production into late fall and early spring, thereby decreasing the need for accumulation of forage reserves during the winter season in the USA (Izaurralde et al. 2011). Higher temperatures in lower latitudes may result in more water stress for plants, although higher temperatures in tropical highland areas may increase their suitability for cropping. It is highly likely (more than 90 % chance) that growing season temperatures by the end of the twenty-first century will exceed even the most extreme seasonal temperatures recorded from 1900 to 2006 for most of the tropics and subtropics (Battisti and Naylor 2009). High seasonally averaged temperatures will challenge crop production in the future, unless major adaptations are made. Above-optimal temperatures have been reported to induce severe damages to corn and soybean crops in the USA, leading to large potential negative impacts in the future (Schlenker and Roberts 2009). As corn and soybean are vital resources for the livestock and since the USA is a major player in the global export market for these commodities, the decline due to warming will seriously impact the productivity and profitability of animal agriculture. Like grain crops, the forage crops too have temperature thresholds, and these, together with the optimal ranges, differ among crops, cultivars of individual forage crop, and, also, among the crop developmental stages. As pollination is one of the most sensitive crop development stages to temperature, warmer temperatures at that period can greatly affect the yield. Similarly, higher nighttime temperatures during the grain filling stage of feed crops will reduce yields as well as quality. Higher temperatures can cause plants to mature and complete their stages of development faster, leading to less time for accumulation of sufficient dry matter and result in yield loss for grain crops as well as forage grasses. This impact was clearly recorded in southwestern France during the summer of 2003 when unusually higher temperatures shortened the life cycle of grasses, and seven forage regions out of ten had a production deficit of at least 25 % (Coret et al. 2005). They also reported the shortening of the maturity period of spring wheat resulting in a significant decrease of the seed yield (18 % less) and quality in addition to the reduction in quality and quantity of wheat straw. Similarly, maize crop matured fast due to warm and dry conditions leading to about 29 % decline in the grain yields. Global warming will increase crop water demand and also raise the rate of water use by crops. When crops are grown in soils with low water holding capacity, the risk of crop failure will increase considerably due to high temperature-induced crop water needs.

Tubiello et al. (2007) rightly pointed out that the conclusions like beneficial effects on crop yields in temperate regions corresponding to local mean temperature increases of 1–3 °C and associated CO_2 increases and rainfall changes due to the climate change are based on modeling studies which most often do not account adequately for the impacts of an increased climatic variability. Moreover, several key interactions are currently poorly described by crop and pasture models including (1) nonlinearity and threshold effects in response to extreme weather events; (2) modification of weed, insect, and disease incidence; (3) field response of crops to elevated CO_2 concentration; and (4) interactions of climate and management variables with elevated CO_2.

Increased temperatures increase lignification of plant tissues and therefore reduce the digestibility and the rates of degradation of plant species (Minson 1990). It will result in reduced nutrient availability for animals and ultimately leading to a reduction in livestock production affecting food security and incomes for smallholders (Thornton et al. 2007).

7.2.4 Changes in Precipitation

As water plays a vital role in plant growth, climate impacts on crops significantly depend on the precipitation scenario considered. Because over 80 % of total agricultural land and close to 100 % of pastureland are rain fed, general circulation model-projected changes in precipitation will often shape both the direction and magnitude of the overall impacts (Reilly et al. 2003). Water availability may play a major role in the response of pasturelands to climate change although there are differences in species response (Izaurralde et al. 2011). The fourth assessment report of IPCC pointed out that amplification of the hydrological cycle as a consequence of global warming can lead to more extreme intra-annual precipitation regimes characterized by larger rainfall events and longer intervals between events. More extreme rainfall regimes are expected to increase the duration and severity of soil water stress in mesic ecosystems as intervals between rainfall events increase (Knapp et al. 2008). Such prolonged dry spells and wide fluctuations in rainfall in the coming years will cause poor pasture growth and may also lead to a decline in fodder supplies from residues of agricultural crops. Changes in growing season rainfall in particular have been reported to be associated with declining richness in grass species (Wilkes 2008). Further, the changes in rainfall pattern due to climate change would influence the soil degradation processes such as erosion and salinity due to changes in runoff and drainage pattern (Howden et al. 2008).

At the same time, predicting regional responses of precipitation to anthropogenic greenhouse gases has proven a very difficult task, with leading climate models often disagreeing on the sign of precipitation change (Christensen and Christensen 2007). Changes in intensity, frequency, and seasonality of precipitation will impact the yield of forage crops.

Grassland and savanna productivity is highly sensitive to precipitation variability. In assessments of tallgrass prairie productivity, for example, increased rainfall variability was more significant than rainfall amount, with a 50 % increase in dry-spell duration causing a 10 % reduction in net primary productivity (Fay et al. 2003). The close correspondence between changes in seasonal mean rainfall and extreme rainfall events indicates that the contribution of high percentile rainfall events to seasonal rainfall is also likely to increase in future. In some of the European Union countries, during the summer of 2003, precipitation deficits up to 300 mm coupled with high temperatures reduced crop and pasture yields by 20–36 % in the affected regions, leading to huge uninsured economic losses estimated at 36 billion euros for the agriculture sector (IPCC 2007). Decrease in moderate precipitation can lengthen dry spells and increase the risk of drought because light and moderate precipitation is a critical source of soil moisture as well as groundwater. Increases in heavy precipitation can increase surface runoff and lead to intense floods leading to great impact on crop production. Lobell and Burke (2008) opined that due to climate change, the distribution of rainfall within growing seasons may change, with heavier but less frequent rainfall events in many regions, which could substantially change the relationship between growing season average precipitation and crop production. The impact of the prolonged dry spells translates into a significant decrease in the forage yield (Seligman and Sinclair 1995). Similarly, field flooding due to excess precipitation during the growing season causes yield losses due to low oxygen levels in the soil, increased susceptibility to root diseases, and increased soil compaction due to the use of heavy farm equipment on wet soils. Crops like maize and legumes are highly susceptible to flooding. Wet conditions at harvest time seriously impact the quality of many crops. Storms causing heavy rainfall are often accompanied by gusty winds. The combined force of strong gales and intense precipitation can completely flatten the crops, causing significant damage to the yield.

7.2.5 Elevated Ozone

Ozone is the most phytotoxic of the common air pollutants, and its widespread distribution presents a risk for considerable plant damage. Ozone is taken up by green leaves through stomata during photosynthesis, and its concentration significantly varies depending on geographic location, elevation, and extent of anthropogenic sources. Although ozone at low concentration is a normal component of the unmodified troposphere, background levels have doubled since preindustrial times due to anthropogenic emission of its precursors like carbon monoxide, volatile organic compounds, and oxides of nitrogen by vehicles, power plants, biomass burning, and other sources of combustion, with present average concentrations ranging from 20 to 45 nL/L (Vingarzan 2004). Ground-level ozone is formed when oxides of nitrogen emitted from the burning of fossil fuel interact with other compounds mentioned above, in the presence of sunlight. Visible foliar injury under ambient conditions is reported from more than 20 countries in Asia, Africa, Australia, Europe, and North and South America (Krupa et al. 2001). However, visible foliar ozone injury might not always be a reliable indicator of potential ozone effects on biomass production, yield, and product quality (Booker et al. 2009). More studies on ozone in recent years have increased the knowledge about response of crops to ozone, enabling better understanding of ozone-agriculture interactions under changing conditions of climate. Despite air quality regulations intended to limit ozone pollution, current ground-level ozone concentrations in a number of countries worldwide can suppress growth and yield of many agricultural plants (Mills et al. 2007). They also estimated that over 20 % of the crop production land in Europe in 2002 is at risk for yield losses of 5 % or more due to O_3 pollution, not considering effects on grasslands and changes in forage nutritive value. Climate models forecast that areas with the greatest production of peanut, rice, and soybean, namely, China, Japan, India, Central Africa, the USA, and Indonesia, will continue to experience phytotoxic concentrations of ground-level ozone in the coming 50 years

(Dentener et al. 2005). Ozone, after uptake through the leaf's stomata, interacts with plants' cellular processes, inhibiting photosynthesis, growth, and yield. Global estimates of yield losses due to increased ozone in soybean, wheat, and maize ranged from 8.5 to 14 %, 3.9 to 15 %, and 2.2 to 5.5 %, respectively, amounting to economic losses of $11–18 billion (Avnery et al. 2011). Gene expression and proteomic studies show that detrimental ozone effects are likely caused by a combination of chemical toxicity and plant-mediated responses that either amplify or inhibit injury (Cho et al. 2011). Research studies indicated that current ambient ozone levels are suppressing yields of important forage crops like alfalfa and clover in many regions of the world (Booker et al. 2009).

In addition to yield reduction, changes in leaf chemistry due to elevated ozone exposure in common grassland species have reduced nutritional quality of the pasture consumed by grazing animals. This loss of feed quality may be more significant than biomass losses in the assessment of ozone's effect on forages (Muntifering et al. 2000). In the case of perennial grasslands (pastures and rangelands), deleterious effects of ozone may develop over a longer period. A decline in relative feed value of high-yielding alfalfa in Alberta, Canada was strongly linked to ambient ozone concentrations, based on a multivariate analysis of air pollutant and meteorological data (Lin et al. 2007). Climate models suggest that episodes of high ground-level ozone concentrations will occur more frequently during the growing season in regions such as the northeastern USA and Southeast Asia due to increases in temperature and changes in atmospheric circulation patterns (Mickley et al. 2004). The interactive effects of ozone with other environmental factors such as CO_2, temperature, moisture, and light are important but not well understood. Booker et al. (2009) reported that rising levels of atmospheric carbon dioxide will likely ameliorate deleterious ozone effects on vegetation, although the converse is also true – ozone suppresses the potential carbon dioxide aerial fertilization effect in some plants as well. There is a great deal of variability in injury, yield, growth, and stomatal responses of crops to ozone, some as a result of inherent genetic variability and others due to variable growth conditions (Wilkinson et al. 2012).

7.2.6 Weeds

Elevated CO_2 concentrations disproportionately stimulate growth of weed species and can contribute to increased risk of crop loss due to higher competition for limited resources for growth. The weed pressure is likely to intensify due to climate change because of their hardy nature as compared to the forage crops. Ziska (2001) studied the effect of elevated carbon dioxide levels on sorghum and cocklebur, a common weed, and noticed that in competitive mixtures, plant relative yield in terms of aboveground biomass and leaf area increased significantly for cocklebur and decreased significantly for sorghum. He concluded that vegetative growth, competition, and potential yield of economically important C_4 crops could be reduced by co-occurring C_3 weeds as atmospheric carbon dioxide increases. Gilgen et al. (2010) compared the effects of summer drought on forages and *Rumex obtusifolius*, a troublesome weed in intensively managed grasslands, and noticed that the net assimilation rate reduced significantly in the crops but only marginally in the weed due to water deficit. They concluded that under a drier climate, a competitive advantage for such weeds will negatively impact forage composition and quality of grasslands. To limit such problems, additional weed management practices will be required.

7.2.7 Extreme Events

Extreme climatic events like heat waves, droughts, floods, cyclones, and heat waves have great impact on crops. Projected changes in the frequency and severity of extreme climatic events are expected to negatively impact crop yields and global food production. Advances in climate modeling provide the opportunity for utilizing global general circulation models at very high resolution for projections of future climate and extreme events. The timing of extreme events will be critical because they may occur at sensitive stages in the life cycle of forage crops. For example, extreme heat stress during the crop reproductive period, particularly at anthesis time, can adversely impact the crop productivity. Short-term natural extremes, such as storms and floods, interannual and decadal climate variations, as well as large-scale circulation changes, such as the El Nino Southern Oscillation, all have important effects on crop and pasture production (Tubiello 2005). More frequent extreme events may lower long-term yields by directly damaging crops at specific developmental stages, such as temperature thresholds during flowering, or by making the timing of field applications more difficult, thus reducing the efficiency of farm inputs (Antle et al. 2004). Extreme events could have major impacts on growth and productivity. For example, the most unusual summer heat wave of 2003 with temperatures up to 6 °C above long-term means and precipitation deficits up to 30 cm reduced crop and pasture yields by 20–36 % in the affected regions of Europe. This reduction was attributed to the combined effects of extreme high maximum temperatures, acute water deficits, and shorter growing season (Olesen and Bindi 2004). This severe heat wave caused significant reduction in phenological cycle of grass meadows as well as crops significantly in southwestern France. Climate models are limited in their ability to accurately project the occurrence and timing of individual extreme events. But the emerging patterns in the recent years point to the increased incidence of droughts and periods of more intense precipitation across the world. During the second half of this century, the occurrence of very hot nights and the duration of periods lacking agriculturally significant rainfall are projected to increase. Recent studies suggest that increased average temperatures and drier conditions will amplify future drought severity and temperature extremes.

Models of future climate not only project changes in mean climate but also changes in occurrence and characteristics of extreme events, thus increasing climate variability (Seneviratne et al. 2012). Rainfall is extremely important to agriculture, and historically, many of the biggest shortfalls in crop production have resulted from droughts caused by anomalously low precipitation (Sivakumar and Stefanski 2011). Duration and intensity of droughts have generally increased in the recent times. While regional droughts have occurred in the past, the widespread spatial extent of current droughts is broadly consistent with expected changes in the hydrologic cycle under global warming. In rangelands, each year's forage crop is produced by a new set of tillers that develops from buds located in the crown and on rhizomes or stolons. Reduced plant growth under drought conditions before the heading of grasses may reduce or eliminate formation of new buds. Extreme drought conditions will cause severe withering of tillers and rhizomes, leading to great decline in forage production and long-term degradation (Briske et al. 2005).

Rajendran et al. (2013) reported intensification of extreme rainfall over most parts of India by the end of the century, with opposite trend over the west coast for both heavy (above 95 percentile) and extreme (above 99 percentile) rainfall events. They also predicted that for the west coast of India, the increase in temperature, coupled with a significant decline in rainfall, will have drastic consequences on the production of crops. The impact of extreme events should be included in crop modeling approaches to prevent the risk of underestimating crop yield losses (Moriondo et al. 2011).

7.3 Impact of Environmental Stresses on Grasslands and Rangelands

Grasslands cover about 70 % of the world's agricultural area, and they face a wide range of challenges from climate change including the effects of elevated atmospheric carbon dioxide, higher temperatures, changes in precipitation regime, and increasing concentrations of ground-level ozone. These changes can adversely affect productivity, species composition, and quality, with potential impacts not only on forage production but also on other ecological roles of grasslands. The complex nature of grasslands and rangelands with multiple interacting perennial and annual plants as well as animal species makes it difficult to fully comprehend the response of these systems to global climate change. Hopkins and Del Prado (2007) compiled the possible scenarios in European grasslands due to the climate change, and the likely responses include increased herbage growth, increased use of forage legumes particularly white and red clover and alfalfa (Lucerne), reduced opportunities for grazing and harvesting on wetter soils, greater incidence of summer drought, and increased leaching from more winter rainfall. Carbon dioxide enrichment and global warming are predicted to increase net primary production on most temperate pastures and rangelands and slow canopy-level evapotranspiration due to reduced stomatal conductance, resulting in slower rate and extent of soil-water depletion (Baron and Belanger 2007). Sustained increase in mean temperatures results in significant changes in rangeland species distribution, composition, patterns, and biome distribution (Hanson et al. 1993). The grassland biodiversity is likely to be affected due to the climate change, and studies in the climate-sensitive sites like Qinghai-Tibet plateau have shown that the warming and drying trends have resulted in transition of highly productive alpine-adapted Kobresia communities to low-productive steppe Stipa communities (FAO 2009). Cullen et al. (2010) reported that for Eastern Australia, the subtropical and subhumid regions would experience warming with little change in annual rainfall and predicted an increased pasture production with an extended C_4 species growing season. Southern Australia would experience higher temperatures and reduced rainfall, leading to only small increases in production in the 2030 scenario but decreasing up to 19 % in the 2070 high scenario. Pasture production was reported to be more resilient to climate change in the cool temperate environment of northern Tasmania. Seo and Mc Carl (2011) reported that under the hotter and drier conditions anticipated for Australia, the landscape is most likely to change from croplands to pasture for livestock. However, the anticipated climate change will reduce the feed from grain production and, also, reduce forage quality. Some of the marginal pastoral ecosystems presently used for livestock production in Australia would potentially become less usable for grazing in the future. As the grazing lands are highly dependent on inherent environmental conditions, the warming effects on them differ across the countries or regions within a nation. For example, Seager and Vecchi (2010) reported that as water is already limiting in the Southwestern United States, rising temperature in combination with altered precipitation will increase droughts and, thus, negatively affect the grazing land productivity. On the contrary, in the northern Great Plains, where low temperatures can restrict the length of growing season, warmer temperatures alone or in combination with increased annual precipitation should increase forage production (Morgan et al. 2008). From CO_2 pulse-labeling experiments in intensively managed grassland of Switzerland, Burri et al. (2013) suggested that a spring drought preceding a summer drought might amplify the impact of summer drought on aboveground productivity as well as carbon allocation belowground, thereby increasing the sensitivity of grassland to consecutive or reoccurring drought. Such events are predicted under future climate conditions. In view of the likelihood of drier summers in Central Europe due to climate change, Bollig and Feller (2014) studied the effect of prolonged summer drought on grassland photosynthesis and concluded that net carbon dioxide assimilation reduced by drought in forbs/legumes, and the impact was much more in grasses.

Studies conducted in eight African countries by Dixon et al. (2003) concluded that average biomass for warm season increased, while there was a decrease for cool season forbs and legumes as optimal grassland conditions shifted from lower to higher latitudes contrary to other studies indicating a favorable response in forbs and legumes over grasses to increasing temperature. Further, they concluded that the impacts are likely to be small on livestock due to their ability to adjust feed intake and the increase in area for livestock production would be site dependent.

Studies by Baars et al. (1990) for New Zealand comparing the impact of climate change on grassland productivity for two cooler/wetter (Southland and Canterbury) and two warmer/drier (East coast and Waikato) sites revealed that the predicted pasture production in cooler regions would be substantially better in spring and autumn and unchanged in summer while for warmer sites improved autumn and winter growth with no change in spring and slight depression in production during summer. South Island sites annual production was predicted to increase by 20 %, while the North Island sites by 5 %, and onset of spring growth was predicted to advance by 2–4 weeks at all sites. IPCC summarized the overall impact of grasslands for different temperature ranges; an increase of 2 °C in humid temperate regions would have positive impacts on pasture and livestock productivity, while the impacts would be negative in arid and semiarid region.

In Europe, the summer heat waves and droughts observed during 2003 may increase by two orders of magnitude in the coming 40 years (Stott et al. 2004), leading to large fodder deficits ranging from 30 to 60 % in France (COPA COGECA 2003). As per the projections of the IPCC AR5, the warming in North America is expected to extend the growing season of forages however with decreased forage quality with variations due to changes in rainfall. The growing season would extend the forage production to late fall and early spring there by reducing the need for storing fodder during the winter (Izaurralde et al. 2011). Negative impacts on forage quality are projected for French grasslands (Graux et al. 2013) and sown pastures in Tasmania (Perring et al. 2010), while the legume content of grasslands in most of the Southern Australia is likely to increase by 2070 with larger increases in wetter locations (Moore and Gharamani 2013).

An elevated carbon dioxide level alters plant community structure in the grasslands and replaces the preferred forage of livestock. A hypothesis has been advanced by researchers that the incursion of woody plants like shrubs into world grasslands over the past two centuries has been driven in part by increasing carbon dioxide concentration as the woody plants have a photosynthetic metabolism and carbon allocation patterns that are responsive to CO_2, and many have tap roots that are more effective than forage grasses for reaching deep soil water stores in the grasslands giving them competitive edge over the warm season forage grasses that they are displacing. This theory was proven by Morgan et al. (2007) from a 5-year study in a Colorado shortgrass steppe, where a doubling of carbon dioxide resulted in about 40-fold increase in aboveground biomass and a 20-fold increase in plant cover of *Artemisia*, a common shrub of some North American and Asian grasslands.

A recent study that looked at 1,350 European species in terms of their distribution envelopes projected that half of these species will become classified as vulnerable or endangered by 2080 because of rising temperatures and precipitation shifts (IPCC 2007). Additionally, thermal stress in livestock may lead to reduced eating and grazing activity (Morand-Fehr and Doreau 2001) affecting productivity. Climatic factors by itself or in interaction with other factors can limit animal performance (King et al. 2005). Climate extremes may thus affect directly and indirectly grazing systems by altering physiology and behavior of animals and pasture biomass through affects on the productivity, seasonality, and quality of pasture (Tubiello et al. 2007).

7.4 Impact of Climate Change on Water Availability and Irrigation Needs

The agricultural sector is the largest user of freshwater resources, accounting for over 70 % of water use. In general, the crop yields are more sensitive to the precipitation than temperature. Climate changes increase irrigation demand in the majority of world regions due to combination of decreased rainfall and increased evaporation arising from increased temperatures. Higher temperatures and uncertain rainfall will affect the soil moisture status and groundwater levels, thereby impacting the crop yields. Due to increasing temperatures and fluctuating precipitation, crop production will decrease in the future due to diminished water availability from reduced stream flows, dried-up reservoirs, and steeply dropping groundwater levels. High temperatures coupled with low precipitation may push irrigation systems to their limits or beyond, so that drought stress occurs even when the system is operating at full capacity. When water supplies are restricted, the impacts on forage production become more severe. With the changes in soil evaporation and plant transpiration due to climate change, the water-use efficiency may decrease in the future (Kang et al. 2009). The increasing temperature further aggravates the water supply needs of the crops, especially in drier regions of the globe. For example, the demand for agricultural irrigation in arid and semiarid regions of Asia is estimated to increase by at least 10 % for an increase in temperature of 1 °C (Liu 2002).

7.5 Adaptation Strategies

There have been many studies of crop adaptation. Overall, these studies indicate that with proper adaptations to climate change, substantial benefits are possible. Most studies have assessed key farm-level adaptations such as changing planting dates and associated decisions to match evolving growing seasons and improving cultivar tolerance to high temperature, drought conditions, and elevated CO_2 levels.

Other adaptations include matching stocking rates with pasture production, adjusting herd and water point management to altered seasonal and spatial patterns of forage production, managing diet quality (using diet supplements, legumes, choice of introduced pasture species, and pasture fertility management), more effective use of silage, pasture seeding and rotation, fire management to control woody thickening, using more suitable livestock breeds or species, migratory pastoralist activities, and a wide range of biosecurity activities to monitor and manage the spread of pests, weeds, and diseases (Nardone et al. 2010). Combining adaptations can result in substantial increases in benefits in terms of production and profit when compared with single adaptations. Technological developments like new forage varieties with increased tolerance to temperature extremes as well as moisture deficits, better forecasting of seasonal weather conditions, and efficient water management methods help in the process of adaptation to the climate change. The timing of farm operations needs to be adjusted to cope with the seasonal vagaries and associated changes in moisture and temperature. The options for supplemental irrigation have to be explored to overcome increased likelihood of moisture deficits and recurring droughts. Diversification of farm production using different types and varieties of forage crops and livestock helps to meet the challenges posed by environmental variations and the resulting economic risks. Similarly, diversification of household income and investing in crop insurance policies can tackle the projected income losses due to the climate change. The governments should take a proactive role by extending support to the farmers with programs related to crop subsidy and by designing innovative crop insurance schemes with active role for private insurance agencies for better adaptation.

7.6 Climate Change and Pastoralists: Policy Implications

Pastoralists' livelihoods are linked to the area and productivity of the pastures, rangelands, and grasslands and are an important source of livestock products. Growing demand for livestock products and the shrinking grazing resources are putting pressure on the pastoralist. This would be further aggravated due to the impact of the climate change that is likely to alter the number, distribution, and productivity of pastures and water points that are likely to decline in dry seasons for affecting the survival of livestock. Diminishing resources and population pressure are likely to lead to stronger competition between pastoral communities and other groups for the scarce resources leading to conflicts and loss of livelihoods (Hesse and Cotula 2006). There is a need for appreciating the rationale for pastoralism, and policy support includes enabling herd mobility securing rights to critical resources, better water access and livelihood diversification, building conflict management institutions and drought mitigation systems with early forecast and safety nets, capacity strengthening of pastoralist group to engage on policy issues, and financial support from developed countries (Hesse and Cotula 2006).

7.7 Conclusions

The complex nature of pasturelands and rangelands with multiple interacting perennial and annual plants as well as animal species makes it difficult to fully comprehend the response of these systems to global climate change. Integrating grain crops with pasture plants and livestock could result in a more diversified system that will be more resilient to higher temperatures, elevated carbon dioxide levels, uncertain precipitation changes, and other dramatic effects resulting from the global climate change. Such integrated systems have a greater possibility to stay productive in an increasingly variable climate as well as retain greater biological diversity. Keeping a close watch on the quality of forage crops is essential for taking better management decisions to ensure optimum livestock productivity under changing climate. Even without the climate change-induced effects on agriculture and livestock, the present livestock production systems are already under pressure to produce more to cater to the growing demands against the shrinking resources for feed resources. The present production systems are undergoing a major transformation in terms of intensification shifting of pastoralist to mixed crop livestock systems, subsistence to commercial production, and greater reliance on better inputs in terms of breeds, feed, and management. With the likely emerging scenarios that are already evident from impact of the climate change effects, the livestock production systems are likely to face more of negative than the positive impact. Hence, additional safeguards for the climate change need to be built to ensure that current livestock production systems are oriented not only to achieve the desired resilience but remain sustainable and significantly contribute to the food security.

References

Ainsworth EA (2008) Rice production in a changing climate: a meta-analysis of responses to elevated carbon dioxide and elevated ozone concentrations. Glob Change Biol 14:1642–1650

Ainsworth EA, Long SP (2005) What have we learned from 15 years of free air CO_2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO_2. New Phytol 165:351–372

Ainsworth EA, Rogers A (2007) The response of photosynthesis and stomatal conductance to rising [CO_2]: mechanisms and environmental interactions. Plant Cell Environ 30:258–270

Antle JM, Capalbo SM, Elliott ET, Paustian KH (2004) Adaptation, spatial heterogeneity, and the vulnerability of agricultural systems to climate change and CO_2 fertilization: an integrated assessment approach. Clim Change 64:289–315

Avnery S, Mauzerall DL, Liu J, Horowitz LW (2011) Global crop yield reductions due to surface ozone exposure: 1. Year 2000 crop production losses and economic damage. Atmos Environ 45:2284–2296

Baars JF, Radcliffe JE, Rollo MD (1990) Climatic change effects on seasonal patterns of pasture production in New Zealand. Proc N Z Grassl Assoc 51:43–46

Barnes RF, Baylor J (1994) Forages in a changing world. In: Barnes RF, Miller DA, Nelson CJ (eds) Forages, vol 1. An introduction to grassland agriculture, 5th edn. Iowa State University Press, Ames, pp 3–13

Baron VS, Belanger G (2007) Climate and forage adaptation. In: Barnes RF, Nelson CJ, Moore KJ, Collins M (eds) Forages: the science of grassland agriculture. Blackwell, Ames, pp 83–104

Battisti DS, Naylor RL (2009) Historical warnings of future food insecurity with unprecedented seasonal heat. Science 323:240–244

Bollig C, Feller U (2014) Impacts of drought stress on water relations and carbon assimilation in grassland species at different altitudes. Agric Ecosyst Environ 188:212–220

Booker F, Muntifering R, McGrath M, Burkey K, Decoteau D, Fiscus E, Manning W, Krupa S, Chappelka A, Grantz D (2009) The ozone component of global change: potential effects on agriculture and horticultural plant yield, product quality and interactions with invasive species. J Integr Plant Biol 51:337–351

Briske DD, Fuhlendor SD, Smeins EE (2005) State-and-transition models, thresholds, and rangeland health: a synthesis of ecological concepts and perspectives. Rangel Ecol Manag 58:1–10

Burri S, Sturm P, Prechsl UE, Knohl A, Buchmann N (2013) The impact of extreme summer drought on the short-term carbon coupling of photosynthesis to soil CO_2 efflux in a temperate grassland. Biogeosci Discuss 10(7):11671

CBD/UNEP/IUCN (2007) Biodiversity and climate change. Montreal Center, Bogor

Cho K, Tiwari S, Agrawal SB, Torres NL, Agrawal M, Sarkar A, Shibato J, Agrawal GK, Kubo A, Rakwal R (2011) Tropospheric ozone and plants: absorption, responses, and consequences. Rev Environ Contam Toxicol 212:61–111

Christensen JH, Christensen OB (2007) A summary of the PRUDENCE model projections of changes in European climate by the end of this century. Clim Change 81:7–30

COPA COGECA (2003) Assessment of the impact of the heat wave and drought of the summer 2003 on agriculture and forestry. Committee of Agricultural Organisations in the European Union and General Committee for Agricultural Cooperation in the European Union, Brussels, p 15

Coret L, Maisongrande P, Boone A, Lobo A, Dedieu G, Gouaux P (2005) Assessing the impacts of the 2003 hot and dry spell with SPOT HRVIR images time series over southwestern France. Int J Remote Sens 26:2461–2469

Cubasch U, Wuebbles D, Chen D, Facchini MC, Frame D, Mahowald N, Winthe J-G (2013) The physical science basis. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Contribution of Working Group I to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York

Cullen BR, Johnson IR, Eckard RJ, Lodge GM, Walker RG, Rawnsley RP, McCaskill MR (2010) Climate change effects on pasture systems in south-eastern Australia. Crop Pasture Sci CSIRO Publication Open access article 60(10)

Dentener F, Stevenson D, Cofala J, Mechler R, Amann M, Bergamaschi P, Raes F, Derwent R (2005) The impact of air pollutant and methane emission controls on tropospheric ozone and radiative forcing: CTM calculations for the period 1990–2030. Atmos Chem Phys 5:1731–1755

Dixon RK, Smith J, Guill S (2003) Life on the edge: vulnerability and adaptation of African ecosystems to global climate change. Mitig Adapt Strateg Glob Change 8:93–113

Dregne H, Kassa M, Rzanov B (1991) A new assessment of the world status of desertification. Desertification Control Bull 20:6–18

FAO (2009) Implications and opportunities for mitigation and adaptation. FAO, Rome

FAO/LEAD (2006) Livestock’s long shadow. Environmental issues and options. FAO, Rome

Fay PA, Carlisle JD, Knapp AK, Blair JM, Collins SL (2003) Productivity responses to altered rainfall patterns in a C_4-dominated grassland. Oecologia 137:245–251

Gilgen AK, Signarbieux C, Feller U, Buchmann N (2010) Competitive advantage of Rumex obtusifolius L. might increase in intensively managed temperate grasslands under drier climate. Agric Ecosyst Environ 135:15–23

Graux A, Bellocchi G, Lardy R, Soussana J (2013) Ensemble modelling of climate change risks and opportunities for managed grasslands in France. Agric For Meteorol 170:114–131

Hanson JD, Baker BB, Bourdon RM (1993) Comparison of the effects of different climate change scenarios on rangeland livestock production. Agric Syst 41:487–502

Hatfield JL, Boote KJ, Kimball BA, Ziska LH, Izaurralde RC, Ort D, Thomson AM, Wolfe D (2011) Climate impacts on agriculture: implications for crop production. Agron J 103:351–370

Hesse C, Cotula L (2006) Climate change and pastoralists: Investing in people to respond to adversity. Sustainable development opinion. Published by the International Institute for Environment and Development (IIED)

Hopkins A, Del Prado A (2007) Implications of climate change for grassland in Europe: impacts, adaptations and mitigation options: a review. Grass Forage Sci 62:118–126

Howden SM, Crimp SJ, Stokes CJ (2008) Climate change and Australian livestock systems: impacts, research and policy issues. Aust J Exp Agric 48:780–788

IPCC (2007) In: Parry KL, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability: contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge

IPCC AR5 (2014) IPCC fifth assessment report. www.ipcc.ch/news_and_events/press_information.shtml

Izaurralde RC, Thomson AM, Morgan JA, Fay PB, Polley HW, Hatfield JL (2011) Climate impacts on agriculture: implications for forage and rangeland production. Agron J 103(2):371–381

Kang YS, Khan S, Ma X (2009) Climate change impacts on crop yield, crop water productivity, and food security – a review. Prog Nat Sci 19:1665–1674

King JM, Parsons DJ, Turnpenny JR, Nyangaga J, Bakari P, Wathes CM (2005) Ceiling to milk yield on Kenya smallholdings requires rethink of dairy development policy. In: British society of animal science annual conference, New York

Knapp AK, Beier C, Briske DD, Classen AT, Luo Y, Reichstein M, Smith MD, Smith SD, Bell JE, Fay PA, Heisler JL, Leavitt SW, Sherry R, Smith B, Weng E (2008) Consequences of more extreme precipitation regimes for terrestrial ecosystems. Bioscience 58:811–821

Krupa S, McGrath MT, Andersen C, Booker FL, Burkey K, Chappelka A, Chevone B, Pell E, Zilinskas B

(2001) Ambient ozone and plant health. Plant Dis 85:4–17

Lin JC, Nosal M, Muntifering RB, Krupa SV (2007) Alfalfa nutritive quality for ruminant livestock as influenced by ambient air quality in west-central Alberta. Environ Pollut 149:99–103

Liu CZ (2002) Suggestions on water resources in China corresponding with global climate change. China Water Resour 2:36–37

Lobell DB, Burke MB (2008) Why are agricultural impacts of climate change so uncertain? The importance of temperature relative to precipitation. Environ Res Lett 3:034007

Long SP, Ainsworth EA, Leakey ADB, Ort DR (2006) Food for thought: lower-than-expected crop yield stimulation with rising CO_2 conditions. Science 312:1918–1921

Luo Y, Su B, Currie WS, Dukes JS, Finzi A, Hartwig U, Hungate B, McMurtrie RE, Oren R, Parton WJ, Pataki DE, Shaw MR, Zak DR, Field CB (2004) Progressive nitrogen limitation of ecosystem responses to rising atmospheric carbon dioxide. Bioscience 54:731–7399

Mickley LJ, Jacob DJ, Field BD, Rind D (2004) Effects of future climate change on regional air pollution episodes in the United States. Geophys Res Lett 31:24

Mills G, Buse A, Gimeno B, Bermejo V, Holland M, Emberson L, Pleijel H (2007) A synthesis of AOT40-based response functions and critical levels of ozone for agricultural and horticultural crops. Atmos Environ 41:2630–2643

Minson DJ (1990) Forage in ruminant nutrition. Academic, New York

Moore AD, Gharamani A (2013) Climate change and broadacre livestock production across southern Australia: II. Impacts of climate change on pasture and livestock productivity, and on sustainable level of profitability. Glob Change Biol 19:1440–1455

Morand-Fehr P, Doreau M (2001) Ingestion et digestion chez les ruminants soumis a un stress de chaleur. INRA Prod Anim 14:159–227

Morgan JA, Milchunas DG, LeCain DR, West M, Mosier AR (2007) Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the short grass steppe. Proc Natl Acad Sci 104:14724–14729

Morgan JA, Derner JD, Milchunas DG, Pendall E (2008) Management implications of global change for Great Plains rangelands. Rangelands 30:18–22

Moriondo M, Giannakopoulos C, Bindi M (2011) Climate change impact assessment: the role of climate extremes in crop yield simulation. Clim Change 104:679–701

Muntifering RB, Crosby DD, Powell MC, Chappelka AH (2000) Yield and quality characteristics of bahiagrass (Paspalum notatum) exposed to ground-level ozone. Anim Feed Sci Technol 84:243–256

Nardone A, Ronchi B, Lacetera N, Raniere MS, Bernabucci U (2010) Effects of climate change on animal production and sustainability of livestock systems. Livest Sci 130:57–69

Nori M, Switzer J, Crawford A (2005) Herding on the brink: towards a global survey of on environmental, economic and social policy. Gland, Switzerland. Available at www.iisd.org/publications/pub.aspx?id=705

Olesen JE, Bindi M (2004) Agricultural impacts and adaptations to climate change in Europe. Farm Policy J 1:36–46

Parry ML, Arnell NW, McMichael AJ, Nicholls RJ, Martens P, Kovats RS, Livermore MTJ, Rosenzweig C, Iglesias A, Fischer G (2001) Millions at risk: defining critical climate change threats and targets. Glob Environ Change 11:181–183

Perring MP, Cullen BR, Johnson IR, Hovenden MJ (2010) Modelled effects of rising CO_2 concentration and climate change on native perennial grass and sown grass-legume pastures. Clim Res 42:65–78

Poorter H, Navas ML (2003) Plant growth and competition at elevated CO_2: on winners, losers and functional groups. New Phytol 157:175–198

Rajendran K, Sajani S, Jayasankar CB, Kitoh A (2013) How dependent is climate change projection of Indian summer monsoon rainfall and extreme events on model resolution? Curr Sci 104:1409–1418

Reilly J, Tubiello FN, McCarl B, Abler D, Darwin R, Fuglie K, Hollinger S, Izaurralde C, Jagtap S, Jones J, Mearns L, Ojima D, Paul E, Paustian K, Riha S, Rosenberg N, Rosenzweig C (2003) U.S. agriculture and climate change: new results. Clim Change 57:43–69

Rogers A, Ainsworth EA, Leakey ADB (2009) Will elevated carbon dioxide concentration amplify benefits of nitrogen fixation in legumes? Plant Physiol 151:1009–1016

Rötter R, Van de Geijn SC (1999) Climate change effects on plant growth, crop yield and livestock. Clim Change 43:651–681

Safriel U, Adeel Z, Niemeijer D, Puigdefabres J, White R, Lal R, Winslow M, Ziedler J, Prince S, Archer E, King C (2005) Dryland systems. In: Hassan R, Scholes R, Ash N (eds) Ecosystems and human well-being: current state and trends, vol 1. Island Press, Washington/Covelo/London, pp 623–662

Schlenker W, Lobell DB (2010) Robust negative impacts of climate change on African agriculture. Environ Res Lett 5:014010

Schlenker WM, Roberts J (2009) Non-linear temperature effects indicate severe damages to U.S. crop yields under climate change. Proc Natl Acad Sci 106:15594–15598

Seager R, Vecchi GA (2010) Greenhouse warming and the 21st century hydroclimate of southwestern North America. Proc Natl Acad Sci 107:21277–21282

Seligman NG, Sinclair TR (1995) Global environment change and simulated forage quality of wheat, II: water and nitrogen stress. Field Crop Res 40:29–37

Seneviratne SI, Nicholls N, Easterling D, Goodess CM, Kanae S, Kossin J, Luo Y, Marengo J, McInnes K, Rahimi M, Reichstein M, Sorteberg A, Vera C, Zhang X (2012) Changes in climate extremes and their impacts on the natural physical environment. In: Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation field, CB: a special report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, New York, pp 109–230

Seo SN, McCarl B (2011) Managing livestock species under climate change in Australia. Animals 1:343–365

Sivakumar MV, Stefanski R (2011) Climate change in South Asia. In: Lal R, Sivakumar MVK, Faiz SMA, Mustafizur Rahman AHM, Islam KR (eds) Climate change and food security in South Asia. Springer, Dordrecht, pp 13–30

Stokes C, Ash A (2007) Impacts of climate change on marginal tropical animal production systems. In: Newton PCD, Carran RA, Edwards GR, Niklaus PA (eds) Agroecosystems in a changing climate. CRC Press, Boca Raton, pp 323–328

Stott PA, Kettleborough J, Allen MR (2004) Human contribution to the European heatwave of 2003. Nature 432:610–613

Taub D (2010) Effects of rising atmospheric concentrations of carbon dioxide on plants. Nat Educ Knowl 3:21

Thornton P, Herrero M, Freeman A, Mwai O, Rege E, Jones P, McDermott J (2007) Vulnerability, climate change and livestock – research opportunities and challenges for poverty alleviation. SAT eJ 4:1–23

Tubiello FN (2005) Climate variability and agriculture: perspectives on current and future challenges. In: Knight B (ed) Impact of climate change, variability and weather fluctuations on crops and their produce markets. Impact reports, Cambridge, pp 45–63

Tubiello FN, Soussana JF, Howden SM (2007) Crop and pasture response to climate change. Proc Natl Acad Sci 104:19686–19690

Vingarzan R (2004) A review of surface ozone background levels and trends. Atmos Environ 38:3431–3442

Wilkes A (2008) Towards mainstreaming climate change in grassland management: policies and practices on the Tibetan Plateau. Working paper no. 67, World Agroforestry Centre ICRAF, China, p 43

Wilkinson S, Mills G, Illidge R, Davies WJ (2012) How is ozone pollution reducing our food supply? J Exp Bot 63:527–536

Ziska LH (2001) Changes in competitive ability between a C_4 crop and a C_3 weed with elevated carbon dioxide. Weed Sci 49:622–627

Ziska LH, Bunce JA (2007) Predicting the impact of changing CO_2 on crop yields: some thoughts on food. New Phytol 175:607–618

Impact of Climate Change on Livestock Disease Occurrences

8

Serge Morand

Abstract

The first objective of this chapter is to review how climate change and climate variability may affect livestock diseases' occurrences while emphasizing how little the knowledge on the links between livestock diseases and climate change is. The review of the literature shows that most of the investigated diseases are zoonotic ones with few specific to livestock and, moreover, these diseases appeared to be dramatically affected by climate variability rather than by ongoing climate change. A second objective of this chapter is to introduce some new modelling tools that can help predict diseases' occurrences in space and in time in relation to climate variability and change, namely, environmental niche modelling, epidemiological modelling using R_0 map and teleconnection modelling. A working example on cattle trypanosomiasis in China is given to illustrate teleconnection modelling by using data from the World Organization for Animal Health (OIE). The conclusion of this chapter stresses three points: the need to consider the entangled linkages between ecosystems, society and health of animals and humans; the need of elaborated scenarios of livestock diseases linked to climate change and variability, which necessitates to develop and improve the recording of livestock diseases; and the need to incorporate climate-mediated physiological responses into the programs that manage breeding genetic diversity.

Keywords

Climate variability • El Niño Southern Oscillation • Environmental niche modelling • Zoonotic diseases • Teleconnection epidemiology

---

S. Morand (✉)
Department Environment and Societies,
CNRS-CIRAD AGIRs, Centre d'Infectiologie
Christophe Mérieux du Laos, Vientiane, Lao PDR
e-mail: serge.morand@univ-montp2.fr

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_8, © Springer India 2015

8.1 Introduction

Numerous studies have investigated the links between infectious diseases and climate factors such as temperature or rainfall (Baylis and Morse 2012). Many reviews have stressed that any significant change in climate will impact infectious diseases as the routes of infectious transmission will be affected (Altizer et al. 2013) although the evidence other than modelling studies is still scarce (de la Rocque et al. 2008; Morand and Guégan 2008; Lafferty 2009). Moreover, several studies pointed out the importance of climate variability on the epidemics of infectious diseases (Anyamba et al. 2012; Morand et al. 2013).

Baylis and Morse (2012) reviewed the literature on this subject and pointed out that the effects of climate change were mostly focused on human health and vector-borne diseases (Wittmann and Baylis 2000; Kovats et al. 2001; Harvell et al. 2002; Hay et al. 2002; Patz and Kovats 2002; Randolph 2004; Reiter et al. 2004; Zell 2004; Rogers and Randolph 2006; Semenza and Menne 2009), whereas the effects on animal diseases and particularly livestock had received far less attention (Cook 1992; Harvell et al. 2002; de la Rocque et al. 2008; Gale et al. 2008, 2009; McIntyre et al. 2010; Guis et al. 2011). Moreover, most of these studies concern zoonotic diseases, while few have specifically focused on livestock diseases (Guis et al. 2011).

The first objective of this chapter is to emphasize why climate change and climate variability may affect livestock diseases' occurrences, although this brief review shows how little is the knowledge on the links between livestock diseases and climate change. A second objective is to briefly introduce the new modelling tools that can help predict diseases' occurrences in space and in time in relation to climate variability and change.

8.2 Why Climate Change Should Affect Disease Occurrences

Obviously, the attribution of disease occurrences to climate change needs to be confirmed with changes in both disease and climate at the same time and in the same place (Rogers and Randolph 2003). Although statistical congruence between pathogens and climatic shifts has been repeatedly reported (Paz et al. 2007; Pascual et al. 2008, 2009), these many reviews hide the fact that there are still few evidences of the impact of climate change on infectious disease incidence (Lafferty 2009). The reason lies probably in the difficulty to attribute any change in disease occurrence to climate change only rather than to other drivers (in combination or not with climate change). Some authors have emphasized that most climate drivers are unknown for the majority of infectious diseases (Harvell et al. 2007), which renders any quantification difficult, and others have underlined that causal links between climate drivers and disease are not simple (Martens 2002) as many of the climate-linked factors will interact with each other (Gale et al. 2009).

Two examples concerning human health and wildlife health may illustrate the difficulty of finding a simple causal link between disease spread and climate change. The first one concerns malaria, which has decreased consistently in the tropics over the last 100 years, but for which temperature or rainfall observed changes do not seem to explain alone this reduction (Gething et al. 2010). Indeed, change in drivers other than climate seems to have played far more dominant roles in reducing malaria occurrence than the role climate change may have played in increasing it. If in the highlands of Eastern Africa rates of malaria had increased, yet again regional climate change is just one explanation, along with changes in patterns of land use, population movements, increased urban poverty, a decline in the use of pesticides for mosquito control, agricultural practices such as irrigation, public health programmes (e.g. monitoring and treatment), the rise of resistance to antimalarial drugs by the parasite or changes in the socio-economic status of the population (Hales and Woodward 2003; Martens 2002; McMichael and Woodruff 2005). In such cases, the relative importance of climate change versus that of other drivers is difficult to determine and is case dependent (Cohen 2000; McMichael 2004; Patz 2002; Semenza and Menne 2009; Sutherst 2004).

The second well-studied case concerns the extinction of endemic anurans in Costa Rica linked to the emergence of pathogenic chytrid fungi. The emergence of the fungi was hypothesized to be due to global warming (Pounds et al. 2006), but the potential link between global warming and amphibian extinction was challenged by Lips et al. (2008). Although statistical reinvestigations of the data confirmed the positive multi-decade correlation between extinctions and mean tropical air temperature in the previous year, the direct causal link between climate change and the fungi emergence seems to be very weak. Indeed, Rohr et al. (2008) found numerous other variables, such as regional banana and beer production, as better predictors of these extinctions than climate factors. Finally the authors concluded by “Although climate change is likely to play an important role in worldwide amphibian declines, more convincing evidence is needed of a causal link.”

Climate change is mostly hypothesized to influence the geographic distribution of pathogens and/or vectors (Rosenthal 2009). A documented case of climate change-related geographic distribution concerns the protist *Perkinsus marinus* parasitizing oyster. The northward movement of the parasite along the Atlantic coast of North America was associated with increasing surface waters (Cook et al. 1998; Harvell et al. 2009).

Concerning livestock and poultry diseases, few studies have been done. Bluetongue disease, vector-borne viral disease of ruminants, was confined to southern Europe along the Mediterranean. The increasingly warm weather since 1998 has favoured midges that carry the virus to move towards northern Europe (Purse et al. 2005).

The effects of climate factors on the transmission and outbreaks of several animal infectious diseases are summarized in Table 8.1. Most diseases concern viruses and few bacteria and parasites (protist or helminths), and half of them involve vectors: African horse sickness, Rift Valley fever, bluetongue, Japanese encephalitis, trypanosomiasis, trichinosis and fasciolosis.

Some of these diseases are affected by humidity and cold or hot weather. However, most of them seem to be dramatically affected by climate variability (see below). Moreover, several of these diseases are zoonotic—avian influenza, Rift Valley fever, Japanese encephalitis, anthrax, trichinosis and fasciolosis—while relatively few are restricted to livestock and poultries: foot-and-mouth disease, peste des petits ruminants, rinderpest, Newcastle disease, African horse sickness, bluetongue, animal trypanosomiasis, haemonchosis and other strongyloidiasis.

8.3 Why Climate Variability Matters

Outbreaks of several infectious diseases, mostly vector-borne ones, have been linked to the occurrence of ENSO (El Niño Southern Oscillation) (Baylis et al. 1999; Kovats 2000; Gagnon et al. 2001, 2002; Anyamba et al. 2002) or to the NAO (Hubálek 2005; Morand et al. 2013). The outbreaks of vector-borne diseases are the consequences of the increase in the vector population size in response to heavy rainfalls associated with ENSO (Baylis et al. 1999; Anyamba et al. 2002, 2012).

Baylis et al. (1999) investigated the links between African horse sickness (AHS), one of the most lethal infectious horse disease (with mortality rates up to 95%), in South Africa where major epizootics of this viral disease occurred every 10–15 years. They found a strong association between the timing of epizootics of this disease and the warm (El Niño) phase of the El Niño Southern Oscillation (ENSO) and proposed that this association is mediated by the combination of rainfall and drought brought to South Africa by ENSO.

Here, we show with a working example (Fig. 8.1) how climate variability can affect the incidence of cattle trypanosomiasis in China. For this, we used the data on trypanosomiasis occur-

Table 8.1 Effects of climate factors on the transmission and outbreaks of several animal infectious diseases

Disease	Agents/transmission	Zoonotic	Climate factors	References
Foot-and-mouth disease (FMD)	Virus, direct	No	Wind-borne spread is favoured by the humid, cold weather in temperate regions	Donaldson (1972)
Peste des petits ruminants (PPR)	Virus, direct	No	Outbreaks associated with the onset of the rainy season or dry cold periods	Wosu et al. (1992)
Rinderpest	Virus, direct	No	Virus survives best at low or high relative humidity	Anderson et al. (1996)
Newcastle disease (ND)	Virus, direct	No	Wet and cold period favours survival and spread of the virus	Band-Bo et al. (2013)
Avian influenza (AIV)	Virus, direct	Yes	Wet and cold period favours survival and spread of the virus	Brown et al. (2007)
African horse sickness (AHS)	Virus, transmitted by *Culicoides* biting midges	No	Outbreaks associated with the combination of drought and heavy rainfall during the El Niño Southern Oscillation (ENSO)	Baylis et al. (1999)
Rift Valley fever (RVF)	Virus, transmitted by *Aedes* and *Culex* mosquitoes	Yes	Epizootics associated with periods of heavy rainfall and flooding or with the combination of heavy rainfall following drought associated with ENSO	Davies et al. (1985), Linthicum et al. (1987, 1999), Anyamba et al. (2002), and Martin et al. (2008)
Bluetongue	Virus, transmitted by *Culicoides* biting midges	No	Temperature	Guis et al. (2011)
Japanese encephalitis	Virus, transmitted by *Culex* mosquitoes	Yes	Temperature, precipitation	Hsu et al. (2008)
Anthrax	*Bacillus anthracis*, direct (soil)	Yes	Outbreaks with alternating heavy rainfall and drought and high temperatures	Parker et al. (2002)
Animal trypanosomiasis	Protist, transmitted by tsetse flies	No	Tsetse flies vectors sensitive to climate	Rogers and Packer (1993)
Haemonchosis and other strongyloidiases	Nematode, direct (soil)	No	Nematode larvae can survive for months under warmth and moderate humidity conditions	Baylis and Morse (2012) and Fox et al. (2012)
Trichinosis	Nematode, food-borne (reservoirs)	Yes	Warmer temperatures and longer summers increase the number of amplification cycles for parasites and lead to longer summer hunting seasons in Arctic regions	Greer et al. (2008)
Fasciolosis	Trematode, transmitted by aquatic snails	Yes	Areas subject to periodic flooding that favour intermediate snail host	Hall (1988)

Completed from Baylis and Morse (2012)

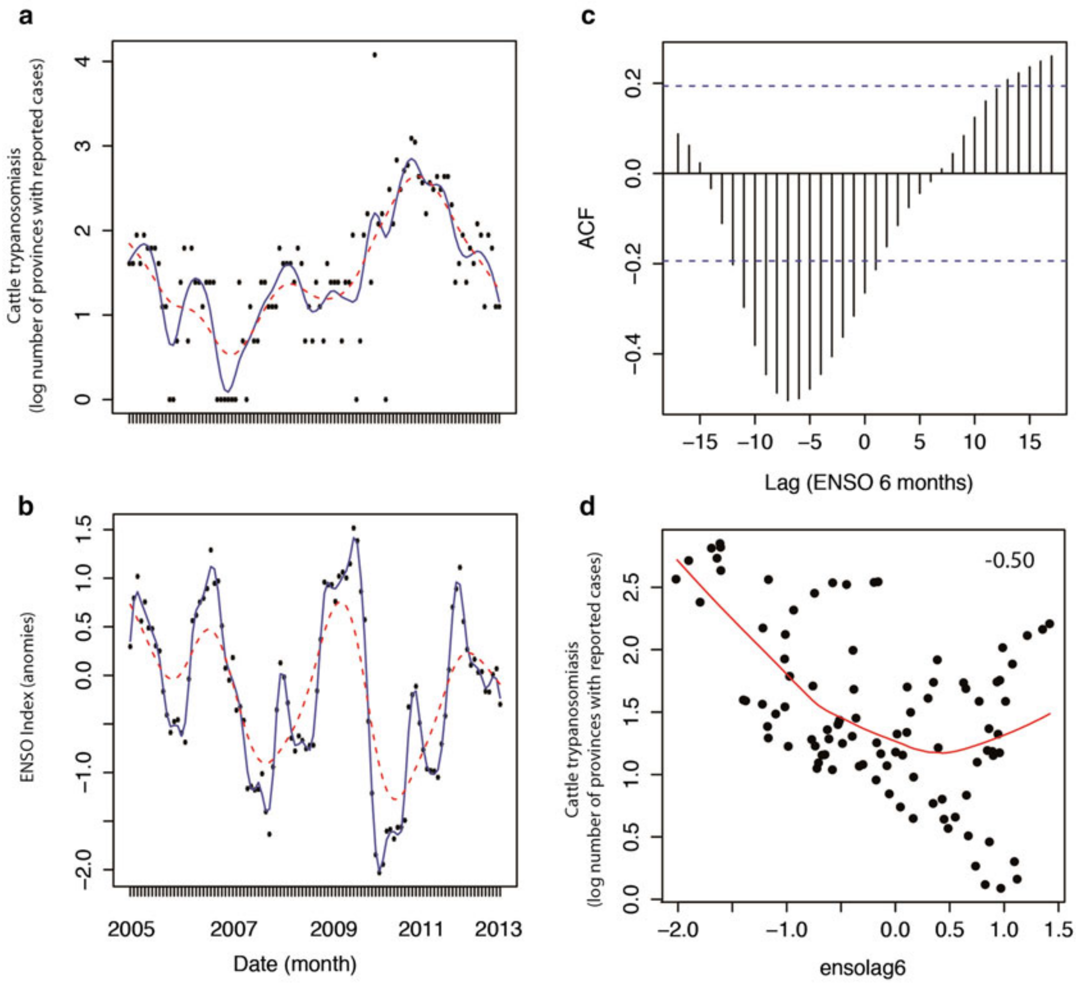


Fig. 8.1 Climate disease teleconnection: a working example using cattle trypanosomiasis in China

rence by Chinese province from the OIE (World Organization for Animal Health) information database, where the reporting cases started from January 2005 to June 2013. The data on ENSO was extracted from NOAA (National Oceanic and Atmospheric Administration). A lag correlation analysis performed on the detrending data showed a negative correlation between trypanosomiasis incidence and ENSO with a 6-month lag (Box 8.1). This result suggests that high negative anomalies of ENSO, corresponding to the La Niña event and characterized by a wet and cool season in China, seem to induce cattle trypanosomiasis outbreaks. However, we are to be aware that the validity of this analysis is

Box 8.1 Climate disease teleconnection: a working example using cattle trypanosomiasis in China

Data on trypanosomiasis occurrence by Chinese province were obtained from OIE (World Organization for Animal Health) information database (http://www.oie.int/wahis_2/public/wahid.php/Wahidhome/Home). The reporting cases started from January 2005 to June 2013.

Data on ENSO was extracted from NOAA (National Oceanic and Atmospheric

(continued)

Box 8.1 (continued)
Administration) (http://www.esrl.noaa.gov/psd/data/climateindices/list/#mei).

Among several potential indices, Multivariate ENSO Index (MEI) was used (Wolter and Timlin 1998).

Cubic smoothing spline was used as a detrending method for long-term series using the function smooth.spline in the R 2.10 statistical freeware package (http://www.R-project.org). This was done for trypanosomiasis incidence (Fig. 8.1a) and for MEI (Fig. 8.1b).

Then a lag correlation analysis was performed using the function cff in the package stats of the R freeware to identify the correlation between ENSO monthly values (MEI) and monthly trypanosiamasis incidence values (using detrended values). The better lag correlation obtained was 6 months between trypanosomiases incidence and MIE (Fig. 8.1c). There was a negative correlation between trypanosomiasis incidence and ENSO with a 6-month lag (Fig. 8.1d).

High negative anomalies of ENSO, corresponding to La Nina event and characterized by a wet and cool season in China, seem to induce cattle trypanosomiasis outbreaks.

crucially depending in the quality of the OIE reporting incidence.

8.4 Prevision of Diseases' Occurrences

Research on climate change has led to the development of elaborated models of future climate change that help at improving policies on mitigation of greenhouse gas emissions and preparing adaptation to the consequences of climate change on human economics and well-being. These climatic models are easily accessible to many other research domains particularly that of animal health science. However, because of the complex links between climate and infectious diseases, the methods and subsequently the results of several climate-based models on infectious diseases spread should be interpreted with caution.

8.4.1 Niche Modelling

Ecological niche modelling is used in biogeography to predict the distributional range of species from existing occurrence data (Anderson et al. 2003). Using appropriate algorithms in a geographic information system (GIS) containing layers of environmental information (such as topography, climate and vegetation), epidemiological and spatial risk stratification can be achieved from data on the location of vectors or pathogens. This approach has been used in the case of Chagas disease and for vectors of leishmaniasis and filovirus infections (Peterson et al. 2002, 2004). Moreover, using scenarios of climate change, it is then possible to project scenarios of pathogen and vector distribution changes.

Niche modelling requires disease occurrence data as a listing of geographical coordinates of localities where the agent/disease of interest is known to exist, raster GIS layers of environmental and/or climate variables and an environmental niche modelling (ENM) algorithm. Environmental data and software tools are now easy to obtain and to manipulate. However, the lack of adequate geo-referenced cases for many animal diseases, particularly in tropical countries, is an obstacle for the development of this approach.

Again, ecological niche modelling has been widely used for zoonotic diseases such as tularaemia (Nakazawa et al. 2010), caused by *Francisella tularensis*. Few have investigated specifically livestock disease as the notable and recent exception of the causative agent of the anthrax, *Bacillus anthracis* (Mullins et al. 2011). As emphasized by the authors, ecological niche modelling of *B. anthracis* helps at finding the potential associations between spore survival and ecological conditions, including climate factors, and can be used as a tool for disease risk and surveillance strategies.

A last point emphasized by many authors is the lack of extensive data collection needed for tuning and running models (Fox et al. 2012).

8.4.2 Epidemiological Modelling (R_0 Map)

Mathematical models of disease transmission may help to gain insight into the epidemiology of disease and estimate parameters such as the basic reproductive number R_0, which represents the number of new infections that arise, on average, from one infected individual when the entire population is susceptible. Integrating observed high spatial resolution climate data to its calculation has enabled the bluetongue transmission risk to be evaluated for the past period of time and simulation of future climate to drive the model in the future (Guis et al. 2011). The model showed that the increase in temperature over the last two decades explains the recent emergence of bluetongue (especially in the north part of Europe). The model can incorporate future climate scenarios, which leads to predictions of further increases in the risk of bluetongue in Europe up to 2050.

8.4.3 Teleconnection Modelling

Anyamba et al. (2012) recently emphasized that teleconnection maps, which correlate long-term monthly global precipitation data with index of climate variability (such as ENSO anomaly index), may help at identifying regional hotspots of rainfall variability influencing the ecology of vector-borne diseases. They showed that reported outbreaks of Rift Valley fever in Africa occurred after 3–4 months of above-normal rainfall. This rainfall was associated with green-up in vegetation, which favours the mosquito vectors. The authors also stressed that the immune status of livestock is a factor that needs to be considered (although largely unknown) as it may likely play a role in the spatial-temporal patterns of these disease outbreaks.

8.5 Conclusion

“Ecosystem approaches to health” or “ecohealth” considers inextricable linkages between ecosystems, society and health of animals and humans (Rapport et al. 1998, 1999). The ongoing global change concerns not only climate change but also land use changes and biodiversity changes, all of these changes affecting the epidemiological environment of humans and their domestic animals.

The frequency and severity of extremes in climate will increase as such the potential for globalization of vectors and disease. Understanding how the global and regional climate variability may impact the ecological drivers of livestock diseases is critical for planning and improving response, control and mitigation strategies. A better adaptation of livestock to the ongoing climate change depends on better scenario of diseases’ occurrences on one hand and on improvement of genetic breed to face new climate regime on the other.

8.5.1 Scenarios of Livestock Diseases Linked to Climate Change

We need to develop and improve both the recording of livestock diseases and the modelling of diseases’ occurrences in relation to climate change and climate variability. Indeed, the quality of the model prediction is depending on the quality of the data. Each country member depends on the ability and quality of their veterinary services to fill the OIE information database. Indeed, strong variability can be observed between countries in relation to their economic development.

8.5.2 Adaptation and Managing Breed Genetic Diversity

Host susceptibility to a pathogen can be altered by the environmental modulation of host immunocompetence (Dobson 2009). Host immune capacity affects the severity of the infection, and climate factors are able to modulate immune functions, which impact the virulence of the pathogen in hosts. Hence, several studies have shown that altered immunocompetence may increase disease spread (Dobson 2009; Murdock et al. 2012). Immune-mediated changes in host susceptibility and resistance as well as climate-related changes in parasite transmission may alter the interaction between hosts and their pathogens. Together with other climate stress-physiological impacts, an impairment of the immunological responses of hosts, and especially livestock, to diseases may favour disease outbreaks. Then preserving the genetic diversity of breed required for maintaining the evolutionary adaptation, the immune system responses to climate change or climate variability, is an imperative.

References

Altizer S, Ostfeld RS, Johnson PTJ, Kutz S, Harvell CD (2013) Climate change and infectious diseases: from evidence to a predictive framework. Science 341(6145):514–519. doi:10.1126/science.1239401

Anderson J, Barrett T, Scott GR (1996) Manual of the diagnosis of rinderpest. Food and Agriculture Organization of the United Nations, Rome

Anderson RP, Lew D, Peterson AT (2003) Evaluating predictive models of species' distributions: criteria for selecting optimal models. Ecol Model 162:211–232

Anyamba A, Linthicum KJ, Mahoney R, Tucker CJ, Kelley PW (2002) Mapping potential risk of rift valley fever outbreaks in African savannas using vegetation index time series data. Photogramm Eng Remote Sens 68:137–145

Anyamba A, Linthicum KJ, Small JL, Collins KM, Tucker CJ, Pak EW, Britch EW, Eastman SC, Pinzon JR, Russell JE E, Russell KL (2012) Climate teleconnections and recent patterns of human and animal disease outbreaks. PLoS Negl Trop Dis 6(1):e1465. doi:10.1371/journal.pntd.0001465

Band-Bo BA, Kebkiba B, Nadjilem D (2013) Facteurs favorisant l'apparition de la maladie de Newcastle au Tchad. J Appl Biol Sci 70:5591–5598

Baylis M, Morse AP (2012) Disease, human and animal health and environmental change. In: Matthews JA (ed) The SAGE handbook of environmental change. Sage, London. [Online] dx.doi.org/10.4135/9781446253052

Baylis M, Mellor PS, Meiswinkel R (1999) Horse sickness and ENSO in South Africa. Nature 397:574

Brown JD, Swayne DE, Cooper RJ, Burns RE, Stallknecht DE (2007) Persistence of H5 and H7 avian influenza viruses in water. Avian Dis 51:285–289

Cohen M (2000) Changing patterns of infectious disease. Nature 406(6797):762–767

Cook G (1992) Effect of global warming on the distribution of parasitic and other infectious diseases: a review. J R Soc Med 85:688–691

Cook T, Folli M, Klinck J, Ford S, Miller J (1998) The relationship between increasing surface water temperature and the northward spread of *Perkinsus marinus* disease epizootics in oysters. Estuar Coast Shelf Sci 40:587–597

Davies F, Linthicum K, James A (1985) Rainfall and epizootic Rift Valley fever. Bull World Health Organ 63:941–943

de la Rocque S, Morand S, Hendrix G (eds) (2008) Climate change and pathogens. Rev Sci Tech Off Int Epizoot 27(2):339–354

Dobson A (2009) Climatic variability, global change, immunity, and the dynamics of infectious diseases. Ecology 90:920–927

Donaldson AI (1972) The influence of relative humidity on the aerosol stability of different strains of foot-and-mouth disease virus suspended in saliva. J Gen Virol 15:25–33

Fox NJ, Marion G, Davidson RS, White PCL, Hutchings MR (2012) Livestock helminths in a changing climate: approaches and restrictions to meaningful predictions. Animals 2:93–107

Gagnon AS, Bush ABG, Smoyer-Tomic KE (2001) Dengue epidemics and the El Nino Southern Oscillation. Clim Res 19:35–43

Gagnon AS, Smoyer-Tomic KE, Bush ABG (2002) The El Nino Southern Oscillation and malaria epidemics in South America. Int J Biometeorol 46:81–89

Gale P, Adkin A, Drew T, Wooldridge M (2008) Predicting the impact of climate change on livestock disease in Great Britain. Vet Rec 162:214–215

Gale P, Drew T, Phipps LP, David G, Wooldridge M (2009) The effect of climate change on the occurrence and prevalence of livestock diseases in Great Britain: a review. J Appl Microbiol 106:1409–1423

Gething PW, Smith DL, Patil AP, Tatem AJ, Snow RW, Hay SI (2010) Climate change and the global malaria recession. Nature 465:342–344

Greer A, Ng V, Fisman D (2008) Climate change and infectious diseases in North America: the road ahead. Can Med Assoc J 178:715–722

Guis H, Caminade C, Calvete C, Morse AP, Tran A, Baylis M (2011) Integration of climate and disease models gives mechanistic insight into vector-borne disease emergence. J R Soc Interface 9:339–350

Hales S, Woodward A (2003) Climate change will increase demands on malaria control in Africa. Lancet 362:1775–1776

Hall HTB (1988) Diseases and parasites of livestock in the tropics. Longman Scientific and Technical, Harlow

Harvell CD, Mitchell CE, Ward JR, Altizer S, Dobson AP, Ostfeld RS, Samuel MD (2002) Ecology – climate warming and disease risks for terrestrial and marine biota. Science 296:2158–2162

Harvell CD, Jordan-Dahlgren E, Merkel S, Raymundo L, Rosenberg E, Smith G, Weil E, Willis B (2007) Coral disease, environmental drivers and the balance between coral and microbial associates. Oceanography 20:58–81

Harvell D, Altizer S, Cattadori IM, Harrington L, Weil E (2009) Climate change and wildlife disease: when does the host matter the most? Ecology 90:912–920

Hay SI, Cox J, Rogers DJ, Randolph SE, Stern DI, Shanks GD, Myers MF, Snow RW (2002) Climate change and the resurgence of malaria in the East African highlands. Nature 415:905–909

Hsu SM, Yen AMF, Chen THH (2008) The impact of climate on Japanese encephalitis. Epidemiol Infect 136:980–987

Hubálek Z (2005) North Atlantic weather oscillation and human infectious diseases in the Czech Republic, 1951–2003. Eur J Epidemiol 20:263–272

Kovats RS (2000) El Nino and human health. Bull World Health Organ 78:1127–1135

Kovats RS, Campbell-Lendrum DH, McMichael AJ, Woodward A, Cox JS (2001) Early effects of climate change: do they include changes in vector-borne disease? Philos Trans R Soc B 356:1057–1068

Lafferty KD (2009) The ecology of climate change and infectious diseases. Ecology 90:888–900

Linthicum KJ, Bailey CL, Davies G, Tucker CJ (1987) Detection of Rift Valley fever viral activity in Kenya by satellite remote sensing imagery. Science 235:1656–1659

Linthicum KJ, Anyamba A, Tucker CJ, Kelley PW, Myers MF, Peters CJ (1999) Climate and satellite indicators to forecast Rift Valley fever epidemics in Kenya. Science 285:397–400

Lips KR, Diffendorfer J, Mendelson JR, Sears MW (2008) Riding the wave: reconciling the roles of disease and climate change in amphibian declines. PLoS Biol 6:e72

Martens P (2002) Health transitions in a globalising world: towards more disease or sustained health? Futures 37(7):635–648

Martin V, Chevalier V, Ceccato P, Anyamba A, DeSimone L, Lubroth J, de La Rocque S, Domenech J (2008) The impact of climate change on the epidemiology and control of Rift valley fever. Rev Sci Tech 27:413–426

McIntyre KM, Setzkorn C, Baylis M, Waret-Szkuta A, Caminade C, Morse AP, Akin S-A, Huynen M, Martens P, Morand S (2010) Impact of climate change on human and animal health. Vet Rec 167(15):586

McMichael AJ (2004) Environmental and social influences on emerging infections. Philos Trans R Soc B 359(1447):1049–1058

McMichael AJ, Woodruff R (2005) Detecting the health effects of environmental change: scientific and political challenge. EcoHealth 2(1):1–3

Morand S, Guégan JF (2008) How the biodiversity sciences may aid biological tools and ecological engineering to assess the impact of climatic changes. Rev Sci Tech Off Int Epizoot 27(2):355–366

Morand S, Owers K, Waret-Szkuta A, McIntyre KM, Baylis M (2013) Climate variability and outbreaks of infectious diseases in Europe. Nat Sci Rep 3:1774

Mullins J, Lukhnova L, Aikimbayev A, Pazilov Y, Van Ert M, Blackburn JK (2011) Ecological niche modelling of the Bacillus anthracis A1.a sub-lineage in Kazakhstan. BMC Ecol 11:32. doi:10.1186/1472-6785-11-32

Murdock CC, Paaijmans KP, Cox-Foster D, Read AF, Thomas MB (2012) Rethinking vector immunology: the role of environmental temperature in shaping resistance. Nat Rev Microbiol 10:869–876

Nakazawa Y, Williams RAJ, Peterson AT, Mead PS, Kugeler KJ, Petersen JM (2010) Ecological niche modeling of Francisella tularensis subspecies and clades in the United States. Am J Trop Med Hyg 82:912–918

Parker R, Mathis C, Looper M, Sawyer J (2002) Anthrax and livestock. Guide B-120: Cooperative Extension Service. College of Agriculture and Home Economics, University of New Mexico, Las Cruces

Pascual M, Cazelles B, Bouma MJ, Chaves LF, Koelle K (2008) Shifting patterns: malaria dynamics and rainfall variability in an African highland. Proc R Soc Lond B 275:123–132

Pascual M, Dobson AP, Bouma MJ (2009) Underestimating malaria risk under variable temperatures. Proc Natl Acad Sci U S A 106:13645–13646

Patz J (2002) A human disease indicator for the effects of recent global climate change. Proc Natl Acad Sci U S A 99(20):12506–12508

Patz JA, Kovats RS (2002) Hotspots in climate change and human health. Br Med J 325:1094–1098

Paz S, Bisharat N, Paz E, Kidar O, Cohen D (2007) Climate change and the emergence of Vibrio vulnificus disease in Israel. Environ Res 103:390–396

Peterson AT, Sánchez-Cordero V, Beard CB, Ramsey JM (2002) Ecologic niche modeling and potential reservoirs for Chagas disease, Mexico. Emerg Infect Dis 8:662–667

Peterson AT, Bauer JT, Mills JN (2004) Ecologic and geographic distribution of filovirus disease. Emerg Infect Dis 10:40–47

Pounds JA, Bustamante MR, Coloma LA, Consuegra JA, Fogden MPL, Foster PN, La Marca E, Masters KL, Merinoviteri A, Puschendorf R, Ron SR, Sanchez-Azofeifa GA, Still CJ, Young BE (2006) Widespread amphibian extinctions from epidemic disease driven by global warming. Nature 439:161–167

Purse BV, Mellor PS, Rogers DJ, Samuel AR, Mertens PPC, Baylis M (2005) Climate change and the recent emergence of bluetongue in Europe. Nat Rev Microbiol 3:171–182

Randolph SE (2004) Evidence that climate change has caused ‘emergence’ of tick- borne diseases in Europe? Int J Med Microbiol 293:5–15

Rapport D, Costanza R, Epstein PR, Gaudet C, Levins R (1998) Ecosystem health. Blackwell Science, Oxford, 372

Rapport D, Böhm G, Buckingham D, Cairns J, Costanza R, Karr JR, de Kruijf HAM, Levins R, McMichael AJ, Nielson NO, Whitford WG (1999) Ecosystem health: the concept, the ISEH, and the important tasks ahead. Ecosyst Health 2:82–90

Reiter P, Thomas CJ, Atkinson PM, Hay SI, Randolph SE, Rogers DJ, Shanks GD, Snow RW, Spielman A (2004) Global warming and malaria: a call for accuracy. Lancet Infect Dis 4:323–324

Rogers DJ, Packer MJ (1993) Vector-borne diseases, models, and global change. Lancet 342:1282–1284

Rogers DJ, Randolph SE (2003) Studying the global distribution of infectious diseases using GIS and RS. Nat Rev Microbiol 1:231–237

Rogers DJ, Randolph SE (2006) Climate change and vector-borne diseases. Adv Parasitol 62:345–381

Rohr JR, Raffel TR, Romansic J, McCallum H, Hudson PJ (2008) Evaluating the links between climate, disease spread, and amphibian declines. Proc Natl Acad Sci U S A 45:17436–17441

Rosenthal J (2009) Climate change and the geographic distribution of infectious diseases. EcoHealth 6:489–495

Semenza JC, Menne B (2009) Climate change and infectious diseases in Europe. Lancet Infect Dis 9:365–375

Sutherst R (2004) Global change and human vulnerability to vector-borne diseases. Clin Microbiol Rev 17(1):136–173

Wittmann EJ, Baylis M (2000) Climate change: effects on culicoides-transmitted viruses and implications for the UK. Vet J 160:107–117

Wolter K, Timlin MS (1998) Measuring the strength of ENSO – how does 1997/98 rank? Weather 53:315–324

Wosu LO, Okiri JE, Enwezor PA (1992) Optimal time for vaccination against peste des petits ruminants (PPR) disease in goats in the humid tropical zone in southern Nigeria. In: Rey B, Lebbie SHB, Reynolds L (eds) Small ruminant research and development in Africa: proceedings of the First Biennial Conference of the African Small Ruminant Research Network. International Laboratory for Research in Animal Diseases (ILRAD), Nairobi

Zell R (2004) Global climate change and the emergence/re-emergence of infectious diseases. Int J Med Microbiol 293:16–26

Adaptive Mechanisms of Livestock to Changing Climate

9

V.P. Maurya, Veerasamy Sejian, Mahesh Gupta, S.S. Dangi, Ankita Kushwaha, Gyanendra Singh, and Mihir Sarkar

Abstract

In the current scenario, climate change is occurring all over the world, which directly or indirectly affecting the agricultural production as well as the production of livestock. The arid and semiarid region of the world, where more than 75 % population of livestock exists, will be going to have pronounced effect of climatic change. Amongst the other stresses, heat stress is the most vital climatic stress which drastically affects the productive potential of livestock, and sometimes it is lethal to animal survival in harsh conditions. High ambient temperature, air movement, solar radiation, wind speed and relative humidity are important attributes of the climatic variables. Amongst the above-mentioned variables, high temperature, radiation and humidity are the most important factors, which drastically affect the overall performance of livestock with substantial reduction in meat, milk and egg production. In this context, the chapter highlights the significance of studying the impact of multiple stresses impacting livestock production simultaneously. The different adaptive means by which livestock respond to fluctuation of climatic changes are physiological, blood-biochemical, neuroendocrine, cellular and molecular mechanisms, respectively. In present climate change scenario, several mitigation strategies are to be implemented by which the production of livestock may be sustained to an extent even in harsh climatic conditions.

Keywords

Climate change • Livestock • Mitigation • Mortality • Productive potential

---

V.P. Maurya (✉) • M. Gupta • S.S. Dangi
A. Kushwaha • G. Singh • M. Sarkar
Division of Physiology and Climatology,
ICAR-Indian Veterinary Research Institute,
Izatnagar, Bareilly, Uttar Pradesh 243122, India
e-mail: vijaipmaurya@gmail.com

V. Sejian
Animal Physiology Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_9, © Springer India 2015

9.1 Introduction

The impact of climatic change on natural resources and livestock is very vital and is being realised all over the world. In a developing country like India, more than 70 % percent population depends on agriculture and livestock, and these together provide sustainability and stability to national economy in the form of food security and farm energy (Singh et al. 2011). Environmental factors such as ambient temperature, solar radiation and humidity have direct and indirect effects on animals and affects worldwide livestock production (Nienaber et al. 1999). Under present climate conditions, in many areas of the world, animals are suffering from heat stress because they lack the ability to dissipate the environmental heat, which results decrease in milk production and reproduction in dairy cows (Fuquay 1981). Under climate change conditions, these responses could be enhanced and even extended to other areas around the world. The hot climate impairs productive and reproductive efficiency, and metabolic and immune response of animals which finally affects the health of livestock. It is evident from the Intergovernmental Panel on Climate Change that the poorest are the most vulnerable people and thus will be the worst affected.

The prominent relation between climatic variables and neuroendocrine system used to change the behaviour of livestock residing in that particular area (Baumgard et al. 2012). It is still not clear how heat stress affects the post-absorptive metabolism and nutrient partitioning/utilisation through hyperthermia's and/ or endocrine system (Collier et al. 2005). Livestock production will be affected by changes in temperature and water availability through impacts on pasture and forage crop quantity and quality, feed-grain production and price and disease and pest distributions. In Indian subcontinent, heat stress is the most important climatic stress which adversely affects the livestock and sometimes even affects their survival (Sejian et al. 2012a). During harsh climate, generally animals cover long distances in the search of feed and water, and sometimes because of long-distance walking, they have negative energy balance (Maurya et al. 2012; Sejian et al. 2012b). In current impending climatic changes, animals experience stress and to maintain homeothermy require extra energy for different productive processes. Along with the large ruminants, small ruminants are also critical to the development of sustainable and environmentally sound production systems (Ben Salem and Smith 2008). The sheep and goats are generally reared in arid and semiarid region of the world and are very important for the socioeconomic uplift of people dependent on these animals. Due to the climate change, the animals are being exposed to feed scarcity and elevated ambient temperature which negatively affect the production and reproductive traits of animals (Maurya et al. 2004; Marai et al. 2007).

Thermal stress affects the physiological and behavioural responses of animals which vary in intensity and duration in relation to the animal's genetic make-up and environmental factors in coordination with the behavioural, endocrinological, cardiorespiratory and immune system. In totality, the climate change has a negative impact in the long run, and it may reduce animal production and profitability by lowering feed efficiency, milk production and reproductive rate (St Pierre et al. 2003). In the face of climate challenges, adaptation of different livestock species to tropical conditions becomes highly imperative. A multifaceted approach is urgently needed to study the animal's ability to survive in harsh environments. The adaptation in the different physiological responses, biochemical status and composition and hormonal changes will be there to help animals to survive and produce in such prevailing climatic conditions. The present book chapter will have an insight about the different adaptive mechanism adopted by livestock to maintain their *internal milieu* and sustain productivity.

9.2 Physiological Responses and Adaptability

All animals thrive well in their thermoneutral zone, and whenever they are exposed outside to their respective zone, some portion of their metabolisable energy is diverted to maintain their thermal balance. The animal tries to maintain a relatively stable body temperature by behavioural and physiological means (Bucklin et al. 1992). High ambient temperature, relative humidity and radiant energy compromise the ability of animals to dissipate heat due to which the body temperature of animals increases. To maintain the body temperature within physiological limit, animals initiate compensatory and adaptive mechanisms to re-establish homeothermy and homeostasis, which is important for the survival of the animal. The relative change in the various physiological responses like respiration rate, pulse rate and rectal temperature gives an indication of stress imposed on livestock. The ability of an animal to withstand the rigours of climatic stress under warm conditions has been assessed physiologically by means of changes in body temperature, respiration rate and pulse rate (Sethi et al. 1994). By assessing the change in the physiological responses, the adaptability of a particular livestock may be studied, and environmental modification may be made to provide some comfort to the livestock.

The respiration rate is considered to be a reliable index under tropical condition and provides the information about the capability and adaptability of animals to that particular environment in which animals are being reared, and it also gives an indication about the discomfort of the animal. The increase in respiration rate is supposed to be the first action to mitigate the effect of heat stress. The onset of sweating is the next rapid reaction of animals to heat exposure and increases linearly with the increase in ambient temperature (Kamal 1975). Animals exposed to hot environment manifest a significant increase in physiological responses and reduction in productive potential. Animals which can maintain their physiological responses within normal limits under stressful environmental condition may be considered adapted to that environment and, hence, may be worth rearing commercially. In comparison to pulse rate, the respiration rate and rectal temperature appear to be more sensitive indicators of heat stress (Lemerle and Goddard 1986). The respiration is affected most with solar radiation and other related environmental variables.

The ambient temperature has significant relation with the fluctuation in the pulse rate (Raizada et al. 1980); however during morning hours, the pulse rate starts with the lower side, and during afternoon, it increases because of circadian rhythm (Maurya et al. 2007; Sejian et al. 2010b). The status of rectal temperature provides a useful and important indication about the heat storage in the animal's body, and higher rectal temperature of the animals drastically affects the allometric measurements, reproduction and lactation efficiency of the livestock (Hansen and Arechiga 1999). The value of rectal temperature also gives an idea about the adaptability of livestock to the particular environment. Even a rise of less than 1 °C in rectal temperature is enough to reduce performance in most livestock species (Lefcourt et al. 1986). RT is generally considered to be a useful measure of body temperature, and changes in RT indicate changes of a similar magnitude in deep body temperature (Maurya et al. 2007). Change in rectal temperature has been considered an indicator of heat storage in an animal's body and may be used to assess the adversity of thermal environment, which can affect growth, lactation and reproduction of dairy animals. The rectal temperature is recognised as an important measure of physiological status as well as an ideal indicator for the assessment of stress in animals (Maurya et al. 2010; Sejian et al. 2012a). During heat stress, high rectal temperature of livestock indicates that their homeothermic status is disturbed. Under such situation, the animals cannot effectively counter heat stress by enhancing heat loss through their physical and physiological process (Joshi and Tripathy 1991).

9.3 Multiple Stresses and Adaptability

In the tropics, grazing animals are exposed to less feed availability and low quality of vegetation. So the animals attempt to adapt to these adverse conditions by increasing the time for which they graze each day and also by dispersing more widely (Sejian et al. 2012c). In some areas, animals walk long distance in search of food and they are exposed to negative energy balance, and their physiological responses, endocrine and enzymes' release status and productivity in animals (Maurya et al. 2012; Sejian et al. 2012c) also alter. In addition to solar radiation, high humidity, severe drought, thermal, nutritional and walking are the major stresses that sheep and goats are exposed to (Sejian et al. 2012c, d). The animals try to adapt theirself to higher temperatures on prolonged exposure, but production losses will occur in response to higher-temperature events which lead to depressed voluntary feed intake, reduced weight gain and lower reproduction during summer. As a result of changing climatic conditions, multiple stresses have become a common occurrence in semiarid tropical environment. When animals are exposed to multiple stresses, the animal starts to use their body reserve to sustain their vital functions of the body, but their body reserves are not sufficient to effectively counter such environmental extremes (Sejian et al. 2010b). As a result, their adaptive capability is hampered and their homeothermy is badly compromised. The climatic stress also affects the body condition score of the animals. The type of nutrition consumed and body condition scoring (BCS) also seem to affect the respiration rate under heat stress conditions (Sejian et al. 2010a). The body condition score also affects the reproductive efficiency and productive performance of animals (Maurya et al. 2009).

The heat stress increases the blood circulation in the periphery of the animal's body to facilitate the heat loss via conduction and convection (Choshniak et al. 1982). Cattle change posture and orientation to the sun to reduce gain of heat from solar radiation. Moreover, chronic exposure to elevated environmental temperatures results in a lightening of the hair coat. Heat stress also leads to activation of evaporative heat loss mechanisms involving an increase in sweating rate and respiratory minute volume. About 70–85 % of maximal heat loss via evaporation is due to sweating with the remainder due to respiration. As air temperatures approach those of skin temperature, evaporation becomes the major route for heat exchange with the environment. There are reports which suggest that during thermal stress, both Hb and PCV decreased significantly (Naqvi 1987; Maurya et al. 2007). This could be attributed to haemodilution effect where more water is transported in the circulatory system for evaporative cooling and increase in the blood volume of these animals. In addition, Marai et al. (2007) reported red cell destruction as a reason for reduced Hb and PCV in thermal-stressed animals. A negative correlation between plasma protein and elevated environmental temperature has been reported in some studies (Sejian et al. 2010b).

The selection of animals which are tolerant to environmental stress results in reduced productivity, and such animals take a long time to reach maturity and a low level of milk production. So in such condition, by altering the environment, production may be increased by faster pace. The climate change and thermal stress affect physiological responses and productive and reproductive potential of animals (Collier et al. 2012). It is the prime importance to understand the complex physiological responses related to other mechanisms of the livestock body.

9.4 Temperature–Humidity Index

The dairy animals of tropical regions are subjected to high ambient temperatures (Ta), relative humidity (RH) and solar radiation for most of the period of a year. In the condition of heat stress, the physiological ability of the animals is being compromised and animals are not able to dissipate heat. There should be some ways and means by which a dairy man is able to assess the level of heat stress on the animals. The Temperature–Humidity Index (THI) is one of the best assessment tools by which we can know the impact of heat stress on producing animals widely used in hot areas all over the world to assess the impact of heat stress on dairy cows. According to Du Preez et al. (1990), milk production is not affected by heat stress when mean THI values are between 35 and 72. However, milk production and feed intake begin to decline when THI reaches 72 and continue to decline sharply at a THI value of 76 or greater. Milk yield decreases of 10–40 % have been reported for Holstein cows during the summer as compared to the winter (Du Preez et al. 1990). The THI is generally at higher side when the high ambient temperature is coupled with more relative humidity (West et al. 1999). It has been widely published in the literature that lactating cows do not experience stress when THI is less than 72 and severe stress when THI exceeds 88. Zimbelman et al. (2007) reported that the THI has very close relation with air movement, solar radiation and above all the milk yield. He found that dairy cows producing more than 35 kg/day of milk need additional cooling when average THI is 68 for more than 17 h/day.

9.5 Metabolic and Hormonal Response to Adaptability

The animals exposed to heat stress reduce feed intake and increase water intake, and in addition to this, the endocrine status of the animal also changes which in turn increases the maintenance requirement (Collier et al. 2005) and drastically affects the production in animals (Rhoads et al. 2009). During prolonged heat stress, the homeostatic responses of animals change in relation to acclimation to a particular environment, and the target tissue responsiveness to the environmental stimuli also alters (Horowitz 2002). The concentration of T_4, T_3, prolactin, GH, mineralocorticoids and glucocorticoids gets affected, and the endogenous heat production is controlled in coordination of the above hormones (Collier et al. 2005). Circulating prolactin levels are increased during thermal stress in a variety of mammals including ruminants (Roy and Prakash 2007). This is paradoxical as reduced nutrient intake in thermoneutral ruminants, decreases circulating prolactin concentrations (Bocquier et al. 1998). A direct (independent of reduced feed intake) effect of heat stress on serum prolactin levels has been shown (Ronchi et al. 2001). The prolactin generally helps in maintaining galactopoiesis and lactogenesis in ruminants, but it may play an important role in helping insensible heat loss and sweat gland function (Beede and Collier 1986).

The thermal stress affects the functioning of hypothalamic–pituitary–adrenal axis (Collier et al. 2005). Corticotropin-releasing hormone stimulates somatostatin, possibly a key mechanism by which heat-stressed animals have reduced GH and thyroid levels (Riedel et al. 1998). In heat-stressed cows, there is an increase in the basal level of insulin despite marked reductions in nutrient intake (Yarney et al. 1990). The increase in basal insulin levels appears due to increase pancreas' secretion. Adrenal corticoids, mainly cortisol, elicit physiological adjustments which enable animals to tolerate stressful conditions (Naqvi and Hooda 1991). During heat stress, plasma cortisol level increases which also enhances glucose formation in heat-stressed animals. The glucocorticoids also work as vasodilators to help heat loss and have stimulatory effect on proteolysis and lipolysis mechanism, which provide energy to the animal during such harsh climatic situations (Cunningham and Klein 2007). Heat stress decreases insulin level in the blood (Haque et al. 2012) due to decrease in heat production. In addition to this heat stress, increases in lipolysis activity in animals also elevate blood nonesterified free fatty acid (NEFA) levels and reduce insulin sensitivity and thus decrease muscle glucose uptake.

The T_3 and T_4 are the calorigenic hormones which fluctuate different cellular processes in the body. The animals exposed to thermal stress have reduced level of T_3 and T_4, and this reduced level of T_3 and T_4 might be an adaptive mechanism followed by animals to reduce metabolic rate and heat production (Sejian et al. 2010b). The thyroid hormone plays a crucial role in the productive efficiency of animals and may be considered as index for the metabolic status of animals (Todini et al. 2007). Uetake et al. (2006) reported that NEFA concentration in the blood is influenced by stress, and it is frequently used to assess the energy status of animals (Macrae et al. 2006). During stress, animals fulfil its metabolic fuel requirement due to mobilisation of NEFA (Cunningham and Klein 2007). The reduction in insulin action during heat stress also allows for adipose lipolysis and mobilisation of nonesterified fatty acids. Post-absorptive carbohydrate metabolism is also altered by the reduced insulin action with the net effect of reduced glucose uptake by systemic tissues (i.e. muscle and adipose). The reduced nutrient uptake and the net release of nutrients (i.e. amino acids and NEFA) by systemic tissues are key homeorhetic (an acclimated response vs. an acute/homeostatic response) mechanisms implemented by heat-stressed animals (Bauman and Currie 1980).

9.6 Cellular Response, Heat Stress and the Adaptability

The heat stress affects the productive performance of the animals which is being reflected in the homeokinetic changes in the animals which is considered to be an effort made by animal to regulate its temperature. The animals thriving in the hot climate have acquired some genes that protect cells from the increased environmental temperatures. Paula-Lopes et al. (2003) reported that lymphocytes from Brahman and Senepol cows were more resistant to heat-induced apoptosis than lymphocytes from Angus and Holstein cows. The heat stress increases the oxidative stress in the body of an animal, and because of that, there is an enhanced production of free radicals in the body and this free radical decreases the antioxidant defence system (Trevisan et al. 2001). The damage made by free radicals during thermal stress may be minimised by the use of vitamin C, vitamin E and β-carotene as they act as vital antioxidant. Besides these, different metalloenzymes, viz. glutathione peroxidase (Se), catalase (Fe) and superoxide dismutase (Cu, Zn and Mn), are very crucial in protecting the internal cells from oxidative damage. The major defences in detoxification of superoxide anion and hydrogen peroxide are superoxide dismutase (SOD), catalase and glutathione peroxidase (Chance et al. 1979). SOD is now known to catalyse the dismutation of superoxide to hydrogen peroxide and oxygen. Bernabucci et al. (2002) reported an increase in superoxide dismutase (SOD) and glutathione peroxidase (GPX) concentration in prepartum cows when animals were exposed to higher ambient temperature. In addition to this, Chandra and Aggarwal (2009) also reported a higher level of SOD in prepartum crossbred cows during summer. During heat stress, there is increased production of hydrogen peroxide (H_2O_2) due to increased activity of SOD and GPX. GPX is a selenium-dependent antioxidant enzyme. It converts H_2O_2 to water. The increased production of H_2O_2 due to increased activity of SOD during heat stress results in a coordinated increase in GPX.

Catalase is a haem-containing enzyme that catalyses the dismutation of hydrogen peroxide into water and oxygen. Catalase takes care of the cytosolic and mitochondrial peroxides formed during urate oxidation. Mitochondrial SOD readily converts the bulk of mitochondrial superoxide ions to H_2O_2. Thus, SOD and catalase protect the cell from the damage due to the secondary generation of highly reactive hydroxyl group from superoxide ion to H_2O_2. Kumar (2005) observed a significant positive correlation of THI with the erythrocyte catalase activity in Murrah buffalo and KF cattle. Chandra and Aggarwal (2009) also reported higher catalase activity in prepartum crossbred cows during summer.

Lipid peroxidation is commonly measured in terms of thiobarbituric acid-reactive substance (TBARS). Erythrocytes, which are rich in polyunsaturated fatty acids (PUFA), on being exposed to high concentration of oxygen, are highly susceptible to peroxidation damage (Clemens and Waller 1987). The thermal stress increases the oxidative stress in the cell, and this leads to the increase of TBARS in the animals' blood which leads to increased erythrocyte membrane fragility

(Bernabucci et al. 2002). More et al. (1980) reported a significant increase in the serum protein of sheep exposed to heat stress. The increase in serum protein could be a physiological attempt to maintain extended plasma volume. In contrast to the above finding, Verma et al. (2000) observed a significant decrease in protein concentration during summer season in a lactating cow and buffalo. The level of plasma albumin plays a vital role in the scavenging activity to remove free radical from the system, that's why albumin works as an antioxidant during thermal stress (Koubkova et al. 2002).

Although there is a good amount of knowledge about the physiological aspects, the effects of heat stress at the cellular and genetic level are still being unrevealed (Collier et al. 2006). Functional genomics research is providing new knowledge about the impact of heat stress on livestock production and reproduction. Using functional genomics to identify genes that are up- or down-regulated during a stressful event can lead to the identification of animals that are genetically superior for coping with stress and towards the creation of therapeutic drugs and treatments that target affected genes (Collier et al. 2012). Identification of SNPs that are associated with variation in animal resistance or sensitivity to thermal stress will permit screening of the presence or absence of desirable or undesirable alleles of animals (Hayes et al. 2009). Another potential route of information flow from the surface to the whole system would be via secreted heat shock proteins (HSPs) released from the skin epithelium during heat stress which would act as an alarm system to assist in mobilising the acute response to thermal shock (Collier et al. 2012). Activation of the heat shock response in cells in many cases leads to secretions of HSPs into the extracellular space and plasma (Ireland et al. 2007). It has been hypothesised that secreted heat shock protein acts as an alarm signal for the immune system and several measures of innate immunity are increased following increases in secreted HSPs in blood (Fleshner and Johnson 2005). Secreted HSPs have also been shown to improve survival of neural cells subjected to environmental and metabolic stressors (Tytell 2005).

9.7 Female Reproduction, Heat Stress and Adaptability

The heat stress drastically affects animals' reproductive efficiency by delaying conception rate of the animals after calving. It may delay rebreeding and decrease the number of cows regularly coming in heat and subsequently decrease the number of inseminated cows that settle as pregnant (Hansen 1994). The heat stress also affects the quality of developing preovulatory follicle by fluctuating the oestrogen and progesterone ratios which in turn affect the intensity of sexual behaviour, oviduct and uterus microenvironment and finally development of embryo. Several research findings show that heat stress compromises the quality of developing oocyte and of the follicle. High air temperatures 10 days before oestrus were associated with low fertility (Al-Katanani et al. 2002). Steroid production by cultured granulosa and thecal cells was low when cells were obtained from cows exposed to heat stress 20–26 days previously (Roth et al. 2001). In goats, heat stress reduced plasma concentrations of oestradiol and lowered follicular oestradiol concentration, aromatase activity and luteinising hormone (LH) receptor level and delayed ovulation (Ozawa et al. 2005). Cultured follicular cells experience reduced steroid production at elevated temperature in cattle (Bridges et al. 2005). The oocyte maturation is disrupted at elevated temperature (Wang et al. 2009). It has been reported by Roth et al. (2000) that lactating dairy cows exposed to heat stress had increased numbers of small and medium follicles.

The heat stress drastically affects preimplantation of embryo at early stage, but the susceptibility declines as development proceeds. It is an established fact that reproduction processes are influenced during thermal exposure (Naqvi et al. 2004; Sejian et al. 2010c) and glucocorticoids are paramount in mediating the inhibitory effects of stress on reproduction. Thermal stress influence on sexual behaviour (Maurya et al. 2005), fertility (Maurya et al. 2011), embryo quality and production is a well-established fact (Naqvi et al. 2004). The birth weights of lambs of heat-stressed ewes are generally lower. This could be attributed to the fact that heat stress may cause a temporal impairment of placental size and function, resulting in a transient reduction in foetal growth rate. In cattle, for example, Ealy et al. (1993) found that exposure of lactating cows to heat stress, when embryos were 1–2 cells, reduced the proportion of embryos that developed to the blastocyst stage at day 8 after oestrus. However, heat stress at days 3 (8–16 cells), 5 (morula) and 7 (blastocysts) had no effect on the proportion of embryos that were blastocysts at day 8. In cows, the adverse effects of heat shock on cultured embryos also are reduced as they become more advanced in development (Sakatani et al. 2004). It has been reported by Matsuzuka et al. (2005) that maternal heat stress resulted in increased reactive oxygen species activity in oviducts and embryos and reduced glutathione content in recovered embryos. Pérez-Crespo et al. (2005) found that female embryos are better able to survive effects of elevated temperature than male mice and this gender difference has been demonstrated to be caused by reduced reactive oxygen species production in females. As embryo development advances, it acquires capacity synthesis of heat shock protein 70 (HSP70), which stabilises intracellular proteins and organelles and inhibits apoptosis (Brodsky and Chiosis 2006).

The animal exposed to thermal stress during the early stage of pregnancy has reduced foetal growth, placental weight and placental hormone level. The effect of heat stress is more pronounced on the developing foetus during mid-gestation as compared to advance gestation (Wallace et al. 2005). During heat stress, the placental function also affects due to redistribution of blood to the periphery and reduced perfusion of the placental vascular bed (Alexander et al. 1987) and reduces the foetal weight in sheep (Wallace et al. (2005)). Similar effects of maternal heat stress on placental function and foetal development occur in cows. It is an well-accepted fact that stress during foetal stage can result in changes in physiological function during adult stage.

9.8 Male Reproduction, Heat Stress and Adaptability

Thermal stress drastically affects each of sexual activity, endocrine and testis functions, spermatogenesis and physical and chemical characteristics of the semen (Abdel Samee et al. 1997). Thermal stress decreases the ability of the male for fertile mating. Seminal plasma provides the suitable medium for spermatozoa which is a mixture of secretions that come from the male accessory reproductive organs. The biochemical constituents of seminal plasma also play a vital role for the well-being of spermatozoa and also act as vehicle for sperms (Mann and Lutwak mann 1981). Testosterone plays an important role in initiation of the sex drive and optimal functioning of the testis (McDonald and Pineda 1989). Physiological concentrations of testosterone are responsible to induce both behavioural and physical changes necessary for exhibiting libido, secreting pre-seminal fluid, protrusion of penis and complete erection. Testosterone is the hormone responsible for spermatogenesis and sexual behaviour. During thermal stress, reduction in testosterone secretion limits the male reproductive efficiency. Higher body or ambient temperature decreases sperm count as well as circulating testosterone levels in blood (Murray 1997).

The testes of the animals are suspended in the scrotum outside the body, and the temperature of the scrotum is slightly less than the general body temperature. A complex thermoregulatory system present in the testis exchanges heat by countercurrent mechanism known as pampiniform plexus. The scrotum also has a unique muscle known as tunica dartos muscle which regulates scrotal surface area, and the position of the scrotum relative to the body is performed by the cremaster muscle. The tunica dartos muscle can be used as an index (TDI) to measure the ability of the male to tolerate increased ambient temperatures, as it reflects the magnitude of vascular heat exchange. During high ambient temperatures, the tunica dartos muscle extends to dissipate as much of the excess heat as possible from the testes. In rams, Marai et al. (2006) used tunica dartos indices (TDI) to measure the ability of the male to tolerate increased ambient temperatures. It is interpreted as the distance between the testes and the abdominal wall. This muscle thus defines the magnitude of vascular heat exchange.

The testis is located outside the body, and thermal stress has a direct effect on it leading to reduced semen quality in the form of reduced sperm output, decreased sperm motility and an increased acrosomal damage and proportion of morphologically abnormal spermatozoa in the ejaculate. The spermatocytes and spermatids are most susceptible to damage by thermal stress. Oxidative stress is a major cause for thermal damage of spermatogenic cells and leads to apoptosis and DNA strand breaks (Paul et al. 2009). The effect of thermal stress did not affect the semen quality immediately after exposure because damaged spermatogenic cells do not enter ejaculates for sometime after heat stress. The spermatogenesis takes about 61 days in bulls, and alteration in semen is observable about 2 weeks after heat stress which does not return to normal until up to 8 weeks following the end of heat stress (Hansen 2009).

During the hot summer, breeds in the tropical and subtropical region have more decreased scrotal circumference, testicular consistency, and size and weight than those of the same breeds reared under temperate environmental conditions (Yarney et al. 1990). This reduction in testicular measurements might be due to degeneration in the germinal epithelium. The intensity of sexual behaviour and reaction time is shorter in summer season and the longest in autumn season in male goats. The scrotum has perfect thermoregulatory mechanism in all the animals, but thermal stress has negative effect on sexual desire (libido), ejaculate volume, live sperm percentage, sperm concentration, viability and motility and sperm concentration (Mathevon et al. 1998). Marai et al. (2008) reported decrease in semen-ejaculate volume during thermal stress. In several reports, it has been found that thermal stress decreases the initial motility of spermatozoa in hot climate conditions. Maurya et al. (1999) reported that the serving capacity and libido of animals vary in individual animals in semiarid region of India. Thermal stress reduces the body condition score of the animals which in turn affects the sexual behaviour, scrotum attributes and seminal quality (Maurya et al. 2010).

The stress induced by high ambient temperatures is a well-known factor that can result in higher numbers of damaged or abnormal spermatozoa, and a long duration of high temperature with increased humidity can cause male infertility over a long period of time. High temperature in combination with high humidity increases free radical production. Reactive molecules tend to affect unsaturated fatty acid-rich cell membranes in mammalian spermatozoa, which are considered highly susceptible to peroxidation (Balic et al. 2012). Since the antioxidant defence in sperm cells is very minimal due to the small amount of the cytoplasm in their heads and tails (Bilodeau et al. 2000) in addition to this, reactive oxygen species (ROS) is also able to stimulate the sulfhydryl radical group oxidation in protein molecules as well as DNA fragmentation, thereby altering the structure and function of spermatozoa (Agarwal et al. 2003). Besides the direct effect of heat stress, tissue hypoxia is likely to be one of the consequences of heat stress since the blood supply in the testes cannot compensate for the increased need for tissue metabolism. Several studies in bulls (Newton et al. 2009) have reported the adverse effect of heat stress on sperm motility and morphology, but the exact stages of spermatogenesis during which such defects occur have not yet been fully documented.

The stressful environmental condition affects semen at cellular level and has a negative impact on semen quality. Stress alters cellular function in various tissues and heat shock protein 70 (Hsp70), which, located in reproductive tissues, has critical roles in spermatogenesis (Kamaruddin et al. 2004). Single nucleotide polymorphisms occurring in the Hsp70 promoter region may impact stress tolerance, and haplotypes of Hsp70 were related to cow fertility and heat tolerance (Basirico et al. 2011). The process of spermatogenesis takes approximately 54 days in bulls and 47 days in bucks, and effect of heat stress on sperm output persists for 8 weeks in bulls and 7 weeks in bucks after the termination of heat stress (Meyerhoeffer et al. 1985). Normal spermatogonium proliferation continues to be drastically reduced for weeks even after the end of the heat treatment. The effects of heat on the spermatogonia seem to be dependent on the method, temperature, the duration of heat application and the livestock species.

Since climate change could result in an increase of heat stress, all methods to help animals cope with or, at least, alleviate the impacts of heat stress could be useful to mitigate the impacts of global change on animal responses and performance. Few basic management schemes for reducing the effect of thermal stress may be considered by which one can sustain the productivity of lactating animals during heat stress.

9.9 Milk Production, Heat Stress and Adaptability

Heat stress can impact animal production and profitability in dairy cattle by lowering milk production. The severity of stress and milk production by a cow depends on THI, length of heat stress period, air flow, size of cow, dry matter intake, water availability and coat colour. THI is commonly used to indicate the degree of stress in dairy cattle. THI values suggest that within the normal range up to 70, cattle show optimal performance. In the warning range of THI values 70–72, dairy cow performance is inhibited and the cooling of animals becomes desirable. Critical THI values are 72–78, when milk production is seriously affected. The dangerous category is at the THI values 78–82. A decrease in milk yield is 0.26 kg/day for each increase in THI. Genetic progress in milk production is related closely to an increase in metabolic heat increment, which makes cows more affected by heat stress (Kadzere et al. 2002). Even under excellent management conditions, dairy cows may be exposed to high ambient temperatures, and one of the most common responses of animals to such a stressor is the activation of the hypothalamic–pituitary–adrenal axis. Heat stress has been associated with depressions in milk component percentages (Maurya et al. 2013). Knapp and Grummer (1991) indicated a decreased milk composition with increased maximum daily temperature. Bouraoui et al. (2002) found that milk fat and milk protein were lower for the summer season. Ozrenk and Inci (2008) reported that milk fat, protein and total solid percentages in cow milk were the highest during winter and the lowest during summer. The yield of milk fat of cows exposed to thermal stress declines with decreasing milk yield. Under hot room conditions, the milk fat yield of Holstein cows declined at temperatures above 27 °C. It was reported that in Haryana, cows' contents of milk like milk fat, solid-not-fat (SNF), protein, ash and calcium were highest in winter than summer and rainy season. Studies of the fatty acid composition of milk fat under controlled high temperature showed that any external heat load that raised rectal temperature by 1° or more caused changes in the characteristics of milk fat. In particular, the content of lower-chain fatty acids decreased, whereas the level of palmitic and stearic acids increased. The reason for the shift in the ratio of fatty acids is unknown. Nevertheless, these shifts can be of practical significance as they influence the quality of the milk for cheesemaking.

High ambient temperature appears to have a more marked influence on the SNF content of milk than on milk fat. Thermal stress also appears to bring about some decrease in percentage of lactose and acidity in the milk, lowers its level of pantothenic acid and lowers its freezing point. It increases the pH and levels of ascorbic acid and riboflavin. But it has little effect on salt balance or the carotenoid and vitamin A levels in milk fat. For Karan Fries and Karan Swiss cows, the comfort zone for the maximum milk yield is 7 °C and 25 °C, respectively, and the milk yield per day decreased with increase in temperature and humidity (Shinde et al. 1990). The Jersey crossbreds were less affected by climate than Holstein crossbreds for average milk yield per day. This decrease can be either transitory or longer term depending on the length and severity of heat stress. These decreases in milk production can range from 10 to >25 %. It has been found that

50 % reduction in milk yield is due to reduced feed intake during thermal stress and other 50 % might depend on heat-related lactogenic hormone fluctuations (Johnson 1987). Besides the thermal stress, the decline in milk yield is also dependent upon breed, stage of lactation and feed availability (Bernabucci and Calamari 1998). The effect of heat stress is more in high-yielding cow as compared to low-yielding cow. The experiment conducted in controlled climatic chamber says that because of heat stress, there is 35 % decrease in milk yield during mid-lactation as compared to 14 % decrease in milk at early lactation. The reason for this may be because at early lactation the milk yield is supported by body tissue reserve mobilisation and less by feed intake; however, in mid-lactation the milk yield is mainly supported by feed intake. The calving time during the year also affects the milk yield. Catillo et al. (2002) reported that buffalo calved during summer yields less milk as compared to buffalo calved during other seasons of the year.

The heat stress not only decreases the milk yield in the animals but it also drastically affects the quality of milk (Bernabucci and Calamari 1998). The cow exposed to heat stress produces milk and colostrums with lower percentage of protein and fat (Nardone et al. 1997). In addition to this, the heat stress-exposed animals' milk has lower value of calcium, phosphorus and magnesium and high chloride (Bernabucci and Calamari 1998). A sheep exposed to solar radiation has lower value of fat, fatty acid and protein content in the milk, and a goat also has decreased concentration of lactose, when exposed to severe heat for 4 h duration. The heat stress also drastically affects the length of the fatty acid chain in the milk. Ronchi et al. (1995) reported that a heat-stressed cow has lower proportion of short-chain (C4–C10) and medium-chain (C12–C16) fatty acids and more long-chain fatty acid (C17–C18). He also found out that the heat-stressed cow had 25 % less milk yield than the cow maintained in the thermal comfort zone. These changes in the fatty acid chain may be due to reduced synthesis of this free fatty acid (FFA) in the mammary gland rather than the incorporation of long-chain FFA in the milk. The lower synthesis of short- and medium-chain fatty acid may also be due to the negative energy status of the cow exposed to thermal stress. Nardone et al. (1997) also reported lower level of short- and medium- and higher proportion of long-chain fatty acid in the colostrums of heifers.

The cheese yield and cheese quality are drastically affected by heat stress. The casein content of the milk also reduced during summer in whole milk as well as colostrums (Nardone et al. 1997). The heat stress also had a negative impact on the milk casein (α- and β-casein), and these caseins have 90 % share of total casein present in milk; in addition to this, casein has high numbers of phosphate group. During thermal stress and negative energy balance, phosphorylation is impaired. The lower content of α- and β-casein tends to increase pH of milk and lower phosphorus content during the summer months (Kume et al. 1989).

Since climate change could result in an increase of heat stress, all methods to help animals cope with or, at least, alleviate the impacts of heat stress could be useful to mitigate the impacts of global climate change on animal responses and performance. The effect of heat stress on animals may be reduced by providing suitable shelter and changing microenvironments by mist cooling. Proper nutritional management may also be adopted by supplying of high-energy feeds along with bypass protein, which will help animals to sustain their productivity under heat stress conditions. Physical modification of the environment, genetic development of less sensitive breed to thermal stress and improved nutritional management schemes help combat ill effects of climate change. Supplementation of *Aspergillus oryzae* (AO) increased dry matter (DM) digestibility of high-concentrate diets through enhanced fibre digestion (Gomez Alarcon et al. 1990) which in turn increases milk yield in the dairy cows. The quality and freezability of buffalo semen may be improved by Sephadex filtration of semen (Maurya et al. 2003a, b; Maurya and Tuli 2003). This is an indirect method to improve productivity of buffalo by increasing conception rate per insemination. The recombinant bovine somatotropin has been known for its potential to increase milk production in cattle. Several experiments have been carried out in the USA and proved this fact. The product is in use in the

USA and several other countries. Bovine somatotropin (bST) is a protein hormone produced by the anterior pituitary gland of cattle. The mechanism of action of bST involves a series of orchestrated changes in the metabolism of body tissues so that more nutrients can be used for milk synthesis (Raymond et al. 2009). So it is also an alternative way to increase milk production in cows. During heat stress, the surrounding of the cow may be changed by providing shade and cooling system. In the long run, some fine strategies may be adopted to develop heat stress tolerance breed of cows and buffaloes with the help of upstream reproductive technologies either on cellular level or by genetic manipulations. By improving the nutritional habit of cows, decrease in the milk yield during heat stress may also be minimised up to some extent.

9.10 Conclusion

The climate change is influencing the humidity and temperature level in different geographical areas, and during the twenty-first century, warming is projected to result in decreased production as well as an increase in the number of days when animals will be experiencing heat stress. Climatic fluctuation is going to affect the arid and semiarid areas of the world severely. The climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their reproductive performance. Elevation of ambient temperature affects male reproductive functions deleteriously. Such phenomenon leads to testicular degeneration and reduces percentages of normal and fertile spermatozoa in the ejaculate of males. The ability of the male to mate and fertilise is also affected. Thermal stress generally affects the biological function of animals which in turn changes enzyme activity, hormonal levels, blood biochemicals and reproductive performance of animals. In addition to this, climatic changes also affect milk production of animals. The climate change affects the performance adaptability and profitability of animals by changing the physico-biochemical and hormonal profile of animals. In addition to this, adverse climatic condition also lowers the feed intake and utilisation and in turn lowers production in animals. Ample scope is there to minimise the effect of climatic changes by feeding some additives which reduce stress and also by providing protection to the animals against the harsh climatic conditions. There is urgent need to have refined and improved knowledge to understand complex physiological mechanism, which is responsible for reduction in productive capability of animals during climatic changes.

References

Abdel Samee AM, Maria IFM, Zedan AEB (1997) Males reaction and management under hot climate conditions. In: Proceedings of the 2nd international conference on animal, poultry and rabbit production and health. Institute of Efficient Productivity, Zagazig University, Zagazig, pp 135–151

Agarwal A, Saleh RA, Bedaiwy MA (2003) Role of reactive oxygen species in the pathophysiology of human reproduction. Fertil Steril 79:829–843

Alexander G, Hales JRS, Stevens D, Donnelly JB (1987) Effects of acute and prolonged exposure to heat on regional blood flows in pregnant sheep. J Dev Physiol 9:1–15

Al-Katanani YM, Paula Lopes FF, Hansen PJ (2002) Effect of season and exposure to heat stress on oocyte competence in Holstein cows. J Dairy Sci 85:390–396

Balic IM, Milinkovic Tur S, Samardzija M, Vince S (2012) Effect of age and environmental factor on semen quality, glutathione peroxidase activity and oxidative parameters in simmental bull. Theriogenology 78:423–431

Basirico L, Morera P, Primi V, Lacetera N, Nardone A, Bernabucci U (2011) Cellular thermotolerance is associated with heat shock protein 70.1 genetic polymorphisms in Holstein lactating cows. Cell Stress Chaperones 16:441–448

Bauman DE, Currie WB (1980) Partitioning of nutrients during pregnancy and lactation a review of mechanisms involving homeostasis and homeorhesis. J Dairy Sci 63:1514–1529

Baumgard LH, Rhoads RP, Rhoads ML, Gabler NK, Ross JW, Keating AF, Boddicker RL, Lenka S, Sejian V (2012) Impact of climate change on livestock production. In: Sejian V, Naqvi SMK, Ezeji T, Lakritzand J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer Verlag GmbH Publisher, Berlin/Heidelberg

Beede DK, Collier RJ (1986) Potential nutritional strategies for intensively managed cattle during thermal stress. J Anim Sci 62:543–554

Ben Salem H, Smith T (2008) Feeding strategies to increase small ruminant production in dry environments. Small Rumin Res 77:174–194

Bernabucci U, Calamari L (1998) Effect of heat stress on bovine milk yield and composition. Zootec Nutr Anim 24:247–257

Bernabucci U, Ronchi B, Lacetera N, Nardone A (2002) Markers of oxidative status in plasma and erythrocytes of transition dairy cows during hot season. J Dairy Sci 85:2173–2179

Bilodeau JF, Chatterjee S, Sirard MA, Gagnon C (2000) Levels of antioxidant defenses are decreased in bovine spermatozoa after a cycle of freezing and thawing. Mol Reprod Dev 55:282–288

Bocquier F, Bonnet M, Faulconnier Y, Guerre-Millo M, Martin P, Chilliard Y (1998) Effects of photoperiod and feeding level on adipose tissue metabolic activity and leptin synthesis in the ovariectomized ewe. Reprod Nutr Dev 38:489–498

Bouraoui R, Lahmar M, Majdoub A, Djemali M, Belyea R (2002) The relationship of temperature humidity index with milk production of dairy cows in a Mediterranean climate. Anim Res 51:479–491

Bridges PJ, Brusie MA, Fortune JE (2005) Elevated temperature (heat stress) in vitro reduces androstenedione and estradiol and increases progesterone secretion by follicular cells from bovine dominant follicles. Domest Anim Endocrinol 29:508–522

Brodsky JL, Chiosis G (2006) Hsp70 molecular chaperones: emerging roles in human disease and identification of small molecule modulators. Curr Top Med Chem 6:1215–1225

Bucklin RA, Hahn GL, Beede DK, Bray DR (1992) Physical facilities for warm climates. In: Van Horn HH, Wilcox, CJ (eds) Large dairy herd management. Am. Dairy Sci. Assoc., Champaign, 61820: 609–618

Catillo G, Macciotta NP, Carretta A, Cappio-Borlino A (2002) Effect of age and calving season on lactation curves of milk production traits in Italian water buffalo. J Dairy Sci 85:1298–1306

Chance B, Sies H, Boveris A (1979) Hydroperoxide metabolism in mammalian organs. Physiol Rev 59:527–605

Chandra G, Aggarwal A (2009) Effect of DL-α-Tocopherol acetate on calving induced oxidative stress in periparturient crossbred cows during summer and winter seasons. Indian J Anim Nutr 26:204–210

Choshniak I, McEwan Jenkinson D, Blatchford DR, Peaker M (1982) Blood flow and catecholamine concentration in bovine and caprine skin during thermal sweating. Comp Biochem Physiol 71C:37–42

Clemens MR, Waller HD (1987) Lipid peroxidation in erythrocytes. Chem Phys Lipids 45:251–268

Collier RJ, Baumgard LH, Lock AL, Bauman DE (2005) Physiological limitations, nutrient partitioning. In: Sylvester-Bradley R, Wiseman J (eds) Yield of farmed species constraints and opportunities in the 21st century. Nottingham University Press, Nottingham, pp 351–377

Collier RJ, Stiening CM, Pollard BC, VanBaale MJ, Baumgard LH, Gentry PC, Coussens PM (2006) Use of gene expression microarrays for evaluating environmental stress tolerance at the cellular level in cattle. J Anim Sci 84:1–13

Collier RJ, Gebremedhin K, Macko AR, Roy KS (2012) Genes Involved in the thermal tolerance of livestock. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer Verlag GmbH Publisher, Berlin/Heidelberg

Cunningham JC, Klein BG (2007) Endocrinology. In: Textbook of veterinary physiology, 4th edn. Saunders Elsevier, St. Louis, pp 439–448

Du Preez JH, Giesecke WH, Hattingh PJ (1990) Heat stress in dairy cattle and other livestock under Southern African conditions. J Vet Res 57:183–187

Ealy AD, Drost M, Hansen PJ (1993) Developmental changes in embryonic resistance to adverse effects of maternal heat stress in cows. J Dairy Sci 76:2899–2905

Fleshner M, Johnson JD (2005) Endogenous extra cellular heat shock protein 72 releasing signal(s) and function. Int J Hyperth 21:457–471

Fuquay JW (1981) Heat stress as it affects animal production. J Anim Sci 52:164–174

Gomez Alarcon RA, Dudas D, Huber IT (1990) Influence of Aspergillus oryzae on rumen and total tract digestion of dietary components. J Dairy Sci 73:703

Hansen PJ (1994) Causes and possible solutions to the problem of heat stress in reproductive management of dairy cows. In: Proceedings of the national reproductive symposium, Pittsburgh

Hansen PJ (2009) Effect of heat stress on mammalian reproduction. Philos Trans R Soc B 364:3341–3350

Hansen JRS, Arechiga CF (1999) Strategies for managing reproduction in the heat stressed dairy cow. J Dairy Sci 77:36–50

Haque N, Ludri A, Hossain SA, Ashutosh M (2012) Alteration of metabolic profiles in young and adult Murrah buffaloes exposed to acute heat stress. Int J Appl Anim Sci 1:23–29

Hayes B, Bowman P, Chamberlain A, Goddard M (2009) A validated genome wide association study to breed cattle adapted to an environment altered by climatic change. PLoS One 4:e6676

Horowitz M (2002) From molecular and cellular to integrative heat defence during exposure to chronic heat. Comp Biochem Physiol Part A 131:475–483

Ireland HE, Leoni F, Altaie O, Birch CS, Coleman RS, Hunter Lavin C, Williams JJH (2007) Measuring the secretion of heat shock proteins from cells. Methods 43:183

Johnson HD (1987) Bioclimate effects on growth, reproduction and milk production. In: Bioclimatology and the adaptation of livestock. Elsevier, Amsterdam. Part II, chapter 3

Joshi BC, Tripathy KC (1991) Heat stress effect on weight gain and related physiological responses of buffalo calves. J Vet Physiol Allied Sci 10:43–48

Kadzere CT, Murphy MR, Silanikove N, Maltz E (2002) Heat stress in lactating dairy cows a review. Live Stock Prod Sci 77:59–91

Kamal TH (1975) Heat stress concept a new tracer methods for heat tolerance in domestic animals. Ist Science congress on peaceful use atomic energy for Scientific and Economic Development. Baghdad Iraq Proceeding of IAEA/FAO Vienna

Kamaruddin M, Kroetsch T, Basrur PK, Hansen PJ, King WA (2004) Immunolocalization of heat shock protein 70 in bovine spermatozoa. Andrologia 36:327–334

Knapp DM, Grummer RR (1991) Response of lactating dairy cows to fat supplementation during heat stress. J Dairy Sci 74:2573–2579

Koubkova M, Knizkova I, Kunc P, Hartlova H, Flusser J (2002) Influence of high environmental temperatures and evaporative cooling on some physiological haematological and biochemical parameters in high yielding dairy cows. Czech J Anim Sci 47:309–318

Kumar A (2005) Status of oxidative stress markers in erythrocytes of heat exposed cattle and buffaloes. MVSc thesis, NDRI Deemed University, Karnal

Kume S, Takahashi S, Kurihara M, Aii T (1989) The effects of a hot environment on the major mineral content in milk. Jpn J Zootech Sci 60:341–345

Lefcourt AM, Bitman J, Wood DL, Stroud B (1986) Radiotelemetry system for continuously monitoring temperature in cows. J Dairy Sci 69:237–242

Lemerle C, Goddard ME (1986) Assessment of heat stress in dairy cattle in Papua New Guinea. Trop Anim Health Prod 18:232–242

Macrae AI, Whitaker DA, Burrough E, Dowell A, Kelly JM (2006) Use of metabolic profiles for the assessment of dietary adequacy in UK dairy herds. Vet Rec 159:655–661

Mann T, Lutwak mann C (1981) Biochemistry of spermatozoa chemical and functional correlations in ejaculated semen. In: Mann T (ed) Male reproductive function and semen. Themes and trends in physiological and biochemical and investigative andrology. Lutwak Mann Spring Verlag, Berlin

Marai IFM, El-Darawany A-HA, Ismail E-SAF, Abdel-Hafez MAM (2006) Tunica dartos index as a parameter for measurement of adaptability of rams to subtropical conditions of Egypt. Anim Sci J 77:487–494

Marai IFM, EI Darawany AA, Fadiel A, Abdel Hafez MAM (2007) Physiological traits as affected by heat stress in sheep a review. Small Rumin Res 71:1–12

Marai IFM, El Darawany AA, Fadiel A, Abdel-Hafez MAM (2008) Reproductive performance traits as affected by heat stress and its alleviation in sheep a review. Trop Subtrop Agroecosyst 8:209–234

Mathevon M, Buhr MM, Dekkers JCM (1998) Environmental management and genetic factors affecting semen production in Holstein bulls. J Dairy Sci 81:3321–3330

Matsuzuka T, Sakamoto N, Ozawa M, Ushitani A, Hirabayashi M, Kanai Y (2005) Alleviation of maternal hyperthermia induced early embryonic death by administration of melatonin to mice. J Pineal Res 39:217–223. doi:10.1111/j.1600-079X.2005.00260.x

Maurya VP, Tuli RK (2003) Post thaw thermal resistance test on motility and acrosomal integrity of filtered frozen spermatozoa of Murrah buffalo bull. Asian-Australas J Anim Sci 16:1424–1428

Maurya VP, Naqvi SMK, Joshi A, Mittal JP (1999) Dominance libido and serving capacity of Garole rams under semi-arid region of Rajasthan. Indian J Anim Sci 69:773–775

Maurya VP, Tuli RK, Pardeep S (2003a) Effect of filtration on freezability and acrosomal integrity of Murrah buffalo bull semen. Indian J Anim Sci 73:983–985

Maurya VP, Tuli RK, Goyal RL (2003b) Effect of buffer composition sephadex grade and column size on filtration based quality improvement of semen from Murrah buffalo bull. Asian-Australas J Anim Sci 16:165–171

Maurya VP, Naqvi SMK, Mittal JP (2004) Effect of dietary energy level on physiological response and reproductive performance of Malpura sheep in the hot semi-arid regions of India. Small Rumin Res 55:117–122

Maurya VP, Naqvi SMK, Joshi A, Gulyani R, Mittal JP (2005) Effect of thermal stress on sexual behavior of superovulated Bharat Merino ewes. Asian-Australas J Anim Sci 18:1403–1406

Maurya VP, Naqvi SMK, Joshi A, Mittal JP (2007) Effect of high temperature stress on physiological responses of Malpura sheep. Indian J Anim Sci 77:1244–1247

Maurya VP, Kumar S, Kumar D, Gulyani R, Joshi A, Naqvi SMK, Arora AL, Singh VK (2009) Effect of body condition score on reproductive performance of Chokla ewes. Indian J Anim Sci 79:1136–1138

Maurya VP, Sejian V, Kumar D, Naqvi SMK (2010) Effect of induced body condition score differences on sexual behavior scrotal measurements, semen attributes and endocrine responses in Malpura rams under hot semi-arid environment. J Anim Physiol Anim Nutr 94:e308–e317

Maurya VP, Naqvi SMK, Joshi A, Mittal JP, Singh VK (2011) Influence of thermal stress on estrus behaviour and fertility in native Malpura sheep under semi-arid region of India. Indian J Anim Sci 81:15–18

Maurya VP, Sejian V, Kumar K, Singh G, Naqvi SMK (2012) Walking stress influence on livestock production. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GmbH Publisher, Berlin/Heidelberg

Maurya VP, Singh G, Sejian V, Sarkar M (2013) Temperature effects on milk composition and production in Livestock. In: V Prasada Rao, G Girish Varma (eds) DST SERB Sponsored training manual on

Fundamentals of Livestock Meteorology, vol I GSLH. Published by Centre for Animal Adaptation to Environment and Climate Change Studies Kerala Veterinary and Animal Sciences University Mannuthy 680651 Thrissur Kerala India

McDonald LE, Pineda MH (1989) Veterinary endocrinology and reproduction. Lea & Febriger, Philadelphia/London

Meyerhoeffer DC, Wettemann RP, Coleman SW, Wells ME (1985) Reproductive criteria of beef bulls during and after exposure to increased ambient temperature. J Anim Sci 60:352–357

More T, Singh M, Rai AK (1980) Observation on excretory pattern of sodium, potassium and water at different temperature. Indian J Anim Sci 50:182–186

Murray MT (1997) Male infertility: a growing concern. Am J Nat Med 4:9–16

Naqvi SMK (1987) Physiological adaptation of sheep during energy crisis and thermal stress. PhD thesis, submitted to Kurukshetra University, Kurukshetra

Naqvi SMK, Hooda OK (1991) Influence of thermal, nutritional and exercise stress on some blood parameters of native and crossbred sheep. Indian J Anim Sci 61:660–662

Naqvi SMK, Maurya VP, Gulyani R, Joshi A, Mittal JP (2004) The effect of thermal stress on superovulatory response and embryo production in Bharat merino ewes. Small Rumin Res 55:57–63

Nardone A, Lacetera N, Bernabucci U, Ronchi B (1997) Composition of colostrum from dairy heifers exposed to high air temperatures during late pregnancy and the early postpartum period. J Dairy Sci 80:838–844

Newton LD, Kastelic JP, Wong B, Van der Hoorn F, Thundathil J (2009) Elevated testicular temperature modulates expression patterns of sperm proteins in Holstein bulls. Mol Reprod Dev 76:109–118

Nienaber JA, Hahn GL, Eigenberg RA (1999) Quantifying livestock responses for heat stress management a review. Int J Biometerol 42:183–188

Ozawa M, Tabayashi D, Latief TA, Shimizu T, Oshima I, Kanai Y (2005) Alterations in follicular dynamics and steroidogenic abilities induced by heat stress during follicular recruitment in goats. Reproduction 129:621–630

Ozrenk E, Inci SS (2008) The effect of seasonal variation on the composition of cow milk in Van Province. Pak J Nutr 7:161–164

Paul C, Teng S, Saunders PTK (2009) A single mild transient scrotal heat stress causes hypoxia and oxidative stress in mouse testes which induces germ cell death. Biol Reprod 80:913–919

Paula Lopes FF, Chase CC Jr, Al-Katanani YM, Krininger CE III, Rivera RM, Tekin S, Majewski AC, Ocon OM, Olson TA, Hansen PJ (2003) Genetic divergence in cellular resistance to heat shock in cattle: differences between breeds developed in temperate versus hot climates in responses of preimplantation embryos, reproductive tract tissues and lymphocytes to increased culture temperatures. Reproduction 125:285–294

Pérez Crespo M, Ramírez MA, Fernández González R, Rizos D, Lonergan P, Pintado B, Gutiérrez-Adán A (2005) Differential sensitivity of male and female mouse embryos to oxidative induced heat stress is mediated by glucose 6 phosphate dehydrogenase gene expression. Mol Reprod Dev 72:502–510. doi:10.1002/mrd.20366

Raizada NS, Sastry NSR, Pal RN, Juneja IJ (1980) Studies on the effect of certain summer managemental practices on lactating Murrah buffaloes 3: physiological reactions and some attributes of blood. Haryana Agric Univ J Res 10:442–447

Raymond R, Bales CW, Bauman DE, Clemmons D, Kleinman R, Lanna D, Nickerson S, Sejrsen K (2009) Recombinant Bovine Somatotropin (rbST) a safety assessment. ADSA-CSAS-ASAS Joint Annual Meeting, Montreal

Rhoads ML, Rhoads RP, Van Baale MJ, Collier RJ, Sanders SR, Weber WJ, Crooker BA, Baumgard LH (2009) Effects of heat stress and plane of nutrition on lactating Holstein cows I production metabolism and aspects of circulating somatotropin. J Dairy Sci 92:1986–1997

Riedel W, Layka H, Neeck G (1998) Secretory pattern of GH TSH thyroid hormones ACTH cortisol FSH and LH in patients with fibromyalgia syndrome following systemic injection of the relevant hypothalamic releasing hormones. Zeitschrift Fur Rheumatologie 57(suppl 2):81–87

Ronchi B, Bernabucci U, Lacetera N, Nardone A (1995) Milk fatty acid composition in cows exposed to hot environment. In: Proceedings of XI Congress Associazione Scientifical Produzione Animale, pp 353–354

Ronchi B, Stradaioli G, Verini Supplizi A, Bernabucci U, Lacetera N, Accorsi PA, Nardone A, Seren E (2001) Influence of heat stress and feed restriction on plasma progesterone, estradiol 17b LH FSH prolactin and cortisol in Holstein heifers. Live Prod Sci 68:231–241

Roth Z, Meidan R, Braw Tal R, Wolfenson D (2000) Immediate and delayed effects of heat stress on follicular development and its association with plasma FSH and inhibin concentration in cows. J Reprod Fertil 120:83–90

Roth Z, Meidan R, Shaham Albalancy A, Braw Tal R, Wolfenson D (2001) Delayed effect of heat stress on steroid production in medium-sized and preovulatory bovine follicles. Reproduction 121:745–751

Roy KS, Prakash BS (2007) Seasonal variation and circadian rhythmicity of the prolactin profile during the summer months in repeat-breeding Murrah buffalo heifers. Reprod Fertil Dev 19:569–575

Sakatani M, Kobayashi S, Takahashi M (2004) Effects of heat shock on in vitro development and intracellular oxidative state of bovine preimplantation embryos. Mol Reprod Dev 67:77–82

Sejian V, Maurya VP, Naqvi SMK, Kumar D, Joshi A (2010a) Effect of induced body condition score differences on physiological response, productive and reproductive performances of Malpura ewes kept in a hot semi arid environment. J Anim Physiol Anim Nutr 94:154–161

Sejian V, Maurya VP, Naqvi SMK (2010b) Adaptive capability as indicated by endocrine and biochemical responses of Malpura ewes subjected to combined stresses (thermal and nutritional) under semi arid tropical environment. Int J Biometeorol 54:653–661

Sejian V, Maurya VP, Naqvi SMK (2010c) Adaptability and growth of Malpura ewes subjected to thermal and nutritional stress. Trop Anim Health Prod 42:1763–1770

Sejian V, Maurya VP, Kumar K, Naqvi SMK (2012a) Effect of multiple stresses on growth physiological response blood biochemical and endocrine responses in Malpura ewes under semi arid tropical environment. Trop Anim Health Prod 45:107–116

Sejian V, Maurya VP, Naqvi SMK (2012b) Effect of walking stress on growth, physiological adaptability and endocrine responses in Malpura ewes under semi arid tropical environment. Int J Biometeorol 56:243–252

Sejian V, Maurya VP, Kumar K, Naqvi SMK (2012c) Effect of multiple stresses (thermal nutritional and walking stress) on the reproductive performance of Malpura ewes. Vet Med Int. doi:10.1155/2012/471760

Sejian V, Maurya VP, Sharma KC, Naqvi SMK (2012d) Concept of multiple stresses and its significance on livestock productivity. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer Verlag GMbH Publisher, Berlin/Heidelberg

Sethi RK, Bharadwaj A, Chopra SC (1994) Effect of heat stress on buffaloes under different shelter strategies. Indian J Anim Sci 64:1282–1285

Shinde S, Taneja VK, Singh A (1990) Association of climatic variables and production and reproduction traits in crossbreds. Indian J Anim Sci 15:29–31

Singh SV, Upadhyay RC, Ashutosh, Hooda, OK, Vaidya, MM (2011) Climate change impacts on reproductive pattern of cattle and buffaloes review. Wayamba J Anim Sci WJASID 1322125457

St Pierre NR, Cobanov B, Schnitkey G (2003) Economic loss from heat stress by US livestock industries. J Dairy Sci 86:52–77

Todini L, Malfatti A, Valbonesi A, Trabalza Marinucci M, Debenedetti A (2007) Plasma total T_3 and T_4 concentrations in goats at different physiological stages as affected by the energy intake. Small Rumin Res 68:285–290

Trevisan M, Browne R, Ram M, Muti P, Freudenheim J (2001) Correlates of markers of oxidative status in the general population. Am J Epidemiol 154:348–356

Tytell M (2005) Release of heat shock proteins (HSPS) and the effects of extracellular HSPS on neural cells and tissues. Int J Hyperth 21:445–455

Uetake K, Ishiwata T, Abe N, Eguchi Y, Tanaka T (2006) Hormonal and metabolic relation to restraint and human handling in growing fattening steers. Anim Sci J 77:370–374

Verma DN, Lal SN, Singh SP, Prakash O (2000) Effect of season on biological response and productivity of buffaloes. Int J Anim Sci 15:237–244

Wallace JM, Regnault TR, Limesand SW, Hay WW Jr, Anthony RV (2005) Investigating the causes of low birth weight in contrasting ovine paradigms. J Physiol 565:19–26

Wang JZ, Sui HS, Miao DQ, Liu N, Zhou P, Ge L, Tan J (2009) Effects of heat stress during in vitro maturation on cytoplasmic versus nuclear components of mouse oocytes. Reproduction 137:181–189

West JW, Hill GM, Fernandez JM, Mandebvu P, Mullinix BG (1999) Effects of dietary fiber on intake milk yield and digestion by lactating dairy cows during cool or hot, humid weather. J Dairy Sci 82:2455–2465

Yarney TA, Sanford LM, Palmer WM (1990) Pubertal development of ram lambs: body weight and testicular size measurements as indices of postpubertal reproductive function. J Anim Sci 70:139–147

Zimbelman RB, Muumba J, Hernandez LH, Wheelock JB, Shwartz G, O'Brien MD, Baumgard LH, Collier RJ (2007) Effect of encapsulated niacin on resistance to acute thermal stress in lactating Holstein cows. J Dairy Sci 86(Suppl. 1):231 (Abstr)

Part III

Livestock Role in Climate Change

Global Warming: Role of Livestock

10

Veerasamy Sejian, Iqbal Hyder, T. Ezeji, J. Lakritz,
Raghavendra Bhatta, J.P. Ravindra,
Cadaba S. Prasad, and Rattan Lal

Abstract

This chapter provides an overview of the current state of knowledge concerning global warming with special reference to contribution from livestock resources. Global warming pertains to the effect of natural greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and halogenated compounds on the environment. These GHGs are generated by humans and human-related activities. Carbon dioxide, CH_4, and N_2O are the principal sources of radiative forcing (Fifth IPCC Report of 2013). Interestingly, livestock contributes to climate change through emissions of CO_2, CH_4, and N_2O into the atmosphere. Globally, the livestock sector directly and indirectly contributes 18 % (7.1 billion tonnes CO_2 equivalent) of GHG emissions. While direct GHG emissions from livestock refer to emissions from enteric fermentations in livestock, urine excretion, and microbial activities in manures, indirect GHG emissions are those not directly derived from livestock activities but from manure applications on farm crops, production of fertilizer for growing crops used for animal feed production, and processing and transportation of refrigerated livestock products. Other indirect emissions include

---

V. Sejian (✉) • J.P. Ravindra
Animal Physiology Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India
e-mail: drsejian@gmail.com

I. Hyder
Department of Veterinary Physiology,
NTR College of Veterinary Science,
Gannavaram 521102, Andhra Pradesh, India

T. Ezeji
Department of Animal Sciences, The Ohio State
University, Wooster Campus, Wooster, OH 44691,
USA

J. Lakritz
Department of Veterinary Clinical Sciences, The
Ohio State University, Columbus, OH 43210, USA

R. Bhatta • C.S. Prasad
ICAR-National Institute of Animal Nutrition
and Physiology, Adugodi, Hosur Road, Bangalore,
Karnataka 560030, India

R. Lal
Carbon Management and Sequestration Center,
School of Environment and Natural Resources, The
Ohio State University, Columbus, OH 43210, USA

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_10, © Springer India 2015

deforestation, desertification, and release of carbons from cultivated soils due to expansion of livestock husbandry. According to FAO's Global Livestock Environmental Assessment Model (GLEAM), the GHG emission from livestock-related activities was estimated to be around 7.1 gigatonnes CO_2-eq. per annum, representing 14.5 % of human-induced emissions. This clearly indicates the significant role for livestock contributions to climate change.

Keywords
Enteric fermentation • GLEAM • Global warming • Livestock • Manure management • Methane and nitrous oxide

10.1 Introduction

The livestock sector accounts for 40 % of the world's agriculture-related gross domestic product (GDP). It employs 1.3 billion people and provides livelihoods for around one billion of the world's population living in poverty (FAO 2006a, b). In many parts of the world, climate change is seen as a major threat to the survival of many species, ecosystems, and the sustainability of livestock production systems (Moss et al. 2000). Global demand for livestock products is expected to double during the first half of this century due to the growing human population and its growing affluence. Over the same period, we expect significant global climate change. The dramatic global expansion of crop production for biofuels is already impacting resources available for food production vis-à-vis food supply and cost. Food security remains one of the highest priority issues in developing countries, and livestock production plays key roles in many of these countries. However, food security is reemerging as an important issue in many developed countries that had previously regarded it as "solved." These interconnected issues are creating immense pressure on the planet's resources. Therefore, there is a need for efficient animal husbandry practices and systems to help meet rising demand for livestock products in an environmentally and socially responsible manner (Dunshea et al. 2013).

Notably, the Intergovernmental Panel on Climate Change (IPCC) used the term "unequivocal" to describe their level of confidence in global temperature data trends, and the Royal Society recognizes that the scientific community agrees with climate change phenomenon (Royal Society 2010; IPCC 2013). The scale of fluctuations in climatic conditions varies from millions of years to decades or less (Lamy et al. 2006; Yang et al. 2006). The current trend of climatic warming is currently a planetwide observation, which may correspond to natural warming phase being accelerated due to changes in anthropogenic factors during the last two centuries. A broad set of observations and analyses reveal that anthropogenic activity or GHG is the main factor triggering the present global warming (Trenerth et al. 2006; Kerr and Balter 2007). However, the IPCC is not clear on the chief cause of global warming but only indicates that anthropogenic activity has a probability greater than 90 % for being the main factor influencing the global temperature (IPCC 2013). Meanwhile, a few recent papers have raised some doubts about the driving role of GHG (Stanhill 2007; Svensmark 2007). A set of scientific community argue that the main reason for the present climatic behavior is natural (sun variability being the most probable) and it is very likely that the future warming will be moderate (Zastawny 2006; Lockwood and Fröhlich 2007). Considering this scenario, the IPCC notes that the temperature will rise by several degrees and the warm phase will last for centuries with dramatic consequences beyond what can reasonably be defined at present. Notably, global surface temperature increased by about 1.4 °F (Smith et al. 2008) during the past century. According to satellite measurements, the global average lower atmosphere warmed by 0.24 °F per decade, equivalent to 2.4 °F per century in the past three decades, indicating an acceleration in warming during the period (Christy and Spencer 2005; Mears and Wentz 2005). The ocean currently takes up over 80 % of heat added to the climate system, and the average temperature of the global ocean has increased to depths of at least 3,000 m (include reference). New analyses of balloon-borne and satellite measurements of lower- and mid-tropospheric temperature show warming rates similar to those observed in surface temperature. As the warming process continues, it will bring about numerous environmental changes, among which will be water resources (Milly et al. 2005; IPCC 2013) which will consequently impact dependent factors.

Climate change may slow the progress toward sustainable development either directly through increased exposure to adverse impacts or indirectly through erosion of the capacity to adapt to products of climate change (Melillo et al. 2014). Over the next half century, climate change could impede attainment of the Millennium Development Goals. Climate change may interact with other trends in global environmental and natural resource concerns, including water, soil, and air pollution, health hazards, disaster risk, and deforestation, at different degrees. In the absence of integrated mitigation and adaptation measures, their combined impacts in the future may be confounding (IPCC 2013). The IPCC predicts that by 2100 the increase in global average surface temperature may be between 1.8 and 4.0 °C. With global average temperature increases of only 1.5–2.5 °C, approximately 20–30 % of plant and animal species are expected to be at risk of extinction (FAO 2007). The temperature record is not the only indication of a changing climate. There are many other indicators such as substantial melting of mountain glaciers around the world, decreased snow cover in the Northern Hemisphere, decreased tropical precipitation, increased mid-to-high latitude precipitation, sea level increases, increased ocean acidification, decreased Arctic ice area, and thinning of Arctic ice.

Climate change is not a new phenomenon in the Earth's history. The geological record shows that climate is in a state of continual change with major ice ages occurring approximately every 100,000 years. Regular occurrence of ice ages has been associated with subtle changes in the separation and relative orientation of the Earth and the Sun. Currently, we are in a period between two ice ages. In the absence of other influences, it is probable to enter another ice age over a timescale of thousands of years. Ecological systems have evolved over geological timescales to suit the prevailing climate. The past 10–20 years have shown disturbing clues that human activities may cause significant changes in future global climate. Since the IPCC Fourth Assessment Report, additional simulations appear to reinforce earlier reasoning that both natural drivers (volcanic aerosols, solar variations, orbital variations) and human drivers (greenhouse gases and aerosols) are required to elucidate the observed recent hemispheric and global temperature variations of which the greenhouse gas increases are the main cause of the warming during the past century (Karl et al. 2006; Tett et al. 2007; Wanner et al. 2008). Temperature changes due to human activities have now been identified in each of the seven continents (Stott et al. 2010). Recent research has extended this conclusion to regional and seasonal scales (Min and Hense 2007; Bhend and von Storch 2008; Bonfils et al. 2008; Jones et al. 2008). "Global warming" is now an issue known to millions of people around the world. We provide herein an overview of the current state of knowledge concerning global warming with special focus on contribution from livestock resources.

10.2 Global Warming/Climate Change

Weather is the state of the atmosphere (temperature, humidity, precipitation, wind, cloud cover, etc.) in a particular location at a particular time. While weather fluctuates greatly and is difficult to predict, the availability of sophisticated new technologies in the past few decades has improved weather prediction (FAO 2012; Tubiello et al. 2013). Therefore, climate may be defined as time-averaged weather in a given geographical region and a temporospatial phenomenon more predictable than weather. Whereas the average temperature in a given month in a particular area (climate) can be predicted with high degree of confidence, the degree of confidence at predicting the temperature at a given time and location (weather) is lower given that climate varies from month to month, season to season, and year to year. Statistically significant changes in climate over a timescale of decades or longer constitute "climate change" (Wallington et al. 2004).

Global warming has been known for over 100 years because water vapor, carbon dioxide, and methane (CH_4) naturally present in the atmosphere have been said to trap heat in the atmosphere. It is relatively simple to estimate the magnitude of this "natural greenhouse effect," dynamics of heat, and radiation exchange between Earth and the surrounding space (Wallington et al. 2004). The only mechanism by which the Earth can cool itself is via emission of infrared radiation into space. At infrared frequencies the Earth behaves like a black body (when seen in IR light even "white" clouds and snow appear "black"). Emission from a black body is given by $\sigma \times T^4$, where σ is the Stefan–Boltzmann constant (5.67×10^{-8} J m^{-2} K^{-4} s^{-1}) and T is the temperature of the black body. Hence, at radiative equilibrium, we would expect the average surface temperature to be approximately 254 K (−19 °C). In reality the average surface temperature of the Earth is 288 K (15 °C); the 34 °C difference is attributable to infrared radiation (heat) trapped in the atmosphere by greenhouse gases, i.e., the natural greenhouse effect. Without the natural greenhouse effect, the planet would be permanently frozen and devoid of life. "Global warming" refers to the enhanced greenhouse effect expected to result from an increase in atmospheric concentration of greenhouse gases resulting from emissions associated with human activities.

While "global warming" and "climate change" are often interchangeably used, the former focuses on temperature increases, for which seemingly contradictory evidence exists – for example, record snowfalls in the Eastern United States in 2010 (Samenow 2010) – whereas the latter, "climate change," conveys more general associations of temperature changes, which can easily accommodate unusually cold temperatures and record snowfalls. Whitmarsh (2009) observed that "global warming" evokes stronger connotations of human causation, whereas "climate change" evokes stronger connotations of natural causation. The term "global warming" entails a directional prediction of rising temperatures, whereas "climate change" lacks a directional commitment and easily accommodates unusual weather of any kind.

10.3 Sources of GHGs for Global Warming

The three most important and long-lived greenhouse gases in the atmosphere are carbon dioxide, CH_4, and nitrous oxide. In addition halogenated organic compounds (of which CFCs are a subset), SF_6, and ozone in the lower and upper atmosphere are also important. To assist policy makers to understand the potential impact of different greenhouse gases on the climate, the concept of global warming potential (GWP) was introduced. This concept compares the potential impact of different greenhouse gases using carbon dioxide as a reference greenhouse gas. The use of carbon dioxide as a reference greenhouse gas is logical since it is the most important greenhouse gas associated with human activities. Global warming potential is an index that attempts to integrate the overall climate impacts of a specific action. It relates the impact of emissions of a gas to that of emission of an equivalent mass of CO_2. Table 10.1 describes the GWP and lifetime of GHGs.

Table 10.1 Global warming potential and lifetime of GHGs

GWP values and lifetimes of GHGs	Lifetime (years)	GWP time horizon	
		20 years	100 years
CH_4	12.4	86	34
HFC-134a	13.4	3,790	1,550
CFC-11	45.0	7,020	5,350
Nitrous oxide	121.0	268	298
Carbon tetrafluoride	50,000	4,950	7,350

Source: IPCC AR5 (2013)

10.3.1 Carbon Dioxide (CO_2)

Carbon is transferred in various forms through the atmosphere, oceans, plants, animals, soils, and sediments as part of the "carbon cycle." The term "carbon budget" is often used to describe the balance of inflows and outflows that lead to the accumulation of carbon dioxide in the Earth's atmosphere. These natural inflows and outflows were approximately equal for several thousands of years before the effects of the industrial revolution became apparent around 1,800 (Raupach et al. 2011). Hence, emissions of CO_2 associated with human activities are small when compared to natural fluxes of CO_2 associated with photosynthesis, respiration, uptake into ocean water, and release from ocean water. Since the early nineteenth century, there has been a large and increasing added inflow of carbon dioxide into the atmosphere from human activities such as deforestation, land clearing, burning of fossil fuels, cement production, and other industrial processes. Emissions from fossil fuels are the largest source of atmospheric carbon dioxide from human activities. Between 2000 and 2008, fossil fuel emissions increased at a rate of 3.4 % per year, compared to 1 % in the 1990s (Le Quere et al. 2009), and have continued to track well above the IPCC scenario ("A1FI") with the highest emissions through to 2100. Land-use changes, such as deforestation and conversion of lands to farms, are the second largest source of carbon dioxide emissions from human activities. Emissions from these sources can be offset to some extent by biosequestration. In contrast to the 29 % increase in fossil fuel emissions during 2000–2008, land-use emissions have been fairly steady (Le Quere et al. 2009).

The human-caused inflow into the carbon cycle is partly offset by natural carbon dioxide "sinks" in both the land and oceans. Changes in the carbon dioxide sink on land are determined by the balance between plant growth and land-use disturbances such as fire and clearing. The ocean acts as a carbon sink because carbon dioxide dissolves in ocean waters when carbon dioxide concentrations in the atmosphere are higher than those at the ocean's surface. This dissolved carbon is moved into the deeper ocean by overturning circulations and by sinking of dead organisms in the ocean (Raupach et al. 2011).

Over the past half century, the uptake of carbons by these natural sinks has resulted in the removal of about half of the total carbon dioxide released into the atmosphere. There is considerable variation in the strength of natural carbon sinks from year to year, largely in response to climate variability (Raupach and Canadell 2010; Raupach et al. 2011). Some recent studies have indicated that there has been a decline in the fraction of carbon dioxide emissions from human activities that is absorbed by natural carbon sinks in the last five decades (Canadell et al. 2007; Le Quere et al. 2009), albeit, there is disagreement in the science community about the validity of these results. Thus, uncertainty remains about the decline in the absorption capacity of the natural carbon sinks.

10.3.2 Methane (CH_4)

Methane (CH_4) is the most abundant well-mixed greenhouse gas after carbon dioxide. The presence of CH_4 in the atmosphere has been known since the 1940s when Migeotte (1948) observed that strong absorption bands in the infrared region of the solar spectrum were attributed to the presence of atmospheric CH_4. The current global average atmospheric concentration of CH_4 is 1,720 ppbv, more than double its preindustrial value of 700 ppbv (Bolle et al. 1986). In contrast to carbon dioxide, CH_4 is removed from the atmosphere via chemical reaction with hydroxyl (OH) radicals. CH_4 plays an important role in atmospheric chemistry, and it can influence the levels of other important trace species via its reaction with OH. All other factors being constant, increased atmospheric levels of CH_4 will result in decreased concentrations of OH and hence a longer lifetime for any gas whose atmospheric lifetime is influenced by reaction with OH. Also, an increase in CH_4 will lead to the production of more tropospheric ozone which is an important greenhouse gas.

Methane is emitted into the atmosphere by a large number of natural and anthropogenic sources. Natural sources are believed to contribute approximately 30 % of the CH_4 flux, while anthropogenic sources account for the remaining 70 %. Natural sources are estimated to contribute a total of approximately 160 teragrams (Tg) (CH_4) year^{-1} (1 Tg = 10^{12} g, 1,000 Tg = 1Gt). The largest natural sources are wetlands, termites, and oceans which emit 115, 20, and 10 Tg(CH_4) year^{-1}, respectively. Anthropogenic sources are natural gas facilities, coal mines, petroleum industry, coal combustion, enteric fermentation, rice paddies, biomass burning, landfills, animal waste and domestic sewage and are estimated to emit 40, 30, 15, 15, 85, 60, 40, 40, 25, and 25 Tg(CH_4) year^{-1}, respectively, for a total anthropogenic contribution of 375 Tg(CH_4) year^{-1}. The identified sources total approximately 535 Tg(CH_4) year^{-1}. Environment (natural and man-made wetlands, enteric fermentation, and anaerobic waste processing) is the major source of CH_4, although emissions associated with coal and natural gas industries are also significant. The primary sink for CH_4 is reaction with hydroxyl radicals in the troposphere (Crutzen 1991, 1995; Fung et al. 1991), but small soil (Mosier et al. 1991; Steudler et al. 1989; Whalen and Reeburg 1990) and stratospheric (Crutzen 1991, 1995) sinks have also been identified.

10.3.3 Nitrous Oxide (N_2O)

Nitrous oxide (N_2O) is the third most abundant greenhouse gas in the atmosphere after CO_2 and CH_4. The N_2O which has a long residence time of 130 years is a trace constituent of the lower atmosphere. Its concentration in the lower atmosphere is currently 313 ppb with annual increment of 0.5–0.9 ppb (provide reference). The industrial sources of N_2O include nylon production, nitric acid production, fossil fuel-fired power plants, and vehicular emissions. It was once thought that emission from automobile catalytic converters was the major source of N_2O, but extrapolating measurements of N_2O emissions from automobiles in roadway tunnels in Stockholm and Hamburg showed that vehicular emissions accounted for only 0.24 ± 0.14 TgN/year (Berges et al. 1993). Later measurements suggest even smaller emissions (0.11 ± 0.04 TgN/year) originated from automobiles (Becker et al. 1999; Jiménez et al. 2000). The concentration of N_2O in the atmosphere has increased by approximately 16 % since preindustrial times. In addition to its significance as a greenhouse gas, N_2O is transported through the troposphere into the stratosphere where it reacts with O (^{1}D) atoms to generate NO_x, becoming the source of stratospheric NO_x. Notably, O (^{1}D) atoms are electronically excited oxygen atoms. Natural sources of N_2O associated with emissions from soils and the oceans are estimated to release 10.2 TgN year^{-1} to the atmosphere. Anthropogenic emissions of N_2O are associated with biomass burning, fossil fuel combustion, industrial production of adipic and nitric acids, and the use of nitrogen fertilizer and are believed to total 3.2 TgN year^{-1}. Photodissociation in the stratosphere is the major (90 %) mechanism with which N_2O is degraded in the atmosphere. The remaining 10 % of N_2O is degraded through reaction with O (^{1}D) atoms to produce NO_x. Enhanced N_2O emissions from agricultural and natural ecosystems are believed to be caused by increasing soil N availability driven by increased fertilizer use, agricultural nitrogen (N_2) fixation, and N deposition; and this scenario may rationalize the steady increase in atmospheric N_2O over the last 150 years (Nevison and Holland 1997). In addition to N availability, soil N_2O emissions are regulated by temperature and soil moisture and are likely to respond to climate changes (Frolking et al. 1998; Parton et al. 1998).

10.3.4 Hydrofluorocarbons

Hydrofluorocarbon (HFC) abundance in the atmosphere is in the following order of magnitude: HFC-23 (CHF_3), HFC-134a (CF_3CH_2F), and HFC-152a (CH_3CHF_2). Recent rise in these HFCs is along with some major hydrochlorofluorocarbons (HCFCs), the latter being controlled under the Montreal Protocol and its amendments.

HFC-23 is a by-product of HCFC-22 production. It has a long atmospheric lifetime of 260 years, so that most emissions, which have occurred over the past two centuries, will still be in the atmosphere. Between 1978 and 1995, HFC-23 increased from about 3–10 ppt; and it continues to increase even at a greater rate (Oram et al. 1996). HFC-134a is used primarily as a refrigerant, especially in car air conditioners. It has an atmospheric lifetime of 13.8 years, and its annual emissions have grown from near zero in 1990 to an estimated 0.032 Tg/year in 1996. The abundance continues to increase almost exponentially as the use of this HFC increases (Oram et al. 1996; Simmonds et al. 1998). HFC-152a gas has a short-residence time with a mean atmospheric lifetime of 1.4 years. Its accumulation in the atmosphere is steadily increasing, but its low emissions and a short lifetime have kept its abundance below 1 ppt.

Carbon–halogen bonds (e.g., C–F, C–Cl, C–Br) absorb strongly at infrared wavelengths, and this is why halogenated organic compounds are strong greenhouse gases. The effectiveness of these compounds as greenhouse gases depends on two factors: (1) the number of carbon–halogen bonds in the molecule and (2) the atmospheric lifetime of the molecule. In general, the atmospheric lifetime of organic compounds is dictated by their reactivity with OH (hydroxyl) radicals. Hydroxyl radicals are essentially unreactive with C–F, C–Cl, and C–Br bonds; hence, increasing halogenation of the molecule increases the atmospheric lifetime and the greenhouse gas effect strength of the molecule. While perfluorocarbons (PFCs) have lifetimes of the order of thousands of years, CFC and Halon residence time in the atmosphere typically is between 50 and 100 years.

10.3.5 Perfluorocarbons

Perfluorocarbons (PFCs), in particular tetrafluoromethane (CF_4), sulfur hexafluoride (SF_6), and hexafluoroethane (C_2F_6), with atmospheric lifetimes longer than 1,000 years, have large absorption cross sections for terrestrial infrared radiation. These compounds are far from a steady state between sources and sinks, and even net emissions will contribute to radiative effects that can extend to the next several millennia.

Current emissions of C_2F_6 and SF_6 are clearly anthropogenic, and this is evident from their higher concentration in the atmosphere. Analysis of SF_6 in the atmosphere showed that this gas has an annual increase of about 7 %/year during the 1980s and 1990s (Geller et al. 1997; Maiss and Brenninkmeijer 1998). Important sinks for PFCs and SF_6 are photolysis or ion reactions in the mesosphere. These gases provide useful tracers of atmospheric transport in both troposphere and stratosphere. On a per molecule basis, sulfur hexafluoride (SF_6) is one of the most potent greenhouse gases known. Its potency stems from its intense absorption at 10.3 μm (969 cm^{-1}) in the atmospheric window region and its extremely long atmospheric lifetime of 3,200 years. SF_6 is present in small amounts in fluorites, and degassing of these minerals provides a small natural source of SF_6 which results in a natural background concentration of 0.01 ppt. SF_6 is a useful industrial chemical used as an insulating gas in electrical switching equipment. As a result of anthropogenic emissions, the current level of SF_6 in the atmosphere is approximately 400 times that of the natural background and increasing at a rate of approximately 0.2 ppt $year^{-1}$ (Wallington et al. 2004).

A new, long-lived, anthropogenic greenhouse gas has recently been found in the atmosphere (Sturges et al. 2000). Trifluoromethyl sulfur pentafluoride (SF5CF3) – a hybrid of PFCs and SF_6 not specifically addressed in Annex A of the Kyoto Protocol – has the largest radiative forcing, on a per molecule basis, of any gas found in the atmosphere to date. Its abundance has grown from near zero in the late 1960s to about 0.12 ppt in 1999.

10.3.6 Ozone (O_3)

Currently, tropospheric ozone (O_3) is the fourth most important greenhouse gas after CO_2, CH_4, and N_2O. It is a product of photochemistry, and its future abundance is controlled primarily by emissions of CH_4, carbon monoxide (CO), nitrogen oxides (NO_x), and volatile organic compounds (VOC). The model assessment of the increase in tropospheric O_3 is becoming more reliable since the preindustrial period and estimated to account for 30% increase in emission or future emissions for scenarios in which the CH_4 abundance doubles and anthropogenic CO and NO_x emissions triple, the tropospheric O_3 abundance is predicted to increase by an additional 50 % above today's abundance.

Limited observations from the late nineteenth and early twentieth centuries when incorporated in climate models (what model?) suggest that tropospheric O_3 has increased from a global mean value of 25 DU (where 1 DU = 2.7×10^{16} O_3 molecules/cm^2) in the preindustrial era to 34 DU today.

10.3.7 Aerosols

Aerosols are tiny submicron particles (e.g., soot, mineral dust) or tiny droplets (e.g., sulfuric acid or organic compounds) that are either emitted directly into the atmosphere (primary aerosols) or formed from emitted gases during chemical reactions (secondary aerosols). While they are generated from human activities such as fossil fuel burning, transport emissions, biomass burning, and land-use changes, they are also produced naturally by vegetation, marine algae, volcanoes, and high wind stress over naturally arid regions.

Atmospheric aerosols are solid or liquid particles suspended in the air, which are often visible as dust, smoke, and haze. Aerosols can affect the Earth's energy budget by scattering and absorbing heat and sunlight (known as "direct effects") and by modifying the properties of clouds (known as "indirect effects") (Chin et al. 2009). These influences can lead to both warming and cooling.

While some aerosols (such as black carbon) can have a warming influence, at the global average level, the overall effect of aerosols is cooling. Most aerosols reflect incoming solar radiation back to space, thereby preventing it reaching the Earth's surface. In this way, increases in the amount of sulfates in the atmosphere have produced a negative forcing of −0.5 W m^{-2} during the past 250 years. An additional negative forcing has also come from extra droplets of organic compounds from fossil fuel and biomass burning. Larger particles like dust can also absorb infrared radiation emitted by the Earth, thus preventing it from reaching the space and, consequently, exerting a greenhouse gas effect. This effect is highly dependent on the surface over which the aerosol lies and the size and the sign of radiative forcing. A recent assessment estimated that the warming contribution of 1 g of black carbon could be anything from 100 to 2,000 times that of the same amount of carbon dioxide UNEP and WMO 2011.

Some types of aerosol can have an "indirect" effect on climate. The particles can act as cloud condensation nuclei, altering the number of droplets in a cloud and, therefore, its lifetime and brightness. These cloud changes then affect the amount of radiation reaching the Earth's surface. During the past 250 years, these effects are thought to have resulted in a negative radiative forcing, the magnitude of which could be (on a global mean scale) nearly as large as the total positive greenhouse gas radiative forcing over the same period of time. However, since we know relatively little about the interaction between aerosols and clouds, the final result is unclear. Additionally, some aerosols can provide surfaces on which chemical reactions can occur (Wallington et al. 2004).

10.3.8 Land-Use Changes

Land-use change is defined as greenhouse gas emissions from human activities and removals which either change the way land is used (e.g., clearing of forests for agricultural use) or have an effect on the amount of biomass in existing biomass stocks (e.g., forests, village trees, woody savannas, etc.) (IPCC 2000a, b). Anthropogenic land-use changes due to agricultural practices, deforestation, overgrazing, desertification, and urbanization lead to a change in the surface characteristics of the Earth. Changes in land use have an impact in carbon fluxes, and many of the land-use changes involve livestock, either occupying the land (as pasture of arable land for feed crops) or releasing land for other purposes. In addition to producing CO_2 emissions, the land conversion may also negatively affect other emissions. Mosier et al. (2004), for example, noted that upon conversion of forest to grazing land, CH_4 oxidation by soil microorganisms is typically greatly reduced and grazing lands even become net source in situations where soil compaction from cattle traffic limits gas diffusion. In the past 200–250 years, such changes have led to an increase in albedo (the fraction of incoming radiation returned to space via scattering by gas molecules and reflection by clouds and at the Earth's surface). Over the past 250 years, land-use changes have produced a negative global mean radiative forcing of -0.2 W m^{-2}. Human-induced land-use change may also indirectly cause other radiative forcing such as increased atmospheric aerosol loading (Wallington et al. 2004).

10.3.9 Solar Variability

The temperature of the Earth and its atmosphere is determined by the balance of the incoming solar radiation and the heat that is radiated by the Earth back into space. Temperature changes can occur as a result of the amount of radiation coming in or out of the Earth (i.e., radiation trapped in the atmosphere). This balance can be influenced by a range of disturbances, including the sun's output, volcanic eruptions, and changes in the Earth's orbit. Changes in the amount of solar radiation reaching the Earth have been implicated in temperature fluctuations in the last 10,000 years. For the last 150 years, and especially since 1970, changes in solar output have been known with greater accuracy. Climate can be affected by changes in the Sun–Earth orbital parameters such as axis tilt, Sun–Earth distance, and the obliquity of the orbit. However, these typically vary on timescales of thousands of years and are generally not considered to have played a major role in climate change over the past 250 years. Recent research suggests that solar output could have contributed up to 10 % of the observed warming trend in the twentieth century; however, other warming influences need to be considered (Lean and Rind 2008).

10.3.10 Volcanic Activity

Large explosive volcanic eruption of Mount Pinatubo in the Philippines that happened in 1991 is capable of releasing enormous sulfur dioxide gas into the stratosphere where it can be converted into sulfuric acid aerosol. Since it is above the weather, this aerosol can remain in the stratosphere for 2–3 years, and for a tropical eruption, aerosol can be spread quickly around the globe by the winds. The aerosol can reflect solar radiation back to space and, consequently, cause the surface to cool. It can absorb some solar and long wave radiation and cause the stratosphere to warm. The Pinatubo eruption produced a peak global mean radiative forcing of about -4 W m^{-2}, and the surface and stratospheric temperatures remained altered by a few tenths of a degree for up to 4 years after the eruption. Individual eruptions give a transient effect on climate and have limited long-term effects. It is therefore difficult to compare their radiative forcing with the other mechanisms. However, the cumulative effect of several eruptions during active volcanic periods could produce a prolonged effect on climate. The difference in radiative forcing between active and quiet decades could be as much as 1 W m^{-2}.

10.4 Impact of Global Warming

The development or disappearance of civilizations may be determined by natural and "moderate" climatic change (Kumar et al. 2006; Issar and Zohar 2007). For instance, a global temperature rise of 28 °C above preindustrial levels is capable of delivering a "dangerous climate change" (Schellnhuber et al. 2006). While it is difficult to attribute specific causes to individual extreme weather events (Allen et al. 2007), climate change is expected to increase the risk of the occurrence of extreme events that can lead to changes in the frequency, intensity, and distribution of "severe" weather events. The magnitude of future consequences can be inferred from the dramatic effects caused by the natural and "moderate" climatic changes that occurred in the last millennium, during which millions of deaths attributed to the alternation of droughts and short cool–warm periods occurred around the world (Fagan 2001; Davis 2002). A comprehensive knowledge of climate variations in space and time is vital to the adaptation and survival of the humanity.

There is going to be an immense pressure on global water resources, especially groundwater resources due to climate change. The global volume of groundwater is estimated at between 13 and 30 % of the total volume of freshwater of the hydrosphere (Jones 1997; Babklin and Klige 2004). The groundwater provides 15 % of the water used annually (Shiklomanov 2004b), while the remainder come from surface water. There is a general consensus that majority of areas that have high precipitation currently are expected to experience precipitation increases, whereas areas with low precipitation and high evaporation and currently experiencing water scarcity are expected to have rain decreases (IPCC 2007a, b, c; Issar and Zohar 2007). As conditions change rapidly, the existing infrastructure network will have to be reshaped rapidly (Potter 2002; Semadeni-Davies et al. 2007).

Anthropogenic warming and sea level rise may continue for centuries even if GHG emissions and concentrations in the atmosphere are reduced and stabilized due to the timescales associated with climate processes and feedbacks. Some systems, sectors, and regions are *likely* to be especially affected by climate change. The systems and sectors are some ecosystems (tundra, boreal forest, mountain, Mediterranean type, mangroves, salt marshes, coral reefs, and the sea-ice biome), low-lying coasts, water resources in some dry regions at mid-latitudes and in the dry topics and in areas dependent on snow and ice melt, agriculture in low-latitude regions, and human health in areas with low adaptive capacity. The regions are the Arctic, Africa, small islands, and Asian and African megadeltas. Impacts of anthropogenic warming are *very likely* to increase due to increased frequencies and intensities of some extreme weather events. Recent events around the globe have demonstrated the vulnerability of some sectors and regions to heat waves, tropical cyclones, and floods and drought, thus providing stronger evidence for concern about climatic change.

10.5 Livestock and Climate Change

Livestock contribute both directly and indirectly to climate change through the emissions of greenhouse gases such as carbon dioxide, CH_4, and nitrous oxide. Globally, the sector contributes 18 % (7.1 billion tonnes CO_2 equivalent) of global greenhouse gas emissions. Although it accounts for only 9 % of global CO_2, it generates 65 % of human-related nitrous oxide (N_2O) and 35 % of CH_4, which have 296 times and 23 times the global warming potential (GWP) of CO_2, respectively. CH_4 emissions mostly occur as part of the natural digestive process of animals (enteric fermentation) and manure management in livestock operations. CH_4 emissions from livestock are estimated at about 2.2 billion tonnes of CO_2 equivalent, accounting for about 80 % of agricultural CH_4 and 35 % of the total anthropogenic CH_4 emissions. Nitrous oxide emissions are associated with manure management and the application and deposition of manure. Indirect N_2O emissions from livestock production include emissions from fertilizer use for feed production, emissions from leguminous feed crops, and emissions from aquatic sources following fertilizer application. The livestock sector contributes about 75 % of the agricultural N_2O emissions (2.2 billion tonnes of CO_2 equivalent). Carbon dioxide emissions from the livestock sector are related to fossil fuel burning during production of fertilizer for feed production, the livestock production process, and processing and transportation of refrigerated products. Furthermore, livestock are a major driver of the global trends in land use and land-use change including deforestation (conversion of forest to pasture and cropland), desertification, as well as the release of carbon from cultivated soils. The overall contribution of CO_2 emissions from the livestock sector is estimated at 2.7 billion tonnes of CO_2. These estimates of the sector's role in climate change are a result of LEAD's efforts to quantify the sector's impacts at a global scale. More detailed analysis is required to shape policies that can effectively mitigate environmental impact at every relevant step of the various commodity chains and help adapting to climate change (FAO 2006a, b).

10.6 Sources of GHG from Livestock

The livestock sector is a key contributor to a range of critical environmental problems (Millennium Ecosystem Assessment 2005; Steinfeld et al. 2006). It is becoming clear that meat and dairy products carry the greatest environmental burden, accounting for approximately half of food-generated GHG emissions (European Commission 2006; Jan Kramer et al. 1999). Substantial projected growth in this sector from 2000 to 2050 due to increasing population and per capita demand will effectively double the production of GHG volumes (FAO 2006a, b; World Bank 2008). A significant share of ruminants' environmental footprint is caused by enteric CH_4 that represents about >25 % of the annual anthropogenic (man-made sources) CH_4 emitted into the atmosphere with global dairy sector contributing 2.7–4 % of the total anthropogenic GHG emissions (FAO 2010). However, ruminants release CO_2 as a by-product of respiration is not considered in the calculation of GHG emission from livestock (EPA et al. 2006; FAO 2006a; Kyoto Protocol 1997). CO_2 emissions from livestock are considered as part of the continuous cycling biological system where plant matter that had once sequestered CO_2 is consumed by livestock and then released back into the atmosphere by respiration to be later reabsorbed by plants (FAO 2006a; Kyoto Protocol 1997). Consequently, the emitted and absorbed CO_2 quantities are considered equivalent, thus making livestock a net zero source of CO_2.

FAO (2006a) developed the concept of Livestock's Long Shadow (LLS) which is a life cycle assessment (LCA) of livestock's global impact on anthropogenic GHG emissions, biodiversity, land use, water depletion, water pollution, and air pollution. LCA is a "compilation and evaluation of inputs, outputs, and the potential environmental impacts of a product or service throughout its life cycle" (International Organization for Standardization 2006). A LCA is a methodology used to assess both the direct and indirect environmental impact of a product from "cradle to grave." Environmental impacts that can be measured include fossil fuel depletion, water use, GWP, ozone depletion, and pollutant production.

The report attempts to quantify the global direct and indirect GHG emissions associated with livestock. Direct emissions from livestock refer to emissions directly produced from the animal including enteric fermentation and manure and urine excretion (Jungbluth et al. 2001). Specifically, livestock produce CH_4 directly as a by-product of digestion via enteric fermentation (i.e., fermenting organic matter via methanogenic microbes producing CH_4 as an end product) (Jungbluth et al. 2001). CH_4 and N_2O emissions are produced from enteric fermentation and nitrification/denitrification of manure and urine, respectively (Kaspar and Tiedje 1981). For livestock production, the term indirect emissions refers to emissions not directly derived from livestock but from feed crops used for animal feed, emissions from manure application, CO_2 emissions during production of fertilizer for feed production, and CO_2 emissions from processing and transportation of refrigerated livestock products (IPCC 1997; Mosier et al. 1998a). Other indirect emissions include net emissions from land linked to livestock including deforestation (i.e., conversion of forest to pasture and cropland for livestock purposes), desertification (i.e., degradation of aboveground vegetation from livestock grazing), and release of C from cultivated soils (i.e., loss of soil organic carbon (SOC) via tilling, natural processes) associated with livestock (IPCC 1997). Previous agricultural estimates have included emissions associated with indirect energy consumption (e.g., electricity requirements, off-site manufacturing, etc.) as five times greater than on-site emissions for cropland production (Wood et al. 2006). Hence, the accurate estimation needs the full environmental impact of livestock including the indirect emissions. While there are international standards with respect to LCA analysis, uncertainties exist regarding the definitions and "boundaries" of indirect environmental impacts. For example, should the energy required to extract the coal that is used to make the fertilizer applied to the cropland to grow crops used for the production of animal feed be included in a "true" LCA of livestock? According to ISO 14040 (International Organization for Standardization 2006), a comprehensive approach would be ideal but is often not practical. Hence, further refinement of the scope and methodology is necessary to increase comparability between LCAs. Lal (2004) described primary (i.e., tilling, sowing, harvesting, pumping water, grain drying), secondary (i.e., manufacturing, packaging, and storing fertilizers and pesticides), and tertiary (i.e., acquisition of raw materials and fabrication of equipment and buildings) emission sources (Lal 2004). Therefore, based on Lal (2004), one possible method would include LCAs with a numerical suffix indicating the "degree of separation" between the product (e.g., animal protein) and the indirect emission source input (i.e., the greater the number, the more complete and complex the LCA). Nevertheless, while a key advantage of life cycle analysis is the level of very detailed, product-specific information it can provide, it is less able to capture some of the dynamic, systemic challenges posed by our globalized, highly complex food system (Garnett 2009). The different sources of GHG from livestock and livestock farm-related activities are depicted in Fig. 10.1.

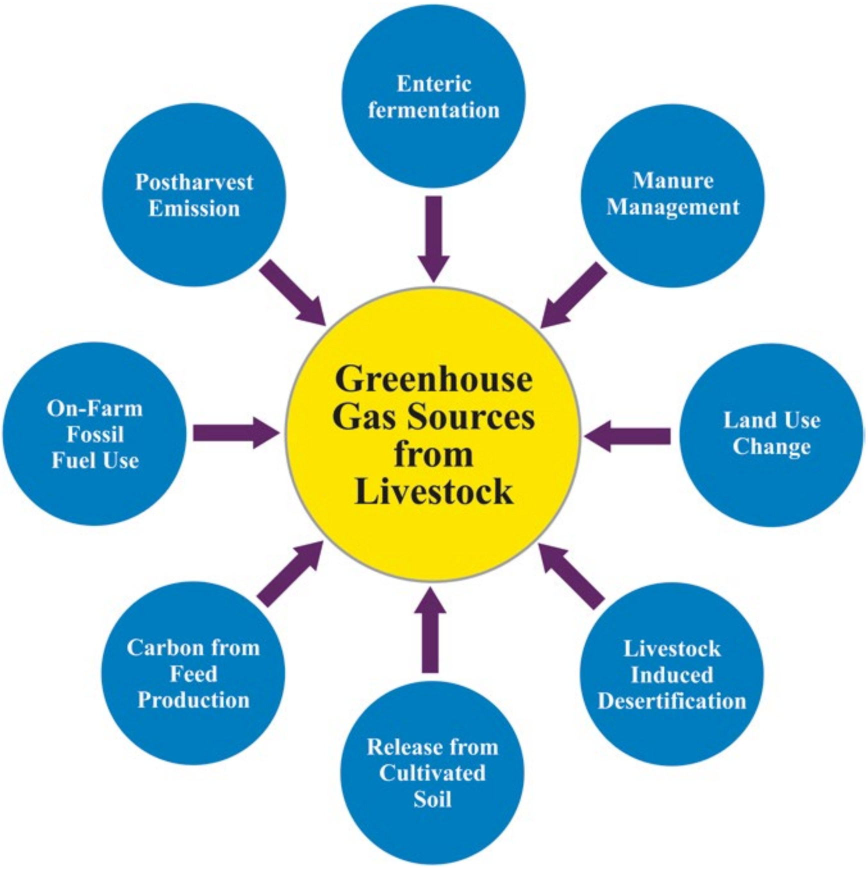


Fig. 10.1 Sources of livestock-related GHG

Further, the major categories of anthropogenic GHG emissions from livestock-related activities are described in Table 10.2 (Steinfeld et al. 2006).

Using the first seven of the eight categories listed above, livestock account for 9, 35–40, and 65 % of the total global anthropogenic emitted CO_2, CH_4, and N_2O, respectively (Steinfeld et al. 2006).

10.6.1 Enteric Fermentation and Its Significance to Global Warming

The rising concentration of CH_4 is correlated with increasing populations, and currently about 70 % of CH_4 production arises from anthropogenic sources and the remainder from natural sources. Ruminants such as cattle, sheep, buffalo, and goats are unique because of their special digestive systems, they can convert otherwise unusable plant materials into nutritious food and fiber. At the same time, they produce CH_4, a potent greenhouse gas that can contribute to global climate change. Globally, ruminant livestock produce about 86 million metric tons of CH_4 annually, accounting for about 28 % of global CH_4 emissions from human-related activities and more than the contribution of transport emissions measured in carbon dioxide equivalent (Steinfeld et al. 2006). In ruminants, current techniques estimate that the majority of CH_4 production occurs in the reticulorumen. Rectal emissions account for about 2–3 % of the total CH_4 emissions in sheep or dairy cows (Murray et al. 1976; Muñoz et al. 2012).

Table 10.2 The major categories of anthropogenic GHG emission for livestock and livestock farm-related activities

Categories of emission	Contribution (Tg CO_2-eq./year)
Enteric fermentation and respiration	1,800
Animal manure	2,160
Livestock-related land-use changes	2,400
Desertification linked to livestock	100
Livestock-related release from cultivated soils	230
Feed production	240
On-farm fossil fuel use	90
Postharvest emissions	10–50

Source: Steinfeld et al. (2006)

The CH_4 production through enteric fermentation is becoming a great concern worldwide for its contribution to GHG effect through its absorption of infrared radiation in the atmosphere (Lashof and Ahuja 1990). Moreover, CH_4 production is associated with considerable dietary energy losses from ruminant leading to decreasing energy gain and productivity, especially in low-input livestock production system. Enteric CH_4 is produced in the rumen and hindgut of animals by methanogenic archaea. In animal production sector, as much as 95–97 % of CH_4 comes from ruminants (Johnson and Ward 1996). CH_4 outputs are estimated to range from 3.1 to 8.3 % of gross energy intake for dry, non-lactating cows and from 1.7 to 14.9 % of gross energy intake for lactating cows (Holter and Young 1992).

The rumen is a fermentation chamber filled with diverse microorganisms (Gregg 1995). The rumen contains a complex microbial ecosystem comprising mainly strictly anaerobic bacteria, protozoa, fungi, and facultative anaerobic bacteria. Specifically, the ruminal microflora consist of bacteria (1,010–1,011 cells/g), bacteriophages (107–109 particles/g), protozoa (104–106 cells/g), fungi (102–104 cells/g), and methanogenic archaea (109–1,010 cells/g) (Joblin 2005; McSweeney et al. 2005). Over 200 species of microorganisms are present in the rumen, although only about 10 % of these are known to play an important role in digestion. These different rumen microbes form a complex community of microorganisms that interact with one another, effectively digesting variety of feedstuffs consumed by ruminants.

Although H_2 is one of the major end products of fermentation by protozoa, archaea, and pure monocultures of some bacteria, it does not accumulate in the rumen because it is immediately used by other bacteria present in the mixed microbial ecosystem. The synergism between fermenting species and H_2-utilizing bacteria (e.g., methanogens) is called “interspecies hydrogen transfer" (Ianotti et al. 1973). Some physical associations between fermentative species (H_2 producers) and H_2 users may facilitate interspecies transfer in the rumen. Attachment of methanogens to the external pellicle of protozoa has been reported by Krumholz et al. (1983) and Stumm et al. (1982). In the rumen, formation of CH_4 is the major way of hydrogen sink through the following reaction:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

Metabolic hydrogen in the form of reduced protons (H) can be used during the synthesis of volatile fatty acids or incorporated into microbial organic matter. When H_2 is not completely used by methanogens, NADH can be reoxidized by dehydrogenases of the fermenting bacteria to produce ethanol or lactate. This situation which occurs in animals fed with large amounts of fermentable carbohydrates is considered as abnormal and illustrates a real dysfunction of the ruminal ecosystem under stress conditions.

Methanogens occupy various niches in the rumen; some are free living in the rumen fluid, while others live on or inside rumen protozoa. Methanogens belong to the domain, Archaea, and the phylum Euryarchaeota. Methanogens living on and within rumen ciliate protozoa may be responsible for up to 37 % of the rumen CH_4 (Hegarty et al. 2007). In the absence of protozoa, rumen CH_4 emissions are reduced by an average of 13 %, but this varies with diet. Decreased CH_4 emissions from the protozoa-free rumen may be a consequence of reduced ruminal dry matter digestion, decreased methanogen population, altered pattern of volatile fatty acid production, decreased hydrogen availability, and increased partial pressure of oxygen in the rumen (Yoon and Stern 1995). Recently, a new group of methylotrophic methanogens (belonging to the so-called rumen cluster-C group) that does not require hydrogen as an energy source has been described and appears to play a role in CH_4 formation in ruminants (Poulsen et al. 2013).

Domestic nonruminant herbivore animals (horses, donkeys, mules, and hinnies) also produce CH_4 as a result of fermentation processes in their hindgut. Hindgut fermenters, however, do not produce comparable CH_4 per unit of fermented feed as ruminants, perhaps due to availability of hydrogen sinks other than CH_4 (Jensen 1996) and lower absolute amounts of H_2 produced due to digestion of feed in the small intestine before entering the hindgut. The Intergovernmental Panel on Climate Change (IPCC 2006) assumed CH_4 emissions from horses at 18 kg/head per year (compared with 128 kg/head per year for a high-producing dairy cow of similar BW).

Wild animals, especially ruminants, also emit CH_4 from enteric fermentation in their reticulorumen or the hindgut (Crutzen et al. 1986; Jensen 1996; Galbraith et al. 1998; Kelliher and Clark 2010). The present-day contribution of wild ruminants to the global GHG emissions, however, is relatively low. Current CH_4 emissions from wild ruminants (bison, elk, and deer) for the contiguous United States were estimated at about 6 Tg CO_2- equivalents (CO_2e)/year, or 4.3 % of the emissions from domestic ruminants (Hristov 2012). In contrast, in the presettlement period, wild ruminants emitted from 62 to 154 Tg CO_2e/year, depending on the assumed size of the bison population, which is about 86 % of the present-day CH_4 emissions from domestic ruminants in the contiguous United States (Hristov 2012). Although their diet is similar to that of ruminants, they reportedly produce little or no CH_4 (Kempton et al. 1976). Recent data by Madsen and Bertelsen (2012), however, reported wallabies produce CH_4 at a rate of about 1.6–2.5 % of their GE intake (GEI), which is about one-third of the expected CH_4 emission from ruminants consuming a similar diet. The composition of the animal feed is a crucial factor in controlling CH_4 emissions (Van Caeseele 2002). Hence, poor diets of ruminant farm animals in developing countries lead to relatively large emissions of CH_4.

10.6.2 GHG Emission from Livestock Manure

Animal manure is an alternative to energy-intensive and high-cost synthetic fertilizer and can be a very effective fertilizer source when the available nutrient content and mineralization rate are synchronized with crop nutrient uptake

(Montes et al. 2013). Application of manure to cropland increases soil organic matter, microbial biomass, and mineralization rate (Spiehs et al. 2010; Langmeier et al. 2002) and improves a number of soil properties including soil tilth, water-holding capacity, oxygen content, and fertility. It can also reduce soil erosion, restores eroded croplands, reduces nutrient leaching, and increases crop yields (Khaleel et al. 1981; Araji et al. 2001). The animal manure can produce anthropogenic CH_4 via anaerobic decomposition of manure and N_2O via nitrification and denitrification of organic N in animal manure and urine (Bouwman 1996). Animal manure is often held in liquid or solid form on the farm, awaiting disposal. During storage time the manure decomposes, and gaseous by-products are released, and the type of gas is determined largely on whether the decomposition is aerobic or anaerobic (Kirchmann and Lundvall 1998). The handling system determines the moisture content and oxygen availability in the manure, with liquid systems producing predominantly CH_4 and solid systems producing both CH_4 and N_2O. In ruminant production systems, enteric CH_4 production is the largest contributor to GHG emissions followed by CH_4 from manure and in beef feedlot systems, N_2O from pen surface, and N_2O emissions from soils. Emissions from nonruminant livestock systems are less than that of ruminants and are mostly CH_4 and N_2O from manure storage and land application (Hristov et al. 2013). LLS (FAO 2006a) estimated that global emissions associated with livestock manure (i.e., manure management, manure land application, and indirect manure emissions) are about a total of 2,160 Tg CO_2-eq./year.

Methane emissions from manure storage were estimated to be 470 million tons (Mt) CO_2e/year in 2010 with an expected 11 % increase by 2020, while N_2O emissions from fertilizer use, manure application, and deposition by grazing livestock were estimated at 2,482 Mt CO_2e/year with an expected 18 % increase by 2020 (USEPA 2006). Whereas N_2O emissions from manure application on the soil are a major contributor to total GHG emissions from agriculture (Davidson 2009), N_2O from animal waste represents 30–50 % of the global agricultural emissions (Oenema et al. 2005). Both CH_4 and N_2O are potent GHG with global warming potentials (GWP) of 25 and 298 kg CO_2e/kg, respectively (Solomon et al. 2007).

Majority of the CH_4 emission from manure is produced under anaerobic conditions during storage, while very little is produced following land application. Manure produces less CH_4 when handled as a solid (e.g., in stacks or pits) or when deposited on pasture or rangelands than liquid (USEPA 2005). Therefore, opportunities to reduce CH_4 emission are centered on preventing anaerobic conditions during storage or capturing and transforming the CH_4 that is produced, if anaerobic conditions are present, into useful products such as cook gas. Data summarized by Chianese et al. (2009) indicate average CH_4 emissions from covered slurry, uncovered slurry, and stacked manure to be 6.5, 5.4, and 2.3 kg/m^2 per year although rates vary with temperature and time in storage.

A major factor influencing N_2O emissions from agricultural land is N application (Jarecki et al. 2008). The form of fertilizer applied as well as the placement in the soil influences the flux of N_2O emissions (Breitenbeck et al. 1980; Bremner et al. 1981). Manure contains most elements necessary for stimulating soil nitrification and denitrification processes that form N_2O. These processes are transient, depending on the amount and form of available N (NH_4^+ or NO_3^-), soil oxidation–reduction potential, degradable C sources, soil temperature, water content, and microbial population (Cavigelli and Parkin 2012). Denitrifying organisms can further reduce N_2O to N_2 at rates dependent on soil conditions, with multiple factors controlling the ratio of N_2O to N_2 produced. The fraction of N completely reduced to N_2 also increases as soil water content approaches saturation. Nitrous oxide can also be produced indirectly when manure N is lost through volatilization as NH_3, NO, and nitrogen dioxide (NO_2) and is nitrified and denitrified in soil following redeposition (USEPA 2010).

The nitrogen assimilation efficiency of animals determines the amount of nitrogen reaching the environment. Nitrogen assimilation efficiencies vary considerably among different livestock range from 10 % for beef cattle and

38–75 % for swine (Castillo et al. 2001; Hoekstra et al. 2007). As a result, significant amounts of N are returned to the environment through animal excretions (Clemens and Huschka 2001; Hoekstra et al. 2007). This N can reenter the crop-production cycle or be emitted as N_2O or NH_3 (Mosier et al. 1998b). Direct N_2O emissions are produced as part of the N cycle through the nitrification and denitrification of organic N in livestock manure and urine (Mosier et al. 1998b). Annual N losses via N_2O have been previously calculated between 0 and 5 % of N applied for manure (Jarecki et al. 2008). Indirect N_2O emissions are produced from N lost as runoff, during storage, leaching during treatment, and during transportation (Mosier et al. 1998b). Due to primarily anaerobic conditions of rice production globally, CH_4 production indirectly associated with animal manure application to irrigated rice fields is considered a significant source of emissions. Specifically, due to microbial breakdown of animal manure under anaerobic conditions, global CH_4 emissions from rice farms account for approximately 60 Tg CO_2-eq./year (Verburg and Van der Gon 2001). In most of the developing world, most rice is grown under these conditions, while within the developed world rice is grown with urea as N source. Half of the synthetic nitrogen fertilizer ever used on Earth has been applied in just the last 15–20 years (International Nitrogen Initiative 2004, 2006). Of this fraction, it is estimated that only 10–20 % was actually consumed by humans, 95 % of which was subsequently lost to the environment (International Nitrogen Initiative 2004, 2006). Under status quo technological and consumption norms, the substantial increases in global food production volumes by 2050 (FAO 2006a, b, 2008, 2009) will strongly exacerbate reactive nitrogen pollution issues. Due to the large fraction of cereal and fodder crops directed toward livestock production, this sector will play a particularly important role.

Direct emissions of N_2O from manure storage are small when compared with CH_4 emissions. For N_2O emissions to occur, manure must first be handled aerobically where ammonium (NH_4^+) or organic N is converted to NO_3^- and nitrite (NO_2^-) during nitrification and then handled anaerobically where the NO_3^- and NO_2^- are reduced to elemental N (N_2), with intermediate production of N_2O and nitric oxide (NO) through denitrification (USEPA 2010). Most of the N_2O resulting from manure is produced in manure-amended soils through microbial nitrification under aerobic conditions and partial denitrification under anaerobic conditions, with denitrification generally producing the larger quantity of N_2O (Tisdale et al. 1993; USEPA 2010).

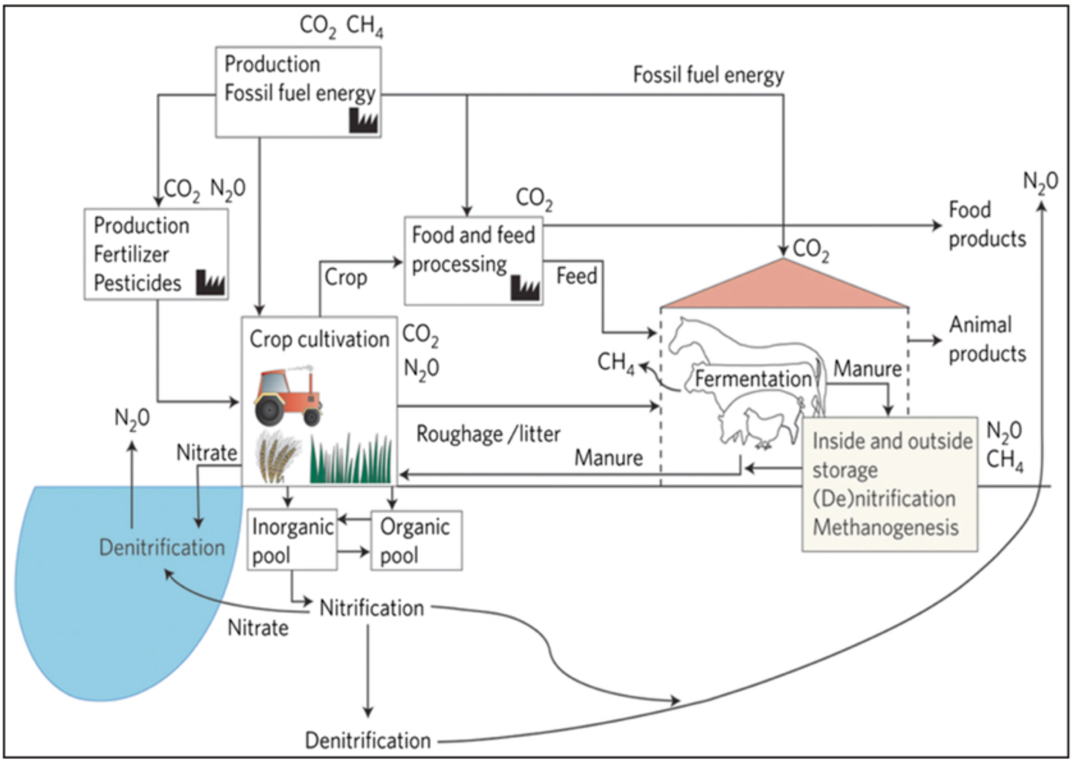
Although not a GHG, NH_3 (and its ionized form, NH_4^+) is an important component of the manure N cycle. Ammonium (a large fraction of the N in manure) is the first product of decomposition of urea through the action of the microbial enzyme urease after urine is deposited on barn floors and pastures. Urease is abundant in fecal matter and in soil, and thus urea excreted in urine is rapidly converted to NH_4^+ when the environmental conditions (temperature, pH) are favorable. Ammonium N can be converted under aerobic conditions to NO_3^-, and both forms of N are readily available to plants, whereas organic forms of manure N are generally not readily available (Beegle et al. 2008). Ammonium N is also the carrier of rapidly available N in the soil and a necessary precursor in the process that leads to N_2O emissions from application of manure and fertilizers and urine deposition in pastures (Tisdale et al. 1993; de Klein 2001). Ammonia volatilization is generally the largest pathway of loss for manure N (Harper et al. 2004; Lee et al. 2011), with losses typically accounting for 30–70 % of the NH_4^+ content of cattle manure (Thompson and Meisinger 2002).

The relationship between manure NH_3 volatilization and N_2O emission is also complex because (1) emissions of both may be reduced by diet manipulation or manure management and (2) if a mitigation technology reduces NH_3 losses, the preserved NH_4^+ may later increase soil N_2O emissions (Petersen and Sommer 2011). On the other hand, gaseous losses of N will reduce the availability of N for nitrification and denitrification processes and, consequently, N_2O formation (USEPA 2010). Therefore, NH_3 emission is considered an important component of the N_2O mitigation practices.

Emissions of GHG from stored manure are affected by environmental factors such as temperature (Khan et al. 1997), wind speed (Sebacher et al. 1983), redox potential (Brown et al. 2000), and crust formation on the slurry surface (Sommer et al. 2000) and by animal factors (Hashimoto et al. 1980). Uncertainties in GHG estimation have been attributed to uncertainties in the types and size of manure storage and to the accuracy of year-round extrapolation of emissions from short-term studies (Kaharabata et al. 1998). Typically, when livestock manure is stored or treated in lagoons, ponds, or tanks (i.e., anaerobic conditions), CH_4 emissions are produced in higher amounts than when manure is handled as a solid (e.g., stacks or dry lot corrals) or deposited on pasture where aerobic decomposition occurs (EPA et al. 2006). Losses of N_2O from the pen surface of open-lot dairy or beef feedlot facilities, however, can be significant. The fact that up to 50 % of the excreted N in beef cattle farms is not recovered in manure has been well documented for various geographic locations (Loh et al. 2008; Cole and Todd 2009). Most of these losses are as ammonia (NH_3), but N_2O emissions are also significant (Leytem et al. 2011; Rahman et al. 2013) and depend on a variety of factors, including surface conditions (Aguilar et al. 2011). With respect to management in the developed world, the increased use of liquid versus dry manure waste systems (liquid systems produce significantly more CH_4) in dairy and pig operations has resulted in a relative increase in CH_4 production (FAO 2006a).

10.6.3 GHG Emission from Livestock-Related Farm Activities

The list of livestock farm activities that contributes to the GHG pool is depicted in Fig. 10.2.



Source: de Boer et al. (2011)

Fig. 10.2 Different sources of GHG in livestock farm and its associated activities

10.6.3.1 Land-Use Change

From a livestock perspective, land-use changes would include any land adapted for livestock rearing (e.g., animal grazing, production of cropland for livestock feed). Forested areas are particularly sensitive to land-use change. When forest ecosystems undergo relatively abrupt land-use changes, such as deforestation, forest regrowth, biomass burning, wildfires, agriculture abandonment, wetland drainage, plowing, and accelerated soil erosion, significant loss of SOC and increase in GHG emissions occur (CAST 2004; Dixon et al. 1994; Houghton et al. 1999; de Boer et al. 2011).

Using the IPCC's definition of land-use change, livestock uses directly (i.e., pasture, LPS) and indirectly (i.e., production of feed crops) the largest landmass in the world (Bruinsma 2003; Naylor et al. 2005) and is a primary driver for land-use change. LLS (FAO 2006a) estimated that livestock-related land-use change produces 2,400 Tg CO_2-eq. year^{-1} or 35 % of the total GHGs attributed to livestock. LLS (FAO 2006a) identifies deforestation in Latin America as the primary source of GHG emissions associated with global livestock. Specifically, land-use changes, including expansion of pasture and arable land for feed crops, primarily occur at the expense of forested land. Forest conversion for permanent crops, cattle ranching, cultivation shifts, and agriculture colonization are considered to contribute equally to the agriculturally driven land-use changes in these countries (Geist and Lambin 2002). Smith et al. (2007) estimated that over the last 40 years, an average of 6 and 7 Mha of forestland and non-forestland, respectively, were converted to agricultural land in the developing world. Houghton (2003) estimated that "Indonesia and Brazil accounted for approximately 50 % of the global land-use change C flux in the 1990s." It has been estimated that the annual net emissions from Brazilian Amazonian deforestation, based on the average deforestation rate of 19,400 km^{-2} per year for the 2007 period, were approximately 191 million tonnes of CO_2-equivalent carbon, or 700 million tonnes CO_2e (McAlpine et al. 2009). This represents more than 2 % of global GHG emissions. The main cause is cattle ranching, and in this case the link between land-use-change-derived CO_2 release and livestock production is very direct.

10.6.3.2 Livestock-Induced Desertification

Desertification can be defined as "land degradation in arid, semi-arid and sub-humid areas resulting from various factors including climatic variations and human activities" (Reynolds and Stafford Smith 2002; UNCCD 1994). Arid and semiarid ecosystems account for more than 45 % of the global land surface (Asner et al. 2003). The most common human agricultural activities on these lands are cattle and sheep grazing/ranching, wood collection, and cultivation (Asner et al. 2003). The annual net emissions from Brazilian Amazonian deforestation, based on the average deforestation rate of 19,400 km^{-2} per year for the 2007 period, were estimated to be approximately 191 million tonnes of CO_2-equivalent carbon, or 700 million tonnes CO_2e (McAlpine et al. 2009). This represents more than 2 % of global GHG emissions. The main cause is cattle ranching, and a relationship between the land-use-change-derived CO_2 release and livestock production can be directly linked. Overgrazing by livestock is the most important cause of desertification in South African drylands (Hofmann and Ashwell 2001; Milton et al. 1994). Compaction is a major problem in areas with high livestock population density and in areas where heavy machinery is used for cultivation. Compaction due to livestock pressure is a severe problem in the Sahelian region, the horn of Africa, Central Asia, north-eastern Australia, Pakistan, and Afghanistan (Nachtergaele et al. 2010). LLS (FAO 2006a) estimated that global emissions associated with livestock-induced desertification total 100 Tg CO_2-eq. year^{-1}. These calculations are based upon studies that show a 25–80 % decline in SOC in areas with long-term grazing (Asner et al. 2003). Desertification (i.e., land degradation of pasture) is mainly an issue in Africa (2.4 million km^2), Asia (2.0 million km^2), and Latin America (1.1 million km^2) (FAO 2006a). The United Nations Environmental Programme (UNEP) estimates that 35 % of the world's land surface is currently at risk for desertification and more than 20 million hectares are reduced annually to near or complete unusableness (Helldén 1991).

As mentioned above, nonanimal factors, such as soil erosion and geographical location (higher latitudes may have increased rates of decomposition of soil C), account for some of the SOC losses (Jenkinson 1991). While animal factors (i.e., degradation of aboveground vegetation) most likely have a more significant contribution to the nonrenewal of decaying organic matter stocks (Asner et al. 2003), calculating the specific amount of soil C loss solely attributed to livestock production is difficult (FAO 2006a). However, livestock do occupy directly and indirectly two-thirds of the global arable dry land area, and the rates of desertification are estimated to be higher in land pasture than other land uses (Bruinsma 2003).

10.6.3.3 Release from Cultivated Soil

Plowing and tilling coupled with wind, rain, and irrigation exacerbate soil erosion of cropland (Lal 2004). Approximately 20–30 % of SOC is mineralized and released into the atmosphere as CO_2 (Lal 1999). During the past 40 years, almost one-third of the world's cropland has been abandoned due to erosion and degradation (Wood et al. 2006). LLS (FAO 2006a) estimated that the loss of C from cultivated soils (i.e., tilling, liming, and emissions related to leguminous feed crops) associated with livestock totals 230 Tg CO_2-eq./year. These estimates have a high degree of error based on environment, land management, and annual loss rate coefficients used under those conditions.

10.6.3.4 Carbon Emissions from Feed Production

Historically, most of the resources utilized for livestock nutrition came from the farm itself. While this type of farming is still practiced in some parts of the developing world, most modern livestock operations require a variety of external inputs (i.e., feed production and transport, herbicides, pesticides, etc.) that directly or indirectly utilize fossil fuels and hence produce net concentrations of GHGs (Sainz 2003). This increased utilization of external inputs allows for increased animal density or intensification of livestock production. In fact, more than half the energy expenditure during livestock production is for feed production (nearly all in the case of intensive beef operations) (FAO 2006a). Globally, livestock have been estimated to consume a third (FAO 2002) or more (37 %) of world cereal output (WRI 2004). While livestock in the developing world generally consume far fewer cereals and rely more on foraging and by-products, this situation may change (Keyzer et al. 2005) as production systems intensify even as we see growth in chicken and pig production, whose diets are predominantly grains, in developing countries. Livestock feed consumes nearly 43 % of the food energy (kilocalories) produced by the world's total harvest of edible crops (Lundqvist et al. 2008; Smil 2000) after postharvest losses. To produce 1 kg of edible meat by typical industrial methods requires 20 kg of feed for beef, 7.3 kg of feed for pig meat, and 4.5 kg of feed for chicken meat (Smil 2000). On average, production of 1 kg of high-quality animal protein requires nearly 6 kg of plant protein and consumption of 15,500 liters of water, the equivalent of 90 full bathtubs (IAASTD 2008). This amount of water is nearly 12 times the quantity needed to produce 1 kg of wheat (Hoekstra and Chapagain 2007). One kcal of food energy from beef requires 40 kcal of fossil fuel energy input to produce (Pimentel and Pimentel 2003). LLS (FAO 2006a) estimated that fossil fuel use in manufacturing fertilizer used for animal feed production and emissions associated with fertilizer application plus indirect emissions generate approximately 240 Tg CO_2-eq./year globally. Total GHG emissions for mineral fertilizer production are based on synthesis of 14 million tonnes of mineral fertilizer directly used for fertilization of cropland used solely for animal feed (FAO 2006a). The energetic cost of synthetic fertilizer synthesis is between 7 and 65 MJ kg of N depending on the fertilizer type and mode of manufacturing (e.g., natural gas versus coal) (FAO 2006a). Lal (2004) compiled data estimating C emissions for production, transportation, storage, and transfer of various fertilizers between 0.03 and 1.8 kg CO_2-eq. kg. The primary use of fertilizer in the animal food chain is for the production of corn (FAO 2006a). While N_2O emissions occur naturally via nitrification and denitrification, the application of excess N increases the rate of N_2O emissions (Bouwman 1996). Mosier et al. (1996) estimated that worldwide application of N as synthetic fertilizer (77.4 Tg/year) is in the same range as that of N from manure (77.4 Tg/year). Synthetic fertilizers have reduced CH_4 emissions (ammonium nitrate and ammonium sulfate appear to inhibit CH4 formation) relative to manure, while synthetic fertilizers have relatively higher N_2O emissions. Therefore, attempts to reduce CH_4 from manure sources may well increase other emissions including N_2O (Mosier et al. 1996). This phenomenon has been termed as pollution swapping.

LLS (FAO 2006a) does not address emissions from production of pesticides, herbicides, and other amendments commonly added to cropland. However, in intensive systems, the combined-energy use for seed and herbicide/pesticide production and fossil fuel for machinery “generally” exceeds that for fertilizer production (Swanton et al. 1996). Lal (2004) conducted a comprehensive review of energy required for production, transportation, and storage of herbicides, insecticides, and fungicides. Means CO_2-eq./kg for herbicides, insecticides, and pesticides were 6.3, 5.1, and 3.9, respectively, which were higher than all N-based fertilizers investigated (Lal 2004). Estimates compiling C emissions for production, transportation, storage, and transfer of herbicides, insecticides, and fungicides had average equivalent C emissions higher than fertilizer (Lal 2004). These numbers are complicated as some research shows that emission factors from production are superseded by net reduction in emissions on the cropland primarily due to no-till farming (Hisatomi et al. 2007).

10.6.3.5 On-Farm Fossil Fuel Use

Fossil energy is a major input of livestock production systems, used mainly for the production, transport, storage, and processing of feed. Depending on location (climate), season of the year, and building facilities, energy is also needed for control of the thermal environment (cooling, heating, or ventilation) and for animal waste collection and treatment. Livestock products are GHG intensive compared with other food groups, and that the vast majority of impacts occur at the farm stage, with subsequent processing, retailing, and transport playing more minor roles (Berlin 2002).

On-farm fossil fuel use is highly dependent on the intensity and type of livestock production and the environment of the farm. Fossil fuels are employed in every facet of farming including tilling, irrigation, sowing, movement of feed, control of the environment (i.e., cooling, heating, and/or ventilation), animal waste collection and treatment (i.e., land application, solid separation), and transportation of farm products (Johnson and Johnson 1995; Lal 2004; Sainz 2003). LLS (FAO 2006a) estimated that on-farm fossil fuel use emits 90 Tg CO_2-eq./year equivalent. Estimates from the United States do not exist currently for CO_2 emissions from on-farm fossil fuel use. However, in an intensive system, on-farm use of fossil fuel often produces greater GHG emissions than those from chemical N fertilizer (Sainz 2003). For the assessment of global on-farm fossil fuel use associated with livestock production, LLS (FAO 2006a) utilizes a single study by Ryan and Tiffany (1998). FAO (2006a) then extrapolates intensive farming globally and adjustments based on latitude (e.g., at lower latitudes less energy would be required for corn drying). Specifically, LLS focuses at on-farm energy use for nine different commodities (corn, soybeans, wheat, dairy, swine, beef, turkeys, sugar beets, and sweet corn/peas). The study identifies diesel or liquefied petroleum gas (LPG) as the primary source of energy for on-farm energy use for eight of the nine commodities. The electrical energy is used for managing extensive stock, space heating for young birds and piglets, and ventilation for pigs and poultry. In dairy farm for milking, milk cooling, water heating and pumping, lighting, ventilation, heating, electrical fencing, manure handling, and office and personnel working environment, conventional electricity consumption represents around 25 % of the nonrenewable energy use at the dairy farm, while the diesel fuel corresponds to 15 % of energy consumption (Bulletin of the International Dairy Federation 2010).

10.6.3.6 Postharvest Emissions

The postharvest system includes processing, distribution (transport and storage), and preparation. LLS (FAO 2006a) estimates that United States generates emissions from postharvest systems between 10 and 50 Tg CO_2-eq. year based on research done in Minnesota (Ryan and Tiffany 1998). The Holtkamp et al. (2006) report does not address postharvest emissions. While postharvest CO_2 relative to the other categories listed is not a major emitter of GHG, the wide range of data available creates some uncertainty. This uncertainty is primarily related to the myriad of value ascribed to food animal by-products from multiple food processing technologies.

In addition, differences in types of electricity source (hydroelectric versus coal) affect the GHG output. From an energy perspective, depending on the efficiency and the product, agriculture represents between 20 and 50 % of the energy consumed within the food supply chain (Wood et al. 2006).

Postharvest emissions associated with animal feed production and processing of nonfood-related animal products were not included in FAO (2006a).

10.7 FAO's Global Livestock Environmental Assessment Model

FAO developed a Global Livestock Environmental Assessment Model (GLEAM) to assess the contribution of livestock sector to climate change. GLEAM represents the main activities of global livestock supply chains which aims at exploring the environmental implications of production practices for main commodities, farming systems, and regions (Gerber et al. 2013). According to this model, the GHG emission from livestock-related activities was estimated to be around 7.1 gigatonnes CO_2-eq. per annum. This quantity represents 14.5 % of all human-induced emissions. This clearly indicates the prominent contribution of livestock to climate change. The model identified that feed production and processing and enteric fermentation are the two main sources of GHG emissions, representing 45 and 39 % of livestock emission. In addition to processing, manure management represents another 10 %. Further, the model predicted that CH_4 is the single largest contributor of GHG pool from livestock sector. Among the animal commodities, beef and milk represent 41 and 20 % of the total GHG production. Further, pig and poultry meat and egg contribute around 9 and 8 %, respectively, of GHG production from animal sector (Gerber et al. 2013). Table 10.3 describes the different categories that contribute to global GHG emission through livestock supply chain.

10.8 Conclusion

Livestock contributes both directly and indirectly to climate change through emissions of greenhouse gases such as carbon dioxide, methane, and nitrous oxide. The livestock play a major role in the emission of methane – a gas with a much more lethal impact on global warming than the

Table 10.3 Global emissions from livestock supply chains by category of emissions

Farm activities	Source of GHG	% contribution
Applied and deposited manure	N_2O	16.4
Fertilizer and crop residues	N_2O	7.7
Feed: rice	CH_4	0.4
Feed	CO_2	13.0
LUC: soybean	CO_2	3.2
LUC: pasture expansion	CO_2	6.0
Enteric fermentation	CH_4	39.1
Manure management	CH_4	4.3
Manure management	N_2O	5.2
Indirect energy	CO_2	0.3
Direct energy	CO_2	1.5
Post farm	CO_2	2.9

Source: Gerber et al. (2013)

usual suspect carbon dioxide. Domestic ruminants, which ferment plants in a specialized stomach during digestion, are estimated to be the largest single human-related source of methane. Reducing demand for ruminant products could help reduce production and reduce substantial GHG in the near term. A reduction in gases other than carbon dioxide will therefore be needed to abate climate change. From the global warming perspectives, assessing the contribution of livestock and its production systems in relation to GHG emissions using the LCA approach is very crucial. This will facilitate better understanding of the sector's impacts, taking into account the differences across production systems and species and the development of effective design and mitigation options. In addition, development of policy options for GHG emission reduction from the livestock sector will help to cost-effectively manage the sector's growing contribution to GHG emissions.

10.9 Future Considerations

Although considerable research has been advanced to further our understanding of contemporary livestock/environment interactions, the implications of these trends for sustainability objectives are not sufficiently resolved. Given the limited consideration of the livestock sector in environmental management to date and the scale of the issues to be addressed, mobilizing the necessary political will to implement such policies is a daunting but necessary prospect. As the human species runs the final course of rapid population growth before beginning to level off midcentury, and food systems expand at commensurate pace, control of the global livestock sector should be considered a key leverage point for averting irreversible ecological change and moving humanity toward a safe and sustainable operating space. To achieve an economically and environmentally sustainable food supply, agriculturalists need to identify systems and practices that make the best use of available resources and minimize the potential environmental impact.

References

Aguilar O, Maghirang R, Rice CW, Trabue S, Erickson LE, Razote E (2011) Nitrous oxide emissions from a commercial cattle feedlot in Kansas. American Society of Agricultural and Biological Engineers (ASABE), p 1110855, St. Joseph, MI

Allen MR, Pall P, Stone DA, Stott P, Frame D, Min S-K, Nozawa T, Yukimoto S (2007) Scientific challenges in the attribution of harm to human influence on climate. Univ Pa Law Rev 155(6):1353–1400

Araji AA, Abdo ZO, Joyce P (2001) Efficient use of animal manure on cropland – economic analysis. Bioresour Technol 79:179–191

Asner GP, Archer S, Hughes RF, Ansley RJ, Wessman CA (2003) Net changes in regional woody vegetation cover and carbon storage in Texas Drylands 1937–1999. Glob Chang Biol 9:316–335. doi:10.1046/j.1365-2486.2003.00594.x

Babklin VI, Klige RK (2004) The contemporary hydrosphere. In: Shiklomanov IA, Rodda JC (eds) World water resources at the beginning of the 21st century. International hydrology series. UNESCO, Cambridge University Press, Cambridge, pp 13–18

Becker KH, Lörzer JC, Kurtenbach R, Wiesen P, Jensen TE, Wallington TJ (1999) Nitrous oxide emissions from vehicles. Environ Sci Technol 33:4134–4139

Beegle DB, Kelling KA, Schmitt MA (2008) Nitrogen from animal manure. In: Schepers JS, Raun WR (eds) Nitrogen in agricultural systems. American Society of Agronomy, Madison, pp 832–881

Berges MGM, Hofmann RM, Schafre D, Crutzen PJ (1993) Nitrous oxide emissions from motor vehicles in tunnels and their global extrapolation. J Geophys Res 98:18527–18531

Berlin J (2002) Environmental life cycle assessment (LCA) of Swedish semi-hard cheese. Int Dairy J 12:939–953

Bhend J, von Storch H (2008) Consistency of observed winter precipitation trends in northern Europe with regional climate change projections. Clim Dyn 31(1):17–28

Bolle HJ, Seiler W, Bolin B (1986) Other greenhouse gases and aerosols: trace gases in the atmospheres. In: Bolin B, Döös BOR, Jäger J, Warrick RA (eds) The greenhouse effect, climatic change & ecosystems (SCOPE 29). Wiley, Chichester, pp 157–203

Bonfils C, Santer BD, Pierce DW, Hidalgo HG, Bala G, Das T, Barnett TP, Dettinger M, Cayan DR, Doutriaux C, Wood AW, Mirin A, Nozawa T (2008) Detection and attribution of temperature changes in the mountainous western United States. J Clim 21:6404–6424

Bouwman A (1996) Direct emissions of nitrous oxide from agricultural soils. Nutr Cycl Agroecosyst 46:53–70

Breitenbeck G, Blackmer A, Bremner J (1980) Effects of different nitrogen fertilizers on nitrous oxide from soil. Geophys Res Lett 7:85–88

Bremner J, Breitenbeck G, Blackmer A (1981) Effects of anhydrous ammonia fertilization on emission of nitrous oxide from soils. J Environ Qual 10:77–80

Brown HA, Wagner-Riddle C, Thurtell GW (2000) Nitrous oxide flux from solid dairy manure in storage as affected by water content and redox potential. J Environ Qual 29:630–638

Bruinsma J (2003) World agriculture: towards 2015/2030, an FAO perspective. Earthscan, London

Bulletin of the International Dairy Federation (2010) A common carbon footprint approach for dairy. The IDF guide to standard lifecycle assessment methodology for dairy sector, 445/2010.42 pp

Canadell JG, Le Quere C, Raupach MR, Field CB, Buitenhuis ET, Ciais P, Conway TJ, Gillett NP, Houghton RA, Marland G (2007) Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. Proc Natl Acad Sci U S A 104(47):18866–18870

CAST (2004) Climate change and greenhouse gas mitigation: challenges and opportunities for agriculture. Council for Agricultural Science and Technology, Task Force Report No 141

Castillo AR, Kebreab E, Beever DE, Barbi JH, Sutton JD, Kirby HC, France J (2001) The effect of energy supplementation on nitrogen utilization in lactating dairy cows fed grass silage diets. J Anim Sci 79:240–246

Cavigelli MA, Parkin TB (2012) Cropland management contributions to greenhouse gas flux: central and eastern U.S. In: Franzluebbers AJ, Follett RF (eds) Managing agricultural greenhouse gases: coordinated agricultural research through GRACEnet to address our changing climate. Academic, New York

Chianese DS, Rotz CA, Richard TL (2009) Whole-farm gas emissions: a review with application to a Pennsylvania dairy farm. Appl Eng Agric 25:431–442

Chin M, Kahn R, Remer L, Yu H, Rind D, Feingold G, Quinn P, Streets D, DeCola P, Halthore R (2009) Atmospheric aerosol properties and climate impacts: synthesis and assessment product 2.3, Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, U.S. Climate Change Science Program, Washington, DC, US

Christy JR, Spencer RW (2005) Correcting temperature data sets. Science 310:972

Clemens J, Huschka A (2001) The effect of biological oxygen demand of cattle slurry and soil moisture on nitrous oxide emissions. Nutr Cycl Agroecosyst 59:93–198

Cole NA, Todd RW (2009) Nitrogen and phosphorus balance of beef cattle feedyards. In: Jordan E (eds) Proceedings of the Texas animal manure management issues conference, Round Rock TX, September 2009, p 1724

Crutzen PJ (1991) CH_4's sinks and sources. Nature 350:380–381

Crutzen PJ (1995) The role of CH_4 in atmospheric chemistry and climate. In: Engelhardt WV, Leonhard-Marek S, Breves G, Giesecke D (eds) Ruminant physiology: digestion, metabolism, growth and reproduction: proceedings of the eighth international symposium on ruminant physiology. Ferdinand Enke Verlag, Stuttgart, pp 291–316

Crutzen PJ, Aselmann I, Seiler W (1986) CH_4 production by domestic animals, wild ruminants, other herbivorous fauna, and humans. Tellus 388:271–284

Davidson EA (2009) The contribution of manure and fertilizer nitrogen to atmospheric nitrous oxide since 1860. Nat Geosci 2:659–662

Davis M (2002) Late Victorian holocausts: El Niño famines and the making of the third world. Verso, London

de Boer IJM, Cederberg C, Eady S, Gollnow S, Kristensen T, Macleod M, Meul M, Nemecek T, Phong LT, Thoma G, van der Werf HMG, Williams AG, Zonderland-Thomassen MA (2011) Greenhouse gas mitigation in animal production: towards an integrated life cycle sustainability assessment. Curr Opin Environ Sustain 3:423–431

de Klein CAM (2001) An analysis of environmental and economic implications of nil and restricted grazing systems designed to reduce nitrate leaching from New Zealand dairy farms. II. Pasture production and cost/benefit analysis. N Z J Agric Res 44:217–235

Dixon RK, Brown S, Houghton RA, Solomon AM, Trexler MC, Wisniewski J (1994) Carbon pools and flux of global forest ecosystems. Science 263:185–190

Dunshea FR, Leury BJ, Fahri F, DiGiacomo K, Hung A, Chauhan S, Clarke IJ, Collier R, Little S, Baumgard L, Gaughan JB (2013) Amelioration of thermal stress impacts in dairy cows. Anim Prod Sci 53(9):965–975

EPA, Holtkamp J, Hayano D, Irvine A, John G, Munds-Dry O, Newland T, Snodgrass S, Williams M (2006) Inventory of U.S. greenhouse gases and sinks: 1996–2006. Environmental Protection Agency, Washington, DC. http://www.epa.gov/climatechange/emissions/downloads/08_Annex_1-7.pdf

European Commission (2006) Environmental impact of products (EIPRO): analysis of the life cycle environmental impacts related to the total final consumption of the EU25. European Commission Technical Report EUR 22284 EN

Fagan BM (2001) The Little Ice Age: how climate made history, 1300–1850. Basic Books, New York

FAO (2002) World agriculture: towards 2015/2030. Summary report. Food and Agriculture Organisation, Rome

FAO (2006a) Livestock's long shadow. Food and Agriculture Organisation, Rome

FAO (2006b) World agriculture: towards 2030/2050. Prospects for Food, Nutrition, Agriculture and Major Commodity Groups. Interim Report, Rome.

FAO (2007) Adaptation to climate change in agriculture, forestry, and fisheries: perspective, framework and priorities. FAO, Rome

FAO (2008) Climate-related transboundary pests and diseases including relevant aquatic species. Expert meeting, FAO

FAO (2009) Carbon sequestration in grasslands: technical, economic and policy issues. Draft briefing paper. FAO, Rome

FAO (2010) The global forest resources assessment 2010 – key findings. FAO, Rome

FAO (2012) Balanced feeding for improving livestock productivity – Increase in milk production and nutrient use efficiency and decrease in methane emission. In: Garg MR (ed), FAO animal production and health paper no. 173. FAO, Rome. 1080/00330124.2014.921017 (2014)

Frolking SE, Mosier AR, Ojima DS, Li C, Parton WJ, Potter CS, Priesack E, Stenger R, Haberbosch C, Dorsch P, Flessa H, Smith KA (1998) Comparison of N_2O emissions from soils at three temperate agricultural sites: simulations of year-round measurements by four models. Nutr Cycl Agroecosyst 52:77–105

Fung I, John J, Lerner J, Matthews E, Prather M, Steele LP, Fraser PJ (1991) Three dimensional model synthesis of the global CH_4 cycle. J Geophys Res 96D:13033–13065

Galbraith JK, Mathison GW, Hudson RJ, McAllister TA, Cheng K-J (1998) Intake, digestibility, CH_4 and heat production in bison, wapiti and white-tailed deer. Can J Anim Sci 78:681–691

Garnett T (2009) Livestock-related greenhouse gas emissions: impacts and options for policy makers. Environ Sci 12:491–503

Geist HJ, Lambin EF (2002) Proximate causes and underlying driving forces of tropical deforestation. Bioscience 52(2):143–150

Geller LS, Elkins JW, Lobert JM, Clarke AD, Hurst DF, Butler JH, Myers RC (1997) Tropospheric SF6: observed latitudinal distribution and trends, derived emissions, and interhemispheric exchange time. Geophys Res Lett 24:675–678

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G (2013) Tackling climate change through livestock – a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome

Gregg K (1995) Engineering gut flora of ruminant livestock to reduce forage toxicity: progress and problems. Trends Biotechnol 13:418–421

Harper LA, Sharpe RR, Parkin TB, de Visscher A, van Cleemput O, Byers FM (2004) Nitrogen cycling through swine production systems: ammonia, dinitrogen, and nitrous oxide emissions. J Environ Qual 33:1189–1201

Hashimoto AG, Chen YR, Varel VH (1980) Theoretical aspects of CH_4 production: state-of-the-art. In: Proceedings, fourth international symposium on livestock wastes. American Society of Agricultural Engineers, St. Joseph, pp 86–91

Hegarty RS, Goopy JP, Herd RM, McCorkell B (2007) Cattle selected for lower residual feed intake have reduced daily CH_4 production. J Anim Sci 85:1479–1486

Helldén U (1991) Desertification: time for an assessment? For Environ 20:372–382

Hisatomi H, Hitomi K, Hayato S (2007) Reduction in greenhouse gas emissions by no-tilling rice cultivation in Hachirogata polder, northern Japan: life-cycle inventory analysis. Soil Sci Plant Nutr 53:668–677

Hoekstra AY, Chapagain AK (2007) Water footprints of nations: water use by people as a function of their consumption pattern. Water Resour Manag 21:35–48. doi:10.1007/s11269-006-9039-x

Hoekstra NJ, Schulte RPO, Struik PC, Lantinga EA (2007) Pathways to improving the N efficiency of grazing bovines. Eur J Agron 26:363–374

Hofmann MT, Ashwell A (2001) Nature divided: land degradation in South Africa. University of Cape Town Press, Lansdowne

Holter JB, Young AJ (1992) CH_4 prediction in dry and lactating Holstein cows. J Dairy Sci 75:2165–2175

Houghton RA (2003) Revised estimates of the annual net flux of carbon to the atmosphere from changes on land use and land management. Tellus 55B:378–390

Houghton RA, Hackler JL, Lawrence KT (1999) The U.S. carbon budget: contributions from land-use change. Science 285:574–578

Hristov AN (2012) Historic, pre-European settlement, and present-day contribution of wild ruminants to enteric CH_4 emissions in the United States. J Anim Sci 90:1371–1375

Hristov AN, Oh J, Lee C, Meinen R, Montes F, Ott T, Firkins J, Rotz CA, Dell C, Adesogan A, Yang WZ, Tricarico J, Kebreab E, Waghorn G, Dijkstra J, Oosting S (2013) Mitigation of greenhouse gas emissions in livestock production – a review of technical options for non-CO_2 emissions. In: Gerber P, Henderson B, Makkar H (eds) FAO animal production and health. FAO, Rome, p 177

Ianotti EL, Kafkewitz D, Wolin MJ, Bryant MP (1973) Glucose fermentation products of Ruminococcus albus in continuous culture with Vibrio succinogenes: changes caused by interspecies transfer of H_2. J Bacteriol 114:1231–1240

International Assessment of Agricultural Science and Technology for Development (IAASTD) (2008) Global summary for decision makers, Johannesburg, South Africa

International Nitrogen Initiative (2004) A preliminary assessment of changes in the global nitrogen cycle as a result of anthropogenic influences. http://www.initrogen.org/fileadmin/user_upload/2005_products/INI_Pre-Assessment_final.pdf

International Nitrogen Initiative (2006) The issues of nitrogen. http://www.initrogen.org/fileadmin/user_upload/2006_docs/INI_Brochure_12Aug06.pdf

International Organization for Standardization (2006) ISO 14040:2006. In: FAO (ed) http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=37456. Accessed 2 Apr 2009

IPCC (1997) Intergovernmental panel on climate change/organization for economic cooperation and development: guidelines for national greenhouse gas inventories. Paris. http://www.ipcc-nggip.iges.or.jp/public/mtdocs/pdfiles/rockhamp.pdf

IPCC (2000a) Good practice guidance and uncertainty management in national greenhouse gas inventories. Intergovernmental Panel on Climate Change (IPCC), IPCC/OECD/IEA/IGES, Hayama

IPCC (2000b) Emission scenarios, summary for policy makers. Online at http://www.grida.no/climate/ipcc/spmpdf/sres-e.pdf

IPCC (2006) IPCC guidelines for national greenhouse gas inventories 2006. Institute for Global Environmental Strategies (IGES), Berlin

IPCC (2007a) Fourth assessment report (AR4). Intergovernmental Panel on Climate Change (IPCC)

IPCC (2007b) The physical science basis – summary for policymakers: contribution of WG1 to the fourth assessment report of the Intergovernmental Panel on Climate Change. http://www.ipcc.ch/ipccreports/ar4-wg1.htm

IPCC (2007c) Climate change 2007: the physical science basis: Working Group I contribution to the fourth assessment report. Cambridge University Press, Cambridge

IPCC (2013) Impacts, adaptation and vulnerability. http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-TS_FGDall.pdf

Issar AS, Zohar M (2007) Climate change: environment and civilisation in the Middle East. Springer, Berlin

Jan Kramer K, Moll HC, Nonhebel S, Wilting HC (1999) Greenhouse gas emissions related to Dutch food consumption. Energ Policy 27:203–216

Jarecki M, Parkin T, Chan A, Hatfield J, Jones R (2008) Greenhouse gas emissions from two soils receiving nitrogen fertilizer and swine manure slurry. J Environ Qual 37:1432–1438

Jenkinson D (1991) The Rothamsted long-term experiments: are they still of use? J Agron 83:2–12

Jensen BB (1996) Methanogenesis in monogastric animals. Environ Monit Assess 42:99–112

Jiménez JL, McManus JB, Shorter JH, Nelson DD, Zahniser MS, Koplow M, McRae GJ, Kolb CE (2000) Cross road and mobile tunable infrared laser measurements of nitrous oxide emissions from motor vehicles. Chemosphere Global Change Sci 2:397–412

Joblin KN (2005) Methanogenic archaea. In: Makkar HPS, McSweeney CS (eds) Methods in gut microbial ecology for ruminants. Springer, Dordrecht, pp 47–53

Johnson KA, Johnson D (1995) CH_4 emissions from cattle. J Anim Sci 73:2483–2492

Johnson DE, Ward GM (1996) Estimates of animal CH_4 emissions. Environ Monit Assess 42:133–141

Jones AA (1997) Global hydrology: processes, resources and environmental management. Longman, Harlow

Jones GS, Stott PA, Christidis N (2008) Human contribution to rapidly increasing frequency of very warm Northern Hemisphere summers. J Geophys Res 113:D02109. doi:10.1029/2007JD008914

Jungbluth T, Hartung E, Brose G (2001) Greenhouse gas emissions from animal houses and manure stores. Nutr Cycl Agroecosyst 60:133–145

Kaharabata SK, Schuepp PH, Desjardins RL (1998) CH_4 emissions from aboveground open manure slurry tanks. Glob Biogeochem Cycles 12:545–554

Karl GCHTR, Allen M, Bindoff NL, Gillett N, Karoly D, Zhang X, Zwiers FW (2006) Climate change detection and attribution: beyond mean temperature signals. J Clim 19:5058–5077

Kaspar HF, Tiedje JM (1981) Dissimilatory reduction of nitrate and nitrite in the bovine rumen nitrous oxide production and effect of acetylene. Appl Environ Microbiol 41:705–709

Kelliher FM, Clark H (2010) CH_4 emissions from bison – an historic herd estimate for the North American Great Plains. Agric For Meteorol 150:473–477

Kempton TJ, Murray RM, Leng RA (1976) CH_4 production and digestibility measurements in the grey kangaroo and sheep. Aust J Biol Sci 29:209–214

Kerr RA, Balter M (2007) Climate change: scientists tell policymakers we're all warming the world. Science 315:754–757

Keyzer MA, Merbis MD, Pavel IFPW, van Wesenbeeck CFA (2005) Diet shifts towards meat and the effects on cereal use: can we feed the animals in 2030? Ecol Econ 55(2):187–202

Khaleel R, Reddy KR, Overcash MR (1981) Changes in soil physical properties due to organic waste applications: a review. J Environ Qual 10:133–141

Khan RZ, Muller C, Sommer SG (1997) Micrometeorological mass balance technique for measuring CH_4 emission from stored cattle slurry. Biol Fertil Soils 24:442–444

Kirchmann H, Lundvall A (1998) Treatment of solid animal manures: identification of low NH_3 emission practices. Nutr Cycl Agroecosyst 51:65–71

Krumholz LR, Forsberg CW, Veira DM (1983) Association of methanogenic bacteria with rumen protozoa. Can J Microbiol 29:676–680

Kumar R, Nunn PD, Field SJ, De Biran A (2006) Human responses to climate change around AD 1300: a case study of the Sigatoka Valley, Viti Levu Island, Fiji. Quat Int 151:133–143

Kyoto Protocol (1997) United Nations framework convention on climate change. Kyoto Protocol, Kyoto

Lal R (1999) Soil management and restoration for C sequestration to mitigate the accelerated greenhouse effect. Prog Environ Sci 1:307–326

Lal R (2004) Carbon emission from farm operations. Environ Int 30:981–990

Lamy F, Arz HW, Bond GC, Bahr A, Patzold J (2006) Multicentennial-scale hydrological changes in the Black Sea and northern Red Sea during the Holocene and the Arctic/North Atlantic Oscillation. Paleoceanography 21:PA1008

Langmeier M, Frossard E, Kreuzer M, Mäder P, Dubois D, Oberson A, Recous S, Nicolardot B (2002) Nitrogen fertilizer value of cattle manure applied on soils originating from organic and conventional farming systems. Agronomie 22:789–800

Lashof DA, Ahuja DR (1990) Relative contributions of greenhouse gas emissions to global warming. Nature 344(6266):529–531

Le Quere C, Raupach MR, Canadell JG, Marland G, Bopp L, Ciais P, Conway TJ, Doney SC, Feely RA, Foster P, Friedlingstein P, Gurney K, Houghton RA, House JI, Huntingford C, Levy PE, Lomas MR, Majkut J, Metzl N, Ometto JP, Peters GP, Prentice IC, Randerson JT, Running SW, Sarmiento JL, Schuster U, Sitch S, Takahashi T, Viovy N, van der Werf GR, Woodward FI (2009) Trends in the sources and sinks of carbon dioxide. Nat Geosci 2(12):831–836

Lean JL, Rind DH (2008) How natural and anthropogenic influences alter global and regional surface temperatures: 1889 to 2006. Geophys Res Lett 35:L18701

Lee C, Hristov AN, Cassidy TW, Heyler K (2011) Nitrogen isotope fractionation and origin of ammonia nitrogen volatilized from cattle manure in simulated storage. Atmosphere (Toronto) 2:256–270

Leytem AB, Dungan RS, Bjorneberg DL, Koehn AC (2011) Emissions of ammonia, CH_4, carbon dioxide, and nitrous oxide from dairy cattle housing and manure management systems. J Environ Qual 40:1383–1394

Lockwood M, Fröhlich C (2007) Recent oppositely directed trends in solar climate forcings and the global mean surface air temperature. Proc R Soc A. doi:10.1098/rspa.2007. 1880, Published online

Loh Z, Chen D, Bai M, Naylor T, Griffith D, Hill J, Denmead T, McGinn S, Edis R (2008) Measurement of greenhouse gas emissions from Australian feedlot beef production using open-path spectroscopy and atmospheric dispersion modeling. Aust J Exp Agric 48:244–247

Lundqvist J, de Fraiture C, Molden D (2008) Saving water: from field to fork – curbing losses and wastage in the food chain. SIWI Policy Brief, SIWI, Stockholm

Madsen J, Bertelsen MF (2012) CH_4 production by red-necked wallabies (Macropus rufogriseus). J Anim Sci 90:1364–1370

Maiss M, Brenninkmeijer CAM (1998) Atmospheric SF6: trends, sources, and prospects. Environ Sci Technol 32:3077–3086

McAlpine CA, Etter A, Fearnside PM, Seabrook L, Laurance WF (2009) Increasing world consumption of beef as a driver of regional and global change: a call for policy action based on evidence from Queensland (Australia), Colombia and Brazil. Glob Environ Chang 19:21–33

McSweeney CS, Denman SE, Mackie RI (2005) Rumen bacteria. In: Makkar HPS, McSweeney CS (eds) Methods in gut microbial ecology for ruminants. Springer, Dordrecht, pp 23–37

Mears CA, Wentz FJ (2005) The effect of diurnal correction on satellite-derived lower tropospheric temperature. Science 310:1548–1551

Melillo JM, Terese TCR, Gary WY (eds) (2014) Climate change impacts in the United States: the third national climate assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2

Migeotte MJ (1948) Spectroscopic evidence of CH_4 in the earth's atmosphere. Phys Rev 73:519–520

Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: general synthesis. Island Press, Washington, DC

Milly PCD, Dunne KA, Vecchia AV (2005) Global pattern of trends in stream flow and water availability in a changing climate. Nature 438:347–350

Milton SJ, Dean WRJ, Du Plessis MA, Siegfried WR (1994) A conceptual model of arid rangeland degradation: the escalating cost of declining productivity. Bioscience 44:70–76

Min S-K, Hense A (2007) A Bayesian assessment of climate change using multimodel ensembles. Part II: Regional and seasonal mean surface temperatures. J Clim 20(12):2769–2790

Montes F, Meinen R, Dell C, Rotz A, Hristov AN, Oh J, Waghorn G, Gerber PJ, Henderson B, Makkar HPS, Dijkstra J (2013) Mitigation of CH_4 and nitrous oxide emissions from animal operations: II. A review of manure management mitigation options. J Anim Sci 91:5070–5094. doi:10.2527/jas.2013-6584. Originally published online 17 Sept 2013

Mosier AR, Schimel DS, Valentine DW, Bronson KF, Parton WJ (1991) Methane and nitrous oxide fluxes in native, fertilized, and cultivated grasslands. Nature 350:330–332

Mosier A, Duxbury J, Freney J, Heinemeyer O, Minami K (1996) Nitrous oxide emissions from agricultural fields: assessment, measurement and mitigation. Dev Plant Soil Sci 68:589–602

Mosier A, Kroeze C, Nevison C, Oenema O, Seitzinger S, Van Cleemput O (1998a) Closing the global N_2O budget: nitrous oxide emissions through the agricultural nitrogen cycle: OEDC/IPCC/IEA phase II development of IPCC guideline for national greenhouse gas methodology. Nutr Cycl Agroecosyst 52:225–248

Mosier AR, Duxbury JM, Freney JR, Heinemeyer O, Minami K, Johnson D (1998b) Mitigating agricultural emissions of CH_4. Clim Chang 40:39–80

Mosier A, Wassmann R, Verchot L, King J, Palm C (2004) CH_4 and nitrogen oxide fluxes in tropical agricultural soils: sources, sinks and mechanisms. Environ Dev Sustain 6:11–49

Moss AR, Jounany JP, Neevbold J (2000) CH_4 production by ruminants: its contribution to global warming. Ann Zootech 49:231–253

Muñoz C, Yan T, Wills DA, Murray S, Gordon AW (2012) Comparison of the sulfur hexafluoride tracer and respiration chamber techniques for estimating CH_4 emissions and correction for rectum CH_4 output from dairy cows. J Dairy Sci 95:3139–3148

Murray RM, Bryant AM, Leng RA (1976) Rates of production of CH_4 in the rumen and large intestine of sheep. Br J Nutr 36:1–14

Nachtergaele F, Petri M, Biancalani R, Van Lynden G, Van Velthuizen H (2010) Global Land Degradation Information System (GLADIS). Beta version: an information database for land degradation assessment at global level. Land degradation assessment in drylands technical report, no. 17. FAO, Rome

Naylor R, Steinfeld H, Falcon W, Galloway JN, Smil V, Bradford GE, Mooney HA (2005) Losing the links between livestock and land. Science 310:1621–1622

Nevison CD, Holland EA (1997) A reexamination of the impact of anthropogenically fixed nitrogen on atmospheric N_2O and the stratospheric O_3 layer. J Geophys Res 102:25519–25536

Oenema O, Wrage N, Velthof GL, van Groeningen JW, Dolfing J, Kuikman PJ (2005) Trends in global nitrous oxide emissions from animal production systems. Nutr Cycl Agroecosyst 72:51–65

Oram DE, Reeves CE, Sturges WT, Penkett SA, Fraser PJ, Langenfelds RL (1996) Recent tropospheric growth rate and distribution of HFC-134a (CF_3CH_2F). Geophys Res Lett 23:1949–1952

Parton WJ, Hartman M, Ojima D, Schimel D (1998) DAYCENT and its land surface submodel: description and testing. Glob Planet Chang 19:35–48

Petersen SO, Sommer SG (2011) Ammonia and nitrous oxide interactions: roles of manure organic matter management. Anim Feed Sci Technol 166–167:503–513

Pimentel D, Pimentel M (2003) Sustainability of meat-based and plant-based diets and the environment. Am J Clin Nutr 78(suppl):660S–663S

Potter JR (2002) Workshop summary. In: The potential impacts of climate change on transportation. DOT Center for Climate Change and Environmental Forecasting, Federal Research Partnership Workshop, 1–2 October 2002, pp 3–3

Poulsen M, Schwab C, Jensen BB, Engberg RM, Spang A, Canibe N, Højberg O, Milinovich G, Fragner L, Schleper C, Weckwerth W, Lund P, Schramm A, Urich T (2013) Methylotrophic methanogenic Thermoplasmata implicated in reduced methane emissions from bovine rumen. Nat Commun 4:1428

Rahman S, Borhan S, Swanson K (2013) Greenhouse gas emissions from beef cattle pen surfaces in North Dakota. Environ Technol 34:1239–1246

Raupach MR, Canadell JG (2010) Carbon and the anthropocene. Curr Opin Environ Sustain 2:210–218

Raupach MR, Canadell JG, Ciais P, Friedlingstein P, Rayner PJ, Trudinger CM (2011) The relationship between peak warming and cumulative CO_2 emissions, and its use to quantify vulnerabilities in the carbon-climate-human system. Tellus B63(2): 145–162

Reynolds JF, Stafford Smith DM (eds) (2002) Global desertification: do humans cause deserts? Dahlem University Press, Berlin

Royal Society (2010) Climate change: a summary of the science. Royal Society, London

Ryan B, Tiffany DG (1998) Energy use in Minnesota agriculture. Minn Agric Econ 693, Fall 2008

Sainz R (2003) Framework for calculating fossil fuel use in livestock systems. http://www.fao.org/wairdocs/lead/x6100e/x6100e00.htm#Contents

Samenow J (2010) It's history: Winter 2009–2010 snowiest on record. The Washington Post, February 10. Database. Available online at http://voices.washingtonpost.com. Accessed 3 Oct 2010

Schellnhuber HJ, Cramer W, Nakicenovic N, Wigley T, Yohe G (eds) (2006) Avoiding dangerous climate change. Cambridge University Press, Cambridge

Sebacher DI, Harriss RC, Bartlett KB (1983) CH_4 flux across the air–water interface: air velocity effects. Tellus 35B:103–109

Semadeni-Davies A, Hernebring C, Svensson G, Gustafsson L-G (2007) The impacts of climate change and urbanisation on drainage in Helsingborg, Sweden: combined sewer system. J Hydrol 350:100–113. doi:10.1016/j.jhydrol.2007. 05.028

Shiklomanov IA (2004) General conclusions: the outcome of the monograph. In: Shiklomanov IA, Rodda JC (eds) World water resources at the beginning of the 21st century. International hydrology series – UNESCO. Cambridge University Press, Cambridge, pp 414–416

Simmonds PG, O'Doherty S, Huang J, Prinn R, Derwent RG, Ryall D, Nickless G, Cunnold D (1998) Calculated trends and the atmospheric abundance of 1,1,1,2-tetrafluoroethane, 1,1-dichloro-1- fluoroethane, and 1-chloro-1,1-difluoroethane using automated in-situ gas chromatography mass spectrometry measurements recorded at Mace Head, Ireland, from October 1994 to March 1997. J Geophys Res 103:16029–16037

Smil V (2000) Feeding the world: a challenge for the twenty-first century. MIT Press, Cambridge, MA

Smith P, Martino D, Cai ZC, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O, Howden M, McAllister T, Pan G, Romanenkov V, Schneider U, Towpra S (2007) Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. Agric Ecosyst Environ 118:6–28

Smith TM, Reynolds RW, Peterson TC, Lawrimore J (2008) Improvements to NOAA's historical merged land-ocean surface temperature analysis (1880–2006). J Clim 21:2283–2293

Solomon S, Qin D, Manning M, Alley RB, Berntsen T, Bindoff NL, Chen Z, Chidthaisong A, Gregory JM, Hegerl GC, Heimann M, Hewitson B, Hoskins BJ, Joos F, Jouzel J, Kattsov V, Lohmann U, Matsuno T, Molina M, Nicholls N, Overpeck J, Raga G, Ramaswamy V, Ren J, Rusticucci M, Somerville R, Stocker TF, Whetton P, Wood RA, Wratt D (2007) Technical summary. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: the physical science basis: contribution of Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York

Sommer SG, Petersen SO, Søgaard HT (2000) Atmospheric pollutants and trace gases: greenhouse gas emission from stored livestock slurry. J Environ Qual 29:744–751

Spiehs MJ, Woodbury BL, Tarkalson DD, Wienhold BJ, Eigenberg RA (2010) Long term effects of annual additions of animal manure on soil chemical, physical, and biological properties in the Great Plains. In: Proceedings of the international symposium on Air Quality and Manure Management for Agriculture. American Society of Agricultural and Biological Engineers Publication Number 711P0510cd, Dallas, 13–16 September 2010

Stanhill G (2007) A perspective on global warming, dimming, and brightening. Eos 88:58–59

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow. Environmental issues and options. Livestock, environment, and development initiative. United Nations Food and Agriculture Organization, Rome

Steudler PA, Bowden RD, Melillo JM, Aber JD (1989) Influence of nitrogen fertilisation on CH_4 uptake in temperate soils. Nature 341:314–316

Stott PA, Gillett NP, Hegerl GC, Karoly DJ, Stone DA, Zhang X, Zwiers F (2010) Detection and attribution of climate change: a regional perspective. Wiley Interdiscip Rev Clim Chang 1(2):192–211

Stumm CK, Gitzen HJ, Vogels GD (1982) Association of methanogenic bacteria with ovine rumen ciliates. Br J Nutr 48:417–431

Sturges WT, Wallington TJ, Hurley MD, Shine KP, Sihra K, Engel A, Oram DE, Penkett SA, Mulvaney R, Brenninkmeijer CAM (2000) A potent greenhouse gas identified in the atmosphere: SF5CF3. Science 289:611–613

Svensmark H (2007) Cosmoclimatology: a new theory emerges. Astron Geophys 48:1.18–1.24

Swanton CJ, Murphy SD, Hume DJ, Clements DR (1996) Recent improvements in the energy efficiency of agriculture: case studies from Ontario, Canada. Agric Syst 52:399–418

Tett SFB, Betts R, Crowley TJ, Gregory J, Johns TC, Jones A, Osborn TJ, Öström E, Roberts DL, Woodage MJ (2007) The impact of natural and anthropogenic forcings on climate and hydrology since 1550. Clim Dyn 28(1):3–34

Thompson RB, Meisinger JJ (2002) Management factors affecting ammonia volatilization from land-applied cattle slurry in the mid-Atlantic USA. J Environ Qual 31:1329–1338

Tisdale SL, Nelson WL, Beaton JD, Havlin JL (1993) Soil acidity and basicity. In: Soil fertility and fertilizers, 5th edn. Macmillan Publishing, New York

Trenerth KE, Moore B, Karl TR, Nobre C (2006) Monitoring and prediction of the earth's climate: a future perspective. J Clim (CLIVAR Spec Issue) 19:5001–5008

Tubiello FN, Salvatore M, Rossi S, Ferrara A, Fitton N, Smith P (2013) The FAOSTAT database of greenhouse gas emissions from agriculture. Environ Res Lett 8(1):015009

U.S. Environmental Protection Agency (USEPA) (2005) Inventory of U.S. greenhouse gas emissions and sinks: 1990–2003. EPA 430-R-05-003. USEPA, Washington, DC

U.S. Environmental Protection Agency (USEPA) (2006) Global anthropogenic non-CO_2 greenhouse gas emissions: 1990–2020. USEPA, Washington, DC

U.S. Environmental Protection Agency (USEPA) (2010) Inventory of U.S. greenhouse gas emissions and sinks: 1990–2008. USEPA, Washington, DC. www.epa.gov/climatechange/emissions/usinventoryreport.html. Accessed 27 Sept 2012

UNCCD (1994) Intergovernmental Negotiating Committee for a Convention to Combat Desertification. United Nations Convention to Combat Desertification. Elaboration of an International Convention to Combat Desertification in Countries Experiencing Serious Drought and/or Desertification, Particularly in Africa. U.N. Doc. A/AC.241/27, 33 I.L.M. 1328, United Nations, New York

Van Caeseele R (2002) Climate change and agriculture. www.climatechangeconnection.org/pdfs_ccc/Agriculture.pdf. Accessed 14 May 2012

Verburg PH, Van der Gon H (2001) Spatial and temporal dynamics of CH_4 emissions from agricultural sources in China. Glob Chang Biol 7:31–47

Wallington TJ, Hurley MD, Nielsen OJ, Andersen MPS (2004) Atmospheric chemistry of CF3CFHCF2OCF3 and CF3CFHCF2OCF2H:3CFHCF2OCF3 and CF3CFHCF2OCF2H: reaction with Cl atoms and OH radicals, degradation mechanism, and global warming potentials. J Phys Chem A 108(51):11333–11338

Wanner H, Beer J, Bitikofer J, Crowley TJ, Cubasch U, Flückiger J, Goosse H, Grosjean M, Joos F, Kaplan JO, Küttel M, Müller SA, Prentice IC, Solomina O, Stocker TF, Tarasov P, Wagner M, Widmann M (2008) Mid- to late holocene climate change: an overview. J Quat Sci 27(19–20):1791–1828

Whalen M, Reeburg W (1990) Consumption of atmospheric CH_4 by tundra soils. Nature 346: 160–162

Whitmarsh L (2009) What's in a name? Commonalities and differences in public understanding of climate change and global warming. Public Underst Sci 18:401–420

Wood R, Lenzen M, Dey C, Lundie S (2006) A comparative study of some environmental impacts of conventional and organic farming in Australia. Agric Syst 89:324–348

World Bank (2008) Annual world development report. World Bank, New York

WRI (2004) Food security: grain fed to livestock as a percent of total grain consumed 2003/4 data. World Resources Institute, http://earthtrends.wri.org/

Yang M, Yao T, Wang H, Gou X (2006) Climatic oscillations over the past 120 kyr recorded in the Guliya ice core, China. Quat Int 154:11–18

Yoon IK, Stern MD (1995) Influence of direct-fed microbials on ruminal fermentation and performance of ruminants: a review. Asian-Australas J Anim Sci 8:533–555

Zastawny A (2006) Calculation of solar and thermal radiation absorption in the atmosphere, based on the HITRAN data. Meteorol Atmos Phys 92:153–159

11

Methane Emission from Enteric Fermentation: Methanogenesis and Fermentation

Arianna Buccioni, Alice Cappucci, and Marcello Mele

Abstract

Rumen fermentation of carbohydrates plays a fundamental role in ruminant metabolism as the main source of energy. Acetic, propionic and butyric acids (namely, volatile fatty acids, VFA) are the main products of the rumen fermentation of structural and nonstructural carbohydrates contained in the ruminant's diet. The metabolic pathways involved in VFA production are strictly linked to methane emission, because hydrogen is actively produced during the fermentation of structural carbohydrates, and it is rapidly metabolised by methanogens, in order to maintain the optimal thermodynamic condition for the metabolism of the microbe consortium in the rumen. Hydrogen plays also a fundamental role in the maintenance of the equilibrium among VFA pathways and in their interconversion. In this chapter, after a brief chemical description of dietary carbohydrates, individual VFA pathways are described in order to put in evidence the thermodynamic control points of each pathway and the production of energy and reductive equivalent. Then, the relationship between hydrogen, VFA and methane production has been reviewed, considering the role of some dietary factors, the substrate competition between different metabolic pathways and the models of VFA estimation.

Keywords

Fermentation • GHG • Methane • Methanogenesis • Rumen • Propionate • VFA

11.1 Introduction

In ruminant diet, carbohydrates represent the major source of energy needs for animal and rumen microorganisms. They account for 70–80 % of the diet ingredients and are contained mainly in forages and cereal grains supplied with

---

A. Buccioni
Dipartimento di Scienze delle Produzioni Agro-alimentari e dell'Ambiente, University of Florence, Florence, Italy

A. Cappucci • M. Mele (✉)
Dipartimento di Scienze Agrarie, Alimentari e Agro-ambientali, University of Pisa, Pisa, Italy
e-mail: marcello.mele@unipi.it

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_11, © Springer India 2015

the ration. Ruminants have developed, in the first part of their digestive tract (foregut fermenters), a highly specialised symbiosis with microorganisms able to ferment a wide range of dietary carbohydrates, including the lignocellulosic fraction (Van Soest 1994). These kinds of carbohydrates, in fact, are indigestible for mammals, because they do not produce endogenous cellulolytic enzymes. The rumen microorganism community consists of many bacterial, archaeal, protozoal and fungal species, maintained under anaerobic conditions, normally at a pH 5.6–6.7 and at 39 °C (Hackmann and Spain 2010). The output of carbohydrate fermentation consists mainly of volatile fatty acids (VFA, mainly acetate, propionate and butyrate) and other products of microbe metabolism such as formate, ethanol, lactate, succinate and branched chain fatty acids. Acetate, propionate and butyrate account for more than 95 % of total VFA, and they are an important source of energy for ruminants, ranging from 40 to 70 % of the digestible energy intake (France and Dijkstra 2005). The ability of rumen microorganism to ferment lignocellulosic components in an anaerobic environment is strictly linked to the production of high amount of hydrogen, which must be further metabolised to methane and eructated, in order to prevent its accumulation in the rumen environment. Methane eructation by ruminants, therefore, is the direct consequence of a metabolic need of rumen bacteria. For many years, this aspect has been considered only from an energetic loss standpoint, because the methane production accounts for 2–12 % of the ingested energy from the ruminant (Moss et al. 2000). In the last 10 years, the methane production from ruminants is mainly considered as an environmental issue, because methane actively contributes to climatic change and global warming (Boadi et al. 2004).

The extent of rumen degradation and fermentation of carbohydrates and the type of metabolic pathways activated by rumen microbes depend to the nature of dietary carbohydrates, to the rumen environment and to the passage rate of nutrients across the rumen-abomasum tract.

The aim of this chapter is to review the metabolic fate of dietary carbohydrates in the rumen and the relationship between carbohydrates fermentation and methanogenesis.

11.2 Dietary Carbohydrates

According to their cellular localisation, carbohydrates can be divided into two distinct fractions: structural (SC) and nonstructural (NSC).

11.2.1 Structural Carbohydrates

Structural carbohydrates are contained inside the plant cell walls and include different fractions, which are not chemically uniform, like cellulose, hemicellulose, pectins and lignin. The chemical characterisation of SC is usually performed according to the method described by Van Soest (1994). This method is based on the ability of cell wall carbohydrates to form covalent linkages with the lignin component. Molecules with some covalent linkage with lignin are insoluble in neutral detergent and are recovered as neutral detergent fibre (NDF), which consists of cellulose, hemicellulose and lignin. These molecules are incompletely or only partially fermentable in the rumen. Pectins, which do not have covalent links with lignin, are completely soluble in neutral detergent and are completely fermentable in the rumen. Hemicelluloses are soluble in acid detergent, whereas celluloses and lignin are recovered as acid detergent fibre (ADF). As a consequence, hemicellulose content is calculated as the difference between NDF and ADF.

Cellulose is a polymer of β-1,4-D-glucose linked through β-1,4- glycosidic bonds, which forms the cell membranes of plants and most of the supporting tissues (40–60 %). All forages, especially preserved roughages, contain significant amounts of cellulose (20–40 % of dry matter) (Van Soest 1994). Cellulose is highly resistant to hydrolysis by treatment with diluted acids and alkali, while treatments with hot concentrated mineral acids result in a complete hydrolysis of cellulose into glucose. The digestion of cellulose needs several types of enzyme such as endoglucanases (EC 3.2.1.4), exoglucanases (EC

3.2.1.74), cellobiohydrolases (EC 3.2.1.91) and glucosidases (EC 3.2.1.21), which act sequentially in order to progressively reduce the cellulose chain to glucose (Lynd et al. 2002).

Hemicellulose is composed by a mixture of polysaccharides, which share a common β 1–4 linkage in a xylan core polymer (Van Soest 1994). The composition of hemicellulose is greatly variable across plant species, but the different types of hemicellulose have as common characteristic the covalent linkages with lignin in the plant cell wall. As a consequence, the digestibility of hemicellulose is directly related to that of cellulose and inversely related to the amount of lignin (Hespell 1988). Hemicellulose is hydrolysed in hot dilute mineral acids or alkalis, and its degradation results into simpler molecules such as D-glucose, D-galactose, D-mannose, D-xylose and L-arabinose and uronic acids. These molecules are linked together across different combinations and several glycosidic linkages (Van Soest 1994).

Pectins are components of plant cell wall that do not have any linkage with lignin. As a consequence, they are defined as soluble fibre and are completely available for rumen fermentation. Galacturonic acid is the main component of pectins together with arabinan and galactan side chains. The galacturonic acid units are linked by an alpha 1–4 bond, but, unlike starch, these bonds are not hydrolysable by amylases.

Lignin is the main limiting factor for the digestion of plant cell wall material, and its composition is not completely known. Lignin is found in close connection with cellulose and hemicellulose in plant cell walls, and together hemicellulose concurs to form the secondary wall thickening (Van Soest 1994). Lignin is largely contained in the wood (20–40 %), and it is present at lesser amounts in the fibrous portion of the stems and leaves of herbaceous plants, especially when they have reached the stage of maturity. Lignin is practically indigestible, and its presence lowers the digestibility of the other cell wall components (Chesson and Forsberg 1997).

Rumen microbes are able to degrade both cellulose and hemicellulose, with different rates according to the passage rate of feed and to the amount of indigestible fraction that encrusts the fibre fraction. In any case, the rate limiting step of the whole degradation process of cellulose and hemicellulose is the hydrolysis of the polysaccharide structure (Mertens 1992; Chesson and Forsberg 1997).

11.2.2 Nonstructural Carbohydrates

The NSC fraction is contained inside the plant cell and includes organic acids, sugars (mono-, di- and oligosaccharides), starch and fructans. When pectins are included, the term non-fibrous carbohydrates (NFC) is preferred to NSC (Mertens 1992). NSC constituents are highly digestible and are the main source of energy for ruminants.

Starch is the most important NSC and represents the nutrient reserve of plants, particularly in seeds and fruits. In nature, starch is found in amyloplasts, in the form of granules, whose size varies depending to the plants.

Starch is a mixture of amylose and amylopectin, two polysaccharides that are structurally different. The relative content of the two components varies according to the plant species. Amylose has a linear structure based on a chain of D-glucose molecules linked by an alpha 1–4 bond. Amylose is soluble in cold water; it is rapidly hydrolysed in maltose and forms the central part of the granules. Amylopectin has a branched structure, which contains both alpha 1–4 (linear part) and alpha 1–6 bonds (branched part). Amylopectin dissolves only in hot water, forming a colloidal solution. The hydrolysis of amylopectin is slower than that of amylose, but when enzymatic or chemical treatments remove the branched structure, amylopectin also dissolves in cold water as amylose. Depending on the source, the proportion of amylose and amylopectin may differ, although the main component is amylopectin, which accounts for 70–80 % of the total starch (Kotarski et al. 1992).

The rate of starch degradation is greatly variable, depending on the plant species, the passage rate of feed and the chemical structure of the starch. The fractional degradation rate for the potentially degradable fraction of starch in the rumen ranges from 0.04 to 0.05 h^{-1} for untreated corn and sorghum grain to more than 0.3 for untreated barley and wheat grain. Most of technological treatments such as cracking and grinding, toasting, steam flaking and extrusion result in an increase of starch degradability (Offner et al. 2003). Monosaccharides, disaccharides, oligosaccharides and fructans are water-soluble carbohydrates, and they are the most digestible part of NSC. They are rapidly soluble in rumen liquor and are immediately available for fermentation.

11.3 Rumen Fermentation of Dietary Carbohydrates

The breakdown of complex carbohydrates in the rumen produces simpler molecules that are metabolised to glucose and, then, to pyruvate by Embden-Meyerhof pathway also called glycolysis. Cellulose is degraded to glucose by the action of the microbial multienzyme complex known as cellulosome (Morrison and Miron 2000), containing the enzymes, β-1,4 glucosidase (EC 3.2.1.21), which converts cellulose to cellobiose, and cellobiose phosphorylase (EC 2.4.1.20), which acts on cellobiose to obtain glucose-1-phosphate (Weimer 1992). The degradation activity of cellulolytic bacteria is strictly linked to the adhesion of bacteria to plant material. In fact, cellulolytic bacteria produce a cellulose-binding protein type C, which interacts with cellulose and improves the adhesion of bacteria to plant material in the rumen (Morrison and Miron 2000). As a consequence, any factor able to decrease the adhesion of cellulolytic bacteria to plant material results in a decrease of cellulose degradation.

Starch degradation is actively performed by several strains of rumen bacteria and also by protozoa. Unlike protozoa, amylolytic bacteria are unable to ingest starch granules, and then the initial attack of starch granules is performed by surface-associated alpha-amylases or by another mechanism at the cell surface (Kotarski et al. 1992). Amylase enzymatic complex transforms starch in maltose and isomaltose, which are then converted in glucose-1-phosphate by maltase (EC 3.2.1.20), maltose phosphorylase (EC 2.4.1.8) or 1,6 glucosidase (EC 3.2.1.33).

The degradation of 1 mol of sucrose leads directly to 1 mol of α-D-glucose and 1 mol of β-D-fructose, which are the two constitutive monosaccharides bonded together by a 1, 2-O-glycoside linkage. Similarly, fructans are degraded to β-D-fructose and, to a lesser extent, to α-D-glucose, being fructans mainly constituted by fructose molecules linked by 2,3 and 2,1-O-glycoside bonds (Van Soest 1994).

Pectins are hydrolysed to pectic acid by means of pectinesterase (EC 3.1.1.11) action and, successively, to galacturonic acids (or to uronic acids) by means of the polygalacturonase enzyme (EC 3.2.1.15) and finally to pentoses. Also, the hydrolysis of β-1,4 linkages of hemicelluloses contributes to produce pentoses such as xylose, which may originate also by the hydrolysis of xylans. Pentoses may be converted in glucose and then in fructose-6-phosphate and in fructose-1,6-diphosphate, which are the first two steps of the glycolysis (Romano and Conway 1996).

Hence, rumen degradation of both SC and NSC converges to glycolysis (Fig. 11.1).

11.3.1 Glycolysis

Glycolysis is the catabolic process that converts 1 mol of glucose in 2 mol of pyruvate, under anaerobiotic conditions. This metabolic pathway can be divided in two phases. The first one, which includes five steps, is the “phase of energy investment” because it is endergonic: 2 mol of ATP are, in fact, consumed per each mole of degraded glucose (Fig. 11.2). The second phase (Fig. 11.3), in contrast, is the “phase of energy gain” because metabolic steps involved are exergonic: 4 mol of ATP and 2 mol of NADH are, in fact, produced per each mole of degraded glucose. Hence, the net balance of glycolysis includes the production of 2 mol of ATP and 2 mol of NADH that are molecules with a high energy content, useful to counterbalance the endergonic reactions (McDonald et al. 1995):

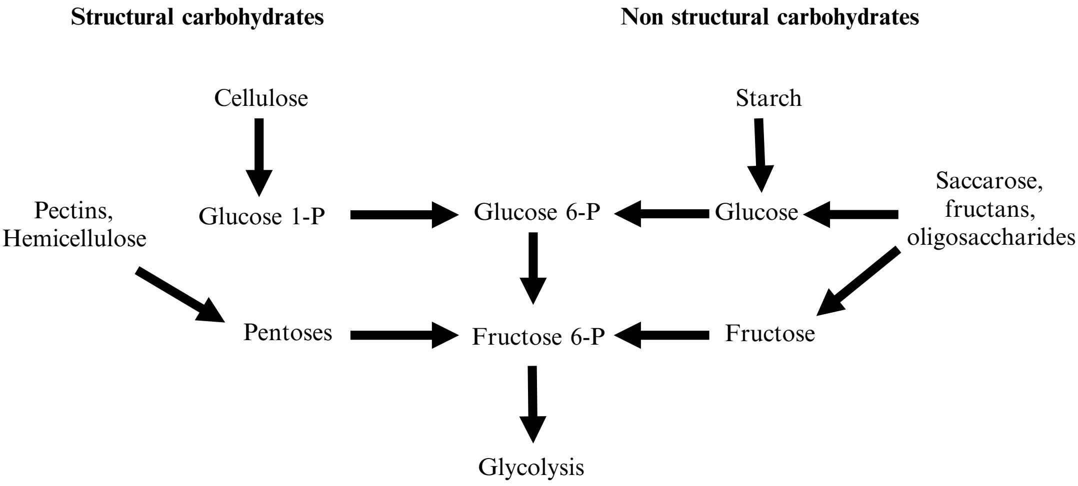


Fig. 11.1 Scheme of the degradation of structural and nonstructural carbohydrates

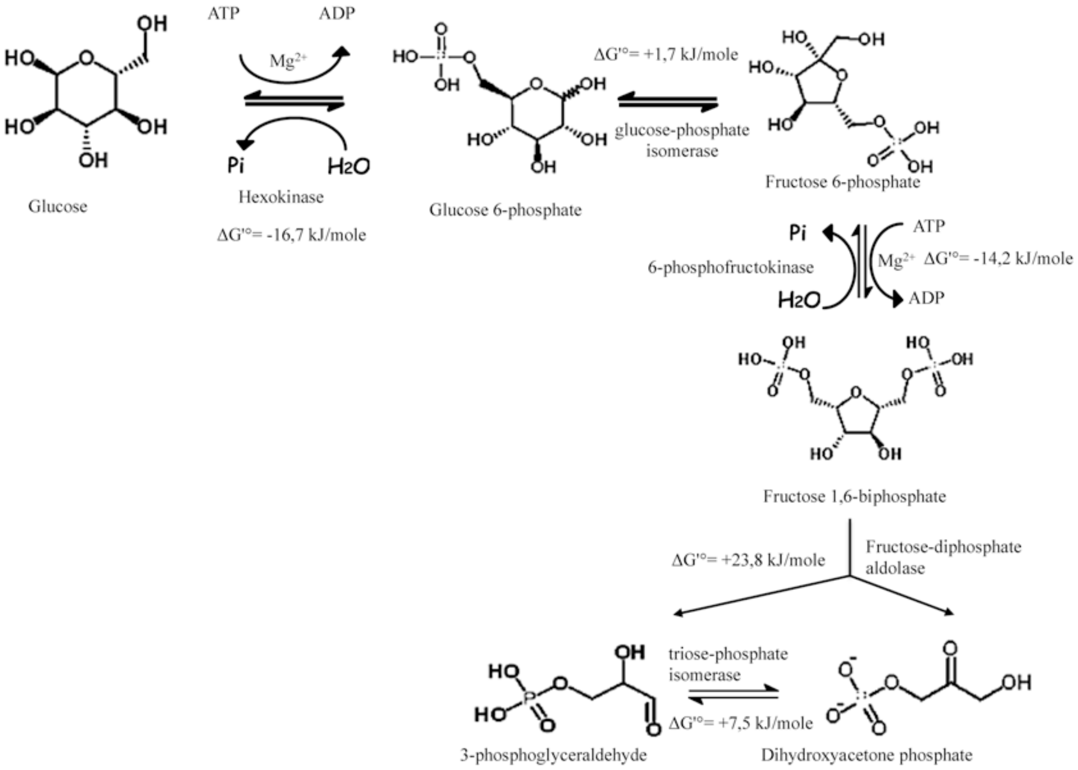


Fig. 11.2 Scheme of the first phase of glycolysis: the energy investment

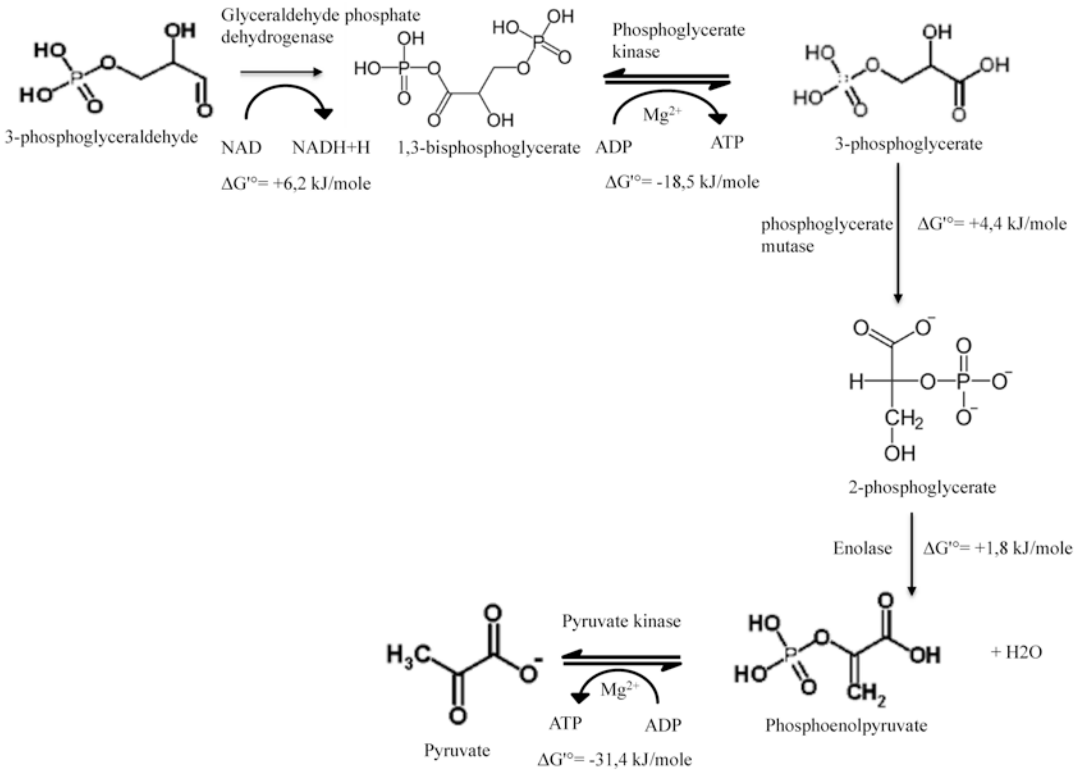


Fig. 11.3 Scheme of the second phase of glycolysis: the energy gain

$$C_6H_{12}O_6 + 2\,NAD^+ + 2\,ADP + 2\,P_i \rightarrow 2\,NADH + 2\,pyruvate + 2\,ATP + 2\,H_2O + 2\,H^+ \qquad (11.1)$$

In the first step of glycolysis, glucose is phosphorylated to glucose-6-phosphate by hexokinase enzyme (EC 2.7.1.1), consuming one ATP. This passage is characterised by high free energy of activation (ΔG), but the enzyme activity allows overcoming the initial energy barrier. Considering the whole reaction, the negative value of the free energy ($\Delta G = -16.7$ kJ/mol) makes this step irreversible. Hexokinase belongs to the family of transferase enzymes, and its activity depends on the presence of Mg^{2+} in the active centre of enzyme, which forms an ion bond with the substrate (Demeyer 1991).

The second step is the isomerisation of glucose-6-phosphate to fructose-6-phosphate, by the action of glucose phosphate isomerase enzyme (EC 5.3.1.9). This enzyme firstly opens the glucose ring and reduces the aldehyde to the correspondent alcohol; then, the alcoholic function is oxidised to the relative ketone, and finally the ring is newly closed to form fructose-6-phosphate. The ΔG of this step is not favourable (+1.7 kJ/mol), but the half-life of fructose 6-phosphate is very short, because the glycolysis proceeds very quickly with a new phosphorylation, subtracting the fructose 6-phosphate to the previous reaction (Demeyer 1991). In the third step, therefore, fructose 6-phosphate is phosphorylated to fructose 1,6-diphosphate, by the enzyme 6-phosphofructokinase (EC 2.7.1.11) that is an allosteric enzyme belonging to the class of the transferases and composed by two mobile subunits able to bond the substrate and the ATP molecule. In this passage, one ATP is requested to insert a phosphate group on the position 1 of fructose-6-phosphate with a $\Delta G = -14.2$ kJ/mol. This step is not reversible and represents a crucial point of the glycolysis process, because both glucose

6-phosphate and fructose 6-phosphate are common intermediates of other metabolic processes, but when the second phosphate group is added to the fructose 6-phosphate, this molecule is destined to be catabolised exclusively to pyruvate. The next step, in fact, consists in the breakdown of fructose 1,6-diphosphate to glyceraldehyde 3-phosphate and dihydroxyacetone phosphate. The reaction ($\Delta G = +23.8$ kJ/mol) is catalysed by the enzyme fructose-diphosphate aldolase (EC 4.1.2.13) that is a lyase enzyme. The "phase of energy investment" is concluded by the isomerisation of the dihydroxyacetone phosphate to glyceraldehyde 3-phosphate by the enzyme triose-phosphate isomerase (EC 5.3.1.1) ($\Delta G = +7.5$ kJ/mol). Although the dihydroxyacetone phosphate synthesis is more energetically favourable, the reaction shifts toward the formation of glyceraldehyde 3-phosphate, because this molecule is dehydrogenated in the next step of the glycolysis pathway, immediately after its synthesis. At the end of this first phase of the glycolysis, from a mole of glucose, 2 mol of glyceraldehyde 3-phosphate are obtained (Demeyer 1991).

The next steps of glycolysis belong to the "phase of energy gain" and the pathway proceeds in positive energy balance. Glyceraldehyde 3-phosphate is transformed in 1,3-diphosphoglycerate by means of the oxidation of the glyceraldehyde 3-phosphate to carboxylic acid, followed by the phosphorylation of the carboxylic group. These two passages are catalysed by the glyceraldehyde 3-phosphate dehydrogenase (EC 1.2.1.12), which is an oxide reductase enzyme, able to compensate the energetic deficit of the phosphorylation passage with the negative value of ΔG (−43 kJ/mol) of the oxidation. The balance of the whole reaction allows to store energy as NADH and the final ΔG is about $+6.2$ kJ/mol (Demeyer 1991). Then, 1,3-diphosphoglycerate is converted in 3-phosphoglycerate by the action of phosphoglycerate kinase (EC 2.7.2.3), which is a Mg^{2+}-dependent transferase enzyme. The energy balance of the step is negative ($\Delta G = -18.5$ kJ/mol), and one ATP is produced, as a consequence of the transfer of one phosphate group to an ADP molecule (Russell and Wallace 1997).

The next step $\left(\Delta G = +4.4 \text{ kJ/mol}\right)$ is a rearrangement of the 3-phosphoglycerate structure coordinated by the phosphoglycerate mutase enzyme (EC 5.4.2.1) that transfers the phosphate group from the third to the second carbon atoms, by way 2,3-phosphoglycerate as intermediate, and the final production of 2-phosphoglycerate. At the next step, the enolase (EC 4.2.1.11), an enzyme belonging to the family of lyases, converts by dehydration the 2-phosphoglycerate into phosphoenolpyruvate $\left(\Delta G = +1.8 \text{ kJ/mol}\right)$ that is transformed in pyruvate by the action of the pyruvate kinase enzyme (EC 2.7.1.40) (Mg^{2+} dependent). Since this reaction is strongly exergonic $\left(\Delta G = -31.4 \text{ kJ/mol}\right)$, 1 mol of ATP is produced per each mole of pyruvate (Russell and Wallace 1997).

The net mass balance of glycolysis, starting from one molecule of glucose, which has 6 atoms of carbon, produces two molecules of pyruvate (3 carbon atoms), via glyceraldehyde-3-phosphate. From an energetic standpoint, during glycolysis, 2 mol of ATP are consumed, whereas 2 mol of NADH and 4 mol of ATP are produced; hence, the final energetic balance is positive, accounting for 2 mol of ATP and 2 mol of NADH (Demeyer 1991).

In the rumen ecosystem, pyruvate is the milestone needed to activate the next pathways for the production of volatile fatty acids (VFAs) such as acetate, propionate and butyrate and the gases (CO_2 and CH_4) related to the biochemical reaction involved in the VFA production. In the rumen, the production of VFA is highly variable (from 2 to 15 g per litre of rumen liquor), and it is strongly affected by the quality of the diet fed to the animals, which, in turn, influences the amount and the composition of rumen microorganisms (Bannink et al. 2006).

11.3.2 The Acetate Pathway and Methanogenesis

Pyruvate is oxidised to acetyl-coenzyme A (Ac-CoA) and formate by an enzymatic system called pyruvate ferredoxin oxidoreductase (EC 1.2.7.1) in the presence of coenzyme A (3-phospho-adenosine-5-diphospho-pantotheine) (Baldwin and Allison 1983). Hence, the Ac-CoA is phosphorylated by the enzyme phosphotransacetylase (EC 2.3.1.8) to acetylphosphate that, in

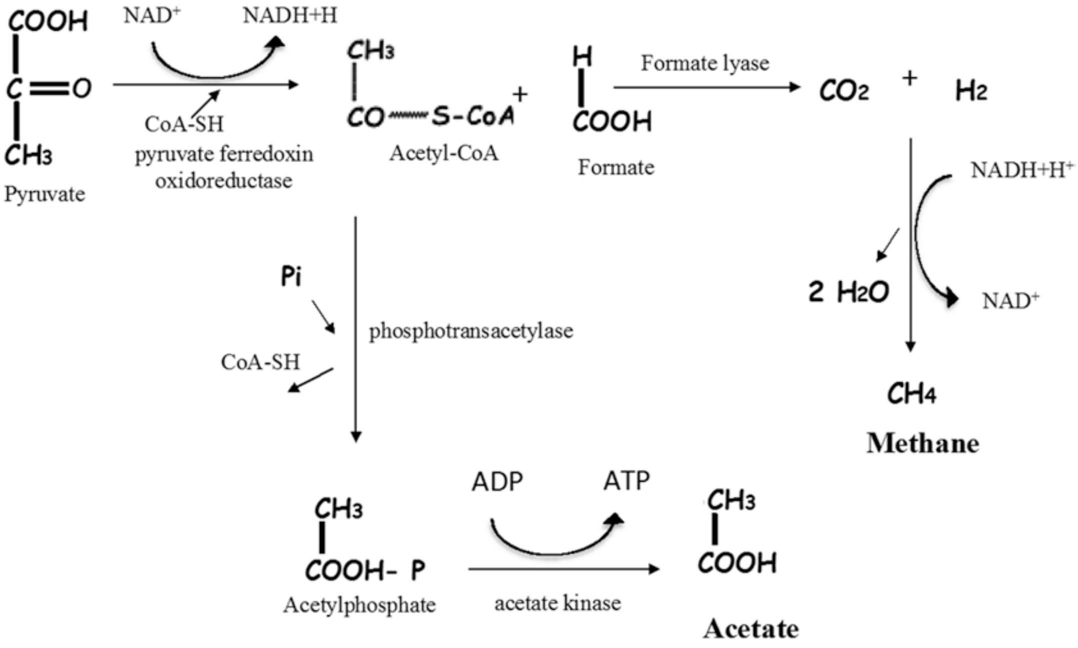


Fig. 11.4 Scheme of acetate pathway via acetylphosphate

the next step, is converted to acetate by the enzyme acetate kinase (EC 2.7.2.1), with the production of 1 mol of ATP (Fig. 11.4). The formate production generates also 1 mol of CO_2 and 1 mol of H_2, and this metabolic step is characterised by $(\Delta G = -130\ \text{kJ/mol})$ (Russell and Wallace 1997). CO_2 and H_2 are the precursors of CH_4 in the methanogenesis pathway, which involves several specific enzymes and coenzymes able to transport carbon units or electrons in the oxidoreduction process (Fig. 11.5). CO_2 is activated by the reaction with the methanofuran coenzyme (MFR) resulting in a formyl moiety (MFR-COH) (Thauer 1998). MFR, in the next passage, is substituted by a methanopterin (5,6,7,8 tetrahydromethanopterin), and then the carboxylic group of the formyl moiety is reduced to a methylene group by means of the F_{420} coenzyme (8-hydroxy-5-deazaflavin), in the presence of 2-mercaptoethanesulfonate (coenzyme M). The last step deals with the reduction of methyl group to methane (Fig. 11.6). This step is an exergonic reaction (coupled with the phosphorylation of ADP), catalysed by methyl-CoM reductase enzyme (EC 2.8.4.1), which contains factor F_{430} as prosthetic group (Ankel-Fuchs et al. 1986).

The net balance of the fermentation of 1 mol of glucose to acetic acid results in the production of 2 mol of acetic acid, 2 mol of CO_2 and 4 mol of H_2:

$$C_6H_{12}O_6 \rightarrow 2C_2H_4O_2 + 2CO_2 + 4H_2 \qquad (11.2)$$

CO_2 and hydrogen are further metabolised as methane by Archaea bacteria according to the following equation:

$$CO_2 + 4H_2 = CH_4 + 2H_2O \qquad (11.3)$$

11.3.3 The Butyrate Pathway

As previously described, pyruvate is firstly transformed in Ac-CoA that, in the case of butyrate pathway, is converted to acetoacetyl CoA by the acetyl-CoA acetyltransferase enzyme (EC 2.3.1.9). The next step is the production of β-hydroxybutyryl-CoA, catalysed by the enzyme

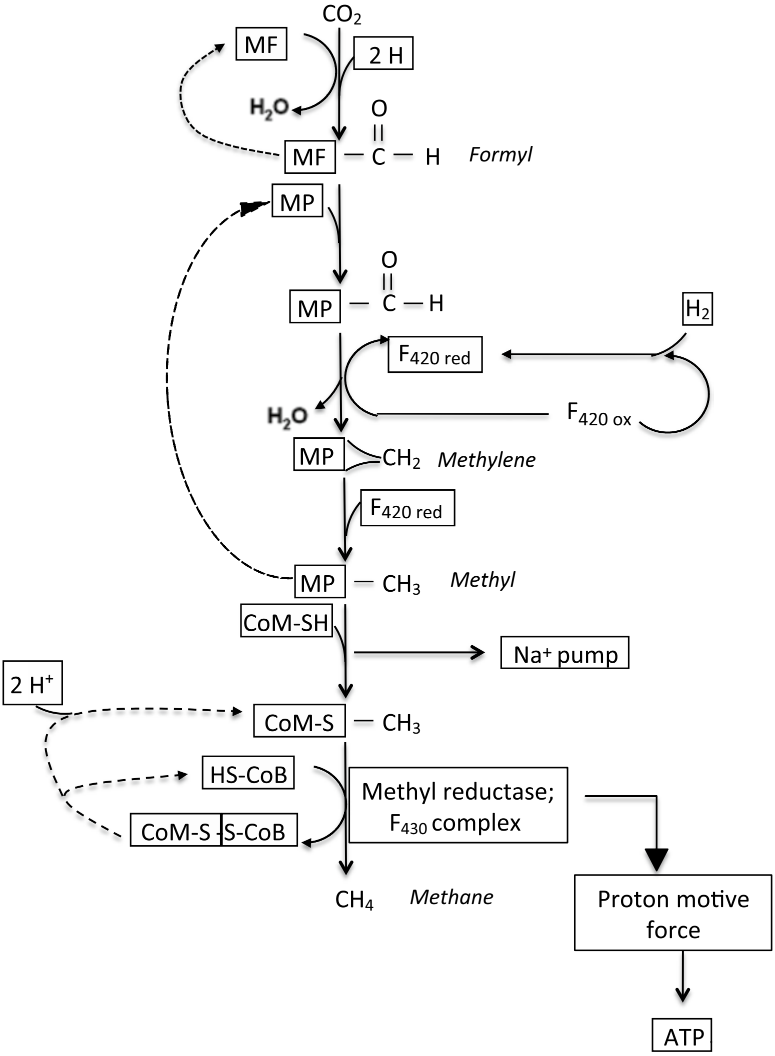


Fig. 11.5 Scheme of methanogenesis

β-hydroxybutyryl-CoA dehydrogenase (EC 1.1.1.157), which uses two hydrogen atoms by the oxidation of NADH. The next step is from β-hydroxybutyryl-CoA to crotonyl-CoA, by means of 3-hydroxybutyryl-CoA dehydratase enzyme (EC 4.2.1.55). Crotonyl-CoA is transformed to butyryl-CoA (using NADH as hydrogen donor) and then to butyryl phosphate, by the action of the enzymes butyryl-CoA dehydrogenase (EC 1.3.99.2) and phosphate butyltransferase (EC 2.3.1.19), respectively. The last step is the formation of butyrate, via the lyses of the phosphate group that is used to form ATP (Demeyer 1991).

In synthesis, the net balance for the complete fermentation of 1 mol of glucose to butyrate is

$$C_6H_{12}O_6 \rightarrow C_4H_8O_2 + 2CO_2 + 2H_2 \quad (11.4)$$

Considering the production of H_2, the butyrate pathway, therefore, is more favourable than the acetate one, because hydrogen is used in the reduction of acetoacetyl CoA and crotonyl-CoA.

11.3.4 The Propionate Pathway

In the case of propionate, two pathways may origin from pyruvate: the first is the synthesis via

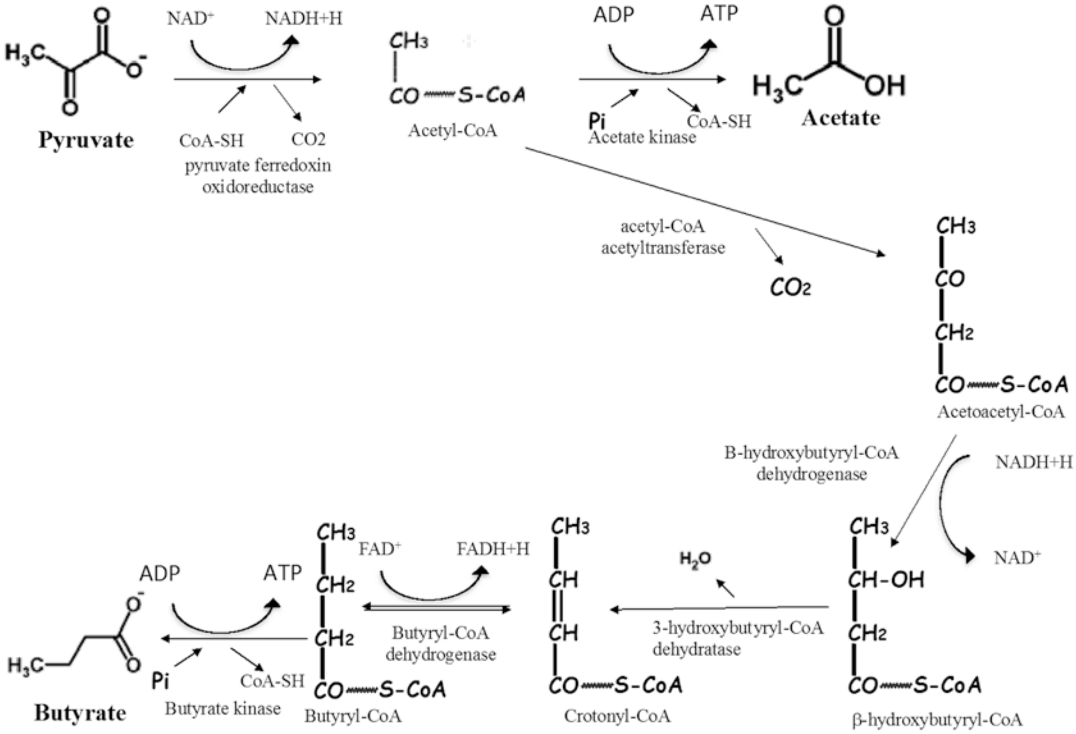


Fig. 11.6 Scheme of acetate and butyrate pathway

lactate and acrylate production (Fig. 11.7) and the second via oxalacetate and succinate (Fig. 11.8). The reduction of pyruvate to lactate in the presence of lactate dehydrogenase (EC 1.1.1.27) involves the oxidation of NADH and results in a net production of 2 mol of ATP from each mole of glucose. The lactate is activated by coenzyme A to form lactoyl-CoA, involving the breakdown of an ATP, which provides the energy for the reaction. This step is catalysed by propionyl-CoA transferase enzyme (EC 2.8.3.1). Then, the lactoyl-CoA is dehydrated by lactoyl-CoA dehydratase (EC 4.2.1.54) to acryloyl-CoA that, subsequently, is reduced to propionyl-CoA by acryloyl-CoA reductase (EC 1.3.1.84). Also, this step involves the oxidation of NADH. The last step is the release of the coenzyme A with a net production of an ATP. The lactate pathway is preferred by some rumen bacteria such as *Megasphaera elsdenii* and its contribution to propionate production becomes more important when ruminants are fed diet with high level of starch (Russell 2002).

The alternative pathway is called the succinate or the dicarboxylic acid pathway. In this pathway, pyruvate is firstly converted to oxaloacetate by means of pyruvate carboxylase enzyme (EC 6.4.1.1), which contains biotin as prosthetic group. This step consumes also a molecule of CO_2 and may start also by phosphoenolpyruvate, which originates by glycolysis. In this case, the synthesis of oxaloacetate is catalysed by phosphoenolpyruvate carboxylase (EC 4.1.1.31) with a gain of one ATP. Then oxalate is reduced to malate, by the malate dehydrogenase enzyme (EC 1.1.1.37) using a NADH. In the next step, firstly, malate is dehydrated to fumarate, via the fumarase enzyme (EC 4.2.1.2), and then, the fumarate reductase enzyme (EC 1.3.1.6) converts fumarate to succinate. Also, in this step, an oxidation of NADH occurs. The succinate is activated by means of coenzyme A to form succinyl-CoA, involving the breakdown of an ATP, which provides the energy for the reaction. Hence, succinyl-CoA is transformed to (S)-methylmalonyl-CoA by the action of

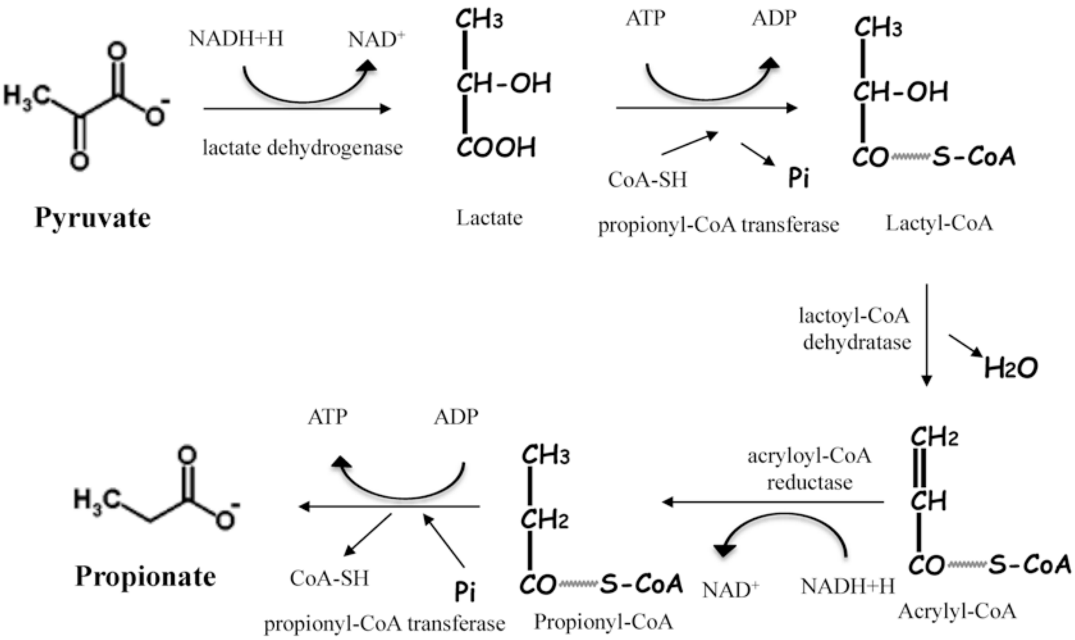


Fig. 11.7 Scheme of propionate pathway via lactate and acrylate

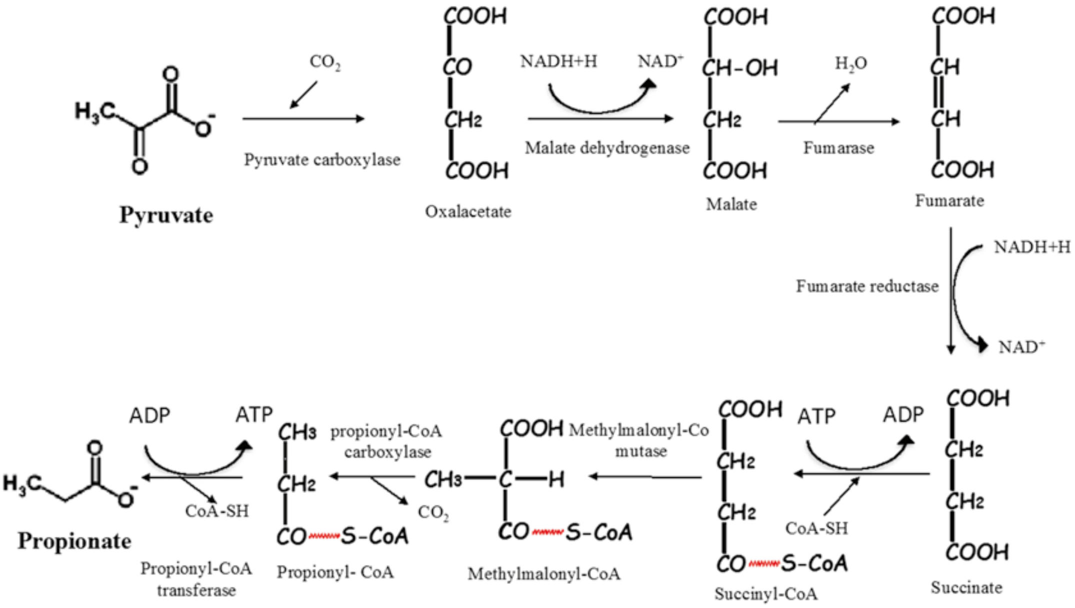


Fig. 11.8 Scheme of propionate pathway via oxalacetate

methylmalonyl-CoA mutase enzyme (EC 5.4.99.2) and methylmalonyl-CoA racemase (EC 5.1.99.1) with vitamin B_{12} as cofactor. Propionyl-CoA is obtained by a carboxylation catalysed by the propionyl-CoA carboxylase enzyme (EC 6.4.1.3) with a loss of a CO_2 molecule. At the end of the process, the conversion of propionyl-CoA to propionate leads to an energy gain by the recovery of one ATP. This pathway accounts for more than 60 % of propionate production in the rumen (Russell and Wallace 1997; Russell 2002).

The net balance for the complete fermentation of 1 mol of glucose to propionate is

$$C_6H_{12}O_6 \rightarrow 2C_3H_6O_2 + 2[O] \tag{11.5}$$

Considering the stoichiometry of VFA production, the acetate synthesis contributes to the formation of 2 mol of CO_2 and 4 mol of H_2 per mole of glucose fermented; since methanogens use 1 mol of CO_2 and 4 mol of H_2 to produce CH_4, the acetate pathway releases 1 mol of CO_2 and 1 mol of CH_4 per mole of fermented glucose. The butyrate results in 1.5 mol of CO_2 and 0.5 mol of CH_4 per mole of fermented glucose, while propionate does not contribute to CH_4 production because it does not result in a net production of H_2 and CO_2. Hence, the energy proportion retained by animal is higher when propionate is produced instead of acetate or butyrate (Demeyer 1991).

11.4 Substrate Competition to Methane Production

As reported in the previous paragraph, H_2 and CO_2 are the main gas produced during rumen fermentation of structural carbohydrates, and they are readily used by methanogens bacteria to produce CH_4 and H_2O, with an energetic expense that may vary between 2 and 12 % of the gross energy intake, according to the type of diet (Johnson and Johnson 1995). However, methanogens may also use different substrates for methane synthesis, and, at the same time, other metabolic pathways may be activated as H_2 sink. As regards the first aspect, methanogens bacteria may use formate, acetate, methanol, methylamines, methylated sulphides and short-chain alcohols as electron donor in CO_2 reduction as an alternative to H_2 (Mills et al. 2003). Since some methanogen strains grow exclusively on these alternative substrates (Zinder 1993), it is very important to improve the basic knowledge about substrate utilisation and preference of methanogens, in order to avoid a systematic underestimation of CH_4 emission by ruminants under different feeding conditions. However, from a thermodynamic standpoint, the methanogenic processes based on the use of H_2 coupled with formate or CO_2 as substrates are the most favourable, accounting for a $\Delta G = -145$ kJ and -135 kJ, respectively. The other substrates reported above are characterised by a less favourable ΔG or, as in the case of carbon monoxide, by a high toxicity for large part of rumen bacteria (Ungerfeld and Kohn 2006; Mills et al. 2003).

Regarding the alternative metabolic pathways for H_2 sink, some rumen microorganism may compete with methanogens bacteria for the use of H_2 (Jeyanathan et al. 2013). Reductive acetogenic bacteria compete with methanogens in the rumen for the use of H_2, in the reduction of CO_2 to acetate. This pathway has been observed in several herbivores species, and it is considered as the main H_2 sink pathway in nonruminant herbivores (Klieve and Ouwerkerk 2007). The number of acetogenic bacteria in the rumen is higher in the early stages of life, and it decreases after few weeks, whereas the number of methanogens increases (Morgavi et al. 2010). In adult, the total concentration of acetogenic bacteria in rumen liquor is usually tenfold lower than that of methanogens, although some differences have been reported according to the feeding regimen (Fonty et al. 2007). Methanogenesis is more favourable than reductive acetogenesis under normal ruminal condition because the value of ΔG is nearly double of that estimated for reductive acetogenesis (-135 kJ vs. -72 kJ, Ungerfeld and Kohn 2006). Moreover, the H_2 thresholds, needed by methanogens bacteria to operate their synthesis, are 10–100-fold lower than that needed for reductive acetogenesis (Le Van et al. 1998; Ungerfeld and Kohn 2006). Therefore, reductive acetogens bacteria are outcompeted by methanogens, because H_2 partial pressure in rumen is maintained to a level lower than that optimal for acetogens metabolism.

Sulphate-reducing bacteria are able to use sulphate, nitro compounds and nitrate as electron acceptors as alternative to CO_2 and, therefore, may be considered as competitors of methanogens for H_2 sink (Gibson et al. 1993). Taking into consideration the thermodynamic aspects and the substrate affinity, sulphate-reducing bacteria have a competitive advantage for H_2 use in the rumen, if compared with methanogens; however, the amount of sulphur compounds in the diet is usually lower than that needed by sulphur-reducing bacteria to be the major H_2 sink in the rumen (Zinder 1993).

An alternative electron sink to methanogenesis is also the biohydrogenation of dietary polyunsaturated fatty acids (PUFAs); in fact, PUFAs are toxic for rumen microorganisms especially for gram-positive bacteria that are the main responsible of SC fermentation and of the acetate and H_2 production (Jenkins et al. 2008). Otherwise, gram-positive bacteria, which are involved in propionate production, are less sensitive to PUFA; hence, the propionate synthesis is enhanced when dietary PUFA increased (Ellis et al. 2008). Moreover, during the biohydrogenation processes, double bonds present in the fatty acid chains are saturated, consuming reducing equivalents and subtracting H_2 to the other pathways (Jenkins et al. 2008). In particular, the biohydrogenation process is more favourable than methanogenesis from both thermodynamic and enzymatic standpoints. Hence, several studies demonstrated that lipid addiction to the diet decreases CH_4 production, and the degree of saturation of fatty acids contained in the lipid supplement is inversely proportional to the reductive effect on CH_4 production (Giger-Reverdin et al. 2003).

11.5 Role of H_2 in the Equilibrium of VFA Pathways

The equilibrium among VFA metabolic pathway plays an important role in the regulation of methane emission. Diet composition may significantly affect this equilibrium and, in particular, the ratio starch/cellulose (Ellis et al. 2008). Cellulolytic bacteria, in fact, produce more acetate and H_2, whereas amylolytic bacteria produce more propionate and less H_2. For instance, when acetate production increases (as in the case of high-forage diets) and propionate and butyrate metabolic routes remain unchanged, an increase in methane production occurs at the expenses of CO_2 emitted by acetate and butyrate pathways, and the amount of methane produced per mole of fermented glucose increases (Baldwin 1970).

However, the activation of VFA pathways is not genetically predetermined, but rumen microorganisms growing on different substrates are able to activate different possible fermentation pathways, according to the more favourable thermodynamic conditions (Janssen 2010). The H_2 pressure in the rumen plays a fundamental role in favouring the prevalence of a specific metabolic pathway and the interconversion among VFA pathways (Janssen 2010). Each metabolic pathway, in fact, is thermodynamically controlled, and the H_2 partial pressure in the rumen environment may actively regulate the fermentation pathways that use or produce H_2. In general, there is equilibrium between H_2 concentration in rumen liquor and CH_4 and propionate production. When H_2 concentration is high (readily degradable feed is rapidly digested, high passage rate of feed, low ruminal pH, presence of inhibitors of methanogens), propionate fermentation increases, because H_2 formation becomes thermodynamically unfavourable, and CH_4 production per unit of fermented feed decreases. Conversely, when H_2 concentration is low (slowly degradable feed is digested, low passage rates of feed, growth conditions of methanogens are near optimal), the propionate pathway becomes unfavourable, and the CH_4 production per unit of fermented feed increases (Janssen 2010).

Rumen pH plays also an important role in the equilibrium of VFA. Rumen pH varies according to the amount of NSC in the diet, rumen degradability of starch, the amount of effective fibre in the diet, the passage rate of feed and the time after feeding (Kolver and de Veth 2002; Zebeli et al. 2010). In general, when rumen pH decreases, rumen fermentation shifts toward propionate production leading to increased utilisation of H_2 and thereby decreases the production of CH_4 (Christophersen et al. 2008). The optimal pH value for the methanogens bacteria growth is close to the neutrality; therefore, there is a direct effect of pH on CH_4 production through an inhibition of bacterial growth of both cellulolytic and methanogens bacteria (Van Kessel and Russell 1996). Moreover, when pH value decreases, the H_2 concentration in the rumen increases resulting in a decrease of net H_2 production by fermentative pathways and, thus, in a decrease of CH_4 production (Janssen 2010).

Also, the concentration of final and intermediate products may induce a shift of VFA pathways, and this aspect has been evaluated as a means to drive H_2 sink toward propionate production instead of CH_4. As described in the previous paragraph, in fact, propionate synthesis involves the use of H_2 in two metabolic steps: the reduction of oxaloacetate to malate and the reduction of fumarate to succinate (Fig. 11.8). From a thermodynamic standpoint, the reduction of fumarate to succinate is more favourable than methanogenesis. However, although stoichiometric calculation shows that 1 mol of fumarate reduced to succinate is expected to decrease methanogenesis by 0.25 mol, when fumarate has been added to ruminant diet, the observed CH_4 reduction was half than that expected (Ungerfeld and Kohn 2006). Since the conversion of fumarate to both acetate and propionate (via succinate) is thermodynamically favoured, the added fumarate is only partially reduced to succinate, whereas a significant part of fumarate is converted to acetate, releasing a pair of reducing equivalent, which counterbalances the reducing equivalent adsorbed by fumarate (Ungerfeld and Kohn 2006).

Similarly to what is observed for fumarate, also other intermediates of propionate pathway (malate, oxaloacetate, acrylate) may actively shift the equilibrium toward an increase of propionate production, subtracting more H_2 to CH_4 pathway. In particular, addition of malate seemed to stimulate both propionate production and other forms of electron sink related to the microbial anabolism (Martin 1998). However, large part of data available in literature refers only to in vitro studies.

11.6 Relation Between VFA Production and Methane Emission

As previously stated, the equilibrium among VFA in the rumen is a mirror of the metabolic pathway activated by rumen microbes to ferment dietary carbohydrates. Since acetate and butyrate pathways produce H_2, whereas propionate pathway uses H_2, the accurate prediction of total VFA production and of production rates of individual VFA in the rumen under different feeding condition is an essential step in order to achieve a proper estimation of the CH_4 emission.

In literature, several studies have proposed different methods to evaluate VFA production, but the level of accuracy achieved is not yet completely satisfactory (Ellis et al. 2008). The main problem observed to improve the accuracy in the VFA estimation is related to the evaluation of the absorption rate of VFA by rumen wall, especially when diets are rich in starch (France and Dijkstra 2005; Bannink et al. 2000). Both empirical and mechanistic mathematical models have been proposed to predict VFA production in the rumen, but mechanistic approaches, which consider several nutritional and microbial factors, seem to be preferable than empirical models that estimate individual VFA production on the basis only of nutritional factors (Bannink et al. 2008).

Recently, Alemu et al. (2011) evaluated four different VFA stoichiometric models previously published in order to assess their ability to predict VFA and CH_4 production, using independent data sources. The authors found that the ability to predict individual VFA production varied according to the model adopted. In general, the models proposed by Bannink et al. (2006) and by Nozière et al. (2010) showed the best prediction ability with values of mean prediction errors ranging from 1.6 (Bannink model) to 2.9 (Noziere model) for butyrate, from 8.6 (Bannink model) to 9.1 (Noziere model) for propionate and from 10.4 (Noziere model) to 11.5 (Bannink model) for acetate. In all cases, the authors considered the amount of unexplained variance relative to differences between predicted and observed values of VFA production still too large to obtain an accurate prediction of CH_4 emission on the basis of VFA values obtained by the application of the stoichiometric model considered (Alemu et al. 2011). However, the mechanistic models proposed seemed to better represent the relationship between individual VFA and between VFA production and adsorption.

Moreover, the study of Alemu et al. (2011) put in evidence an intriguingly aspect about the accuracy of the IPCC tier 2 method that is the current inventory method usually adopted to estimate the CH_4 emission in the livestock sector. According to the result of the study from Alemu et al. (2011), the mean square error of IPCC method was higher than that of three of the four mechanistic models evaluated in the study, suggesting that IPCC method overestimated the CH_4 emission. Hence, results of Alemu et al. (2011) confirmed what previously reported by Ellis et al. (2010) who stated that IPCC tier 2 method does not have the ability to take into consideration the changes in dietary composition, and, therefore, the use of IPCC tier 2 method is considered useful in order to obtain an accurate estimate of the impact of different feeding strategies on CH_4 emissions.

11.7 Conclusions

Rumen fermentation of carbohydrates is strictly linked to methane emission, because H_2 is actively produced during the fermentation of structural carbohydrates, and it must be rapidly metabolised by methanogens in order to maintain the optimal thermodynamic condition for the metabolism of the microbe consortium in the rumen. The balance between acetate and propionate pathway is a critical point to regulate the amount of H_2 available for CH_4 emission. The complete understanding of the relationship between different VFA pathways and the accurate estimate of VFA production could offer great opportunity to improve ruminant production in terms of energy efficiency and methane emission.

References

Alemu AW, Dijkstra J, Bannink A, France J, Kebreab E (2011) Rumen stoichiometric models and their contribution and challenges in predicting enteric methane production. Anim Feed Sci Technol 166–167:761–778

Ankel-Fuchs D, Hüster R, Mörschel E, Albracht SPJ, Thauer RK (1986) Structure and function of methyl-coenzyme M reductase and of factor F_{430} in methanogenic bacteria. Syst Appl Microbiol 7:383–387

Baldwin RL (1970) Energy metabolism in anaerobes. Am J Clin Nutr 23:1508–1518

Baldwin RL, Allison MJ (1983) Rumen metabolism. J Anim Sci 57:461–477

Bannink A, Kogut J, Dijkstra J, France J, Tamminga S, Van Vuuren AM (2000) Modelling production and portal appearance of volatile fatty acids in dairy cows. In: McNamara JP, France J, Beever D (eds) Modelling nutrient utilization in farm animals. CABI Publishing, New York

Bannink A, Kogut J, Dijkstra J, France J, Kebreab E, Van Vuuren AM, Tamminga S (2006) Estimation of the stoichiometry of volatile fatty acid production in the rumen of lactating cows. J Theor Biol 238:36–51

Bannink A, France J, Lopez S, Gerrits WJJ, Kebreab E, Tamminga S, Dijkstra J (2008) Modelling the implications of feeding strategy on rumen fermentation and functioning of the rumen wall. Anim Feed Sci Technol 143:3–26

Boadi D, Benchaar C, Chiquette J, Masse D (2004) Mitigation strategies to reduce enteric methane emissions from dairy cows: update review. Can J Anim Sci 84:319–335

Chesson A, Forsberg CW (1997) Polysaccharide degradation by rumen microorganism. In: Hobson PN, Stewart CS (eds) The rumen microbial ecosystem. Blackie, London

Christophersen CT, Wright ADG, Vercoe PE (2008) In vitro methane emission and acetate:propionate ratio are decreased when artificial stimulation of the rumen wall is combined with increasing grain diets in sheep. J Anim Sci 86:384–389

Demeyer DI (1991) Quantitative aspects of microbial metabolism in the rumen and hindgut. In: Jouany P (ed) Rumen microbial metabolism and ruminant digestion. INRA Editions, Paris

Ellis JL, Dijkstra J, Kebreab E, Bannink A, Odongo NE, Mcbride BW, France J (2008) Aspects of rumen microbiology central to mechanistic modelling of methane production in cattle. J Agric Sci 146:213–233

Ellis JL, Bannink A, France J, Kebreab E, Dijkstra J (2010) Evaluation of enteric methane prediction equations for dairy cows used in whole farm models. Glob Change Biol 16:3246–3256

Fonty G, Joblin K, Chavarot M, Roux R, Naylor G, Michallon F (2007) Establishment and development of ruminal hydrogenotrophs in methanogen- free lambs. Appl Environ Microbiol 73:6391–6403

France J, Dijkstra J (2005) Volatile fatty acid production. In: Dijkstra J, Forbes JM, France J (eds) Quantitative aspects of ruminant digestion and metabolism. CAB International, Wallingford

Gibson GR, Macfariane GT, Cummings JH (1993) Sulphate reducing bacteria and hydrogen metabolism in the human large intestine. Gut 34:437–439

Giger-Reverdin S, Morand-Fehr P, Tran G (2003) Literature survey of the influence of dietary fat composition on methane production in dairy cattle. Livest Prod Sci 82:73–79

Hackmann TJ, Spain JN (2010) Invited review: ruminant ecology and evolution: perspectives useful to ruminant livestock research and production. J Dairy Sci 93:1320–1334

Hespell RB (1988) Microbial digestion of hemicelluloses in the rumen. Microbiol Sci 5:362–365

Janssen PH (2010) Influence of hydrogen on rumen methane formation and fermentation balances through microbial growth kinetics and fermentation thermodynamics. Anim Feed Sci Technol 160:1–22

Jenkins TC, Wallace RJ, Moate PJ, Mosley EE (2008) Board-invited review: recent advances in biohydrogenation of unsaturated fatty acids within the rumen microbial ecosystem. J Anim Sci 86:397–412

Jeyanathan J, Martin C, Morgavi DP (2013) The use of direct-fed microbials for mitigation of ruminant methane emissions: a review. Animal 8:250–261

Johnson KA, Johnson DE (1995) Methane emissions from cattle. J Anim Sci 73:2483–2492

Klieve AV, Ouwerkerk D (2007) Comparative greenhouse gas emissions from herbivores. In: Proceedings of the 7th international symposium on the nutrition of herbivores, Beijing, China pp 487–500

Kolver ES, de Veth MJ (2002) Prediction of ruminal pH from pasture-based diets. J Dairy Sci 85:1255–1266

Kotarski SF, Waniska RD, Thurn KK (1992) Starch hydrolysis by the ruminal microflora. J Nutr 122:178–190

Le Van TD, Robinson JA, Ralph J, Greening RC, Smolenski WJ, Leedle JAZ, Schaefer DM (1998) Assessment of reductive acetogenesis with indigenous ruminal bacterium populations and Acetitomaculum ruminis. Appl Environ Microbiol 64:3429–3436

Lynd LR, Weimer PJ, van Zyl WH, Pretorius IS (2002) Microbial cellulose utilization: fundamentals and biotechnology. Microbiol Mol Biol Rev 66:506–577

Martin SA (1998) Manipulation of ruminal fermentation with organic acids: a review. J Anim Sci 76:3123–3132

McDonald P, Edwards RA, Greenhalgh JFD, Morgan CA (1995) Animal nutrition, 5th edn. Longman, Harlow

Mertens DR (1992) Nonstructural and structural carbohydrates. In: Van Horn HH, Wilcox CJ (eds) Large dairy herd management. American Dairy Science Association, Champaign

Mills JAN, Kebreab E, Yates CM, Crompton LA, Cammell SB, Dhanoa MS, Agnew RE, France J (2003) Alternative approaches to predicting methane emissions from dairy cows. J Anim Sci 81:3141–3150

Morgavi DP, Forano E, Martin C, Newbold CJ (2010) Microbial ecosystem and methanogenesis in ruminants. Animal 4:1024–1036

Morrison M, Miron J (2000) Adhesion to cellulose by Ruminococcus albus: a combination of cellulosomes and Pil-proteins? FEMS Microbiol Lett 185:109–115

Moss AR, Jouany JP, Newbold J (2000) Methane production by ruminants: its contribution to global warming. Ann Zootech 49:231–254

Nozière P, Ortigues-Marty I, Loncke C, Sauvant D (2010) Carbohydrate quantitative digestion and absorption in ruminants: from feed starch and fibre to nutrients available for tissues. Animal 4:1057–1074

Offner A, Bach A, Sauvant D (2003) Quantitative review of in situ starch degradation in the rumen. Anim Feed Sci Technol 106:81–93

Romano AH, Conway T (1996) Evolution of carbohydrate metabolic pathways. Res Microbiol 147:448–455

Russell JB (2002) Rumen microbiology and its role in ruminant nutrition, 1st edn. Cornell University, Ithaca, NY, US

Russell JB, Wallace RJ (1997) Energy-yielding and energy-consuming reactions. In: Hobson PN, Stewart CS (eds) The rumen microbial ecosystem. Blackie Academic and Professional, London

Thauer RK (1998) Biochemistry of methanogenesis: a tribute to Marjory Stephenson. Marjory Stephenson Prize Lecture. Microbiology 144:2377–2406

Ungerfeld EM, Kohn RA (2006) The role of thermodynamics in the control of ruminal fermentation. In: Sejrsen K, Hvelplund T, Nielsen MO (eds) Ruminant physiology: digestion, metabolism and impact of nutrition on gene expression, immunology and stress. Wageningen Academic Publishers, Wageningen

Van Kessel JAS, Russell JB (1996) The effect of pH on ruminal methanogenesis. FEMS Microbiol Ecol 20:205–210

Van Soest PJ (1994) Nutritional ecology of the ruminant, 2nd edn. Cornell University Press, Ithaca

Weimer PJ (1992) Cellulose degradation by ruminal microorganisms. Crit Rev Biotechnol 12:189–223

Zebeli Q, Mansmann D, Steingass H, Ametaj BN (2010) Balancing diets for physically effective fibre and ruminally degradable starch: a key to lower the risk of subacute rumen acidosis and improve productivity of dairy cattle. Livest Sci 127:1–10

Zinder SH (1993) Physiological ecology of methanogens. In: Ferry JG (ed) Methanogens, ecology, physiology, biochemistry and genetics. Chapman and Hall, New York

12

Enteric Methane Emission Under Different Feeding Systems

N.M. Soren, Veerasamy Sejian, and P.K. Malik

Abstract

Methane is a potent greenhouse gas (GHG) which is responsible for global warming, and it is about 23 times more potent than carbon dioxide and is produced worldwide by biotic and anthropogenic activity. Increased industrialisation in the past few decades and an increase in global human population have increased the demand of food particularly of animal origin to a significant level. The livestock population, especially ruminants in particular, is responsible for emitting 16–20 % of the CH_4 to the atmosphere. The enteric fermentation in ruminants is unique, carried out by the anaerobic microorganism, and culminates in the formation of CH_4, which is the sink for hydrogen and carbon dioxide, formed as a result of anaerobic fermentation in the rumen. The population of domesticated ruminant livestock species like cattle, buffalos, sheep, goat, mithun, yak, etc., which provide food to humans has increased worldwide in the recent past. These livestock are reared under different systems that are prevailing in a particular country, and the most common identified livestock rearing systems are intensive, extensive and semi-intensive. In intensive system of rearing, the animals are confined and more concentrates are fed with provision of quality roughages. While in the extensive system of rearing, the livestock are let loose and depend on the pasture for their growth and production, and the quality of the pasture is responsible for the nutrients assimilated by the animal. The semi-intensive system of rearing is a combination of the above two systems. Enteric CH_4 production in ruminants depends on several

N.M. Soren (✉)
Animal Nutrition Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India
e-mail: drmanik75@gmail.com

V. Sejian
Animal Physiology Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India

P.K. Malik
Bioenergetics and Environmental Sciences Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Hosur Road, Bangalore, Karnataka 560030, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_12, © Springer India 2015

factors like type and quality of feed, the physical and chemical characteristics of the feed, species of livestock, feeding level and schedule, the efficiency of feed conversion to livestock products, the use of feed additives to support production efficiency, the activity and health of the animal and genetic make-up of the animal. Therefore, feeding system(s) employed for livestock rearing certainly has an effect on the enteric CH_4 production. A concerted effort has been put in this chapter to get an insight into the different livestock rearing and feeding systems, CH_4 contribution from livestock and global warming, CH_4 production from different feeding systems and means to augment livestock production by reducing enteric CH_4 under different feeding regimens.

Keywords

Enteric methane • Extensive system • Feeding system • Intensive system • Ruminants • Semi-intensive system

12.1 Introduction

The concerns for green and healthy surroundings have increased due to the deterioration of environmental health caused by the release of greenhouse gases (CO_2, CH_4, N_2O, etc.) to the atmosphere. Rapid industrialisation, urbanisation in developing countries and anthropogenic activity have contributed immensely to greenhouse gases (GHGs) emission. In the last few decades, the livestock sectors have undergone rapid development for sustaining the ever-increasing demand for food of animal origin. The production of milk, meat and eggs has also increased in both the developed and developing countries in the recent past with the concomitant increase in livestock population. With the increase in global livestock population, the levels of GHGs in the atmosphere have also increased, particularly CH_4 from enteric fermentation in ruminants. Methane production from ruminants is a normal phenomenon and an inevitable outcome of rumen fermentation – the process through which non-human edible plants such as grass and fibrous crop residues are transformed into valuable products such as milk and meat. The end products of enteric fermentation are volatile fatty acids which are the primary source of energy in ruminants for both maintenance and production. This process proceeds with the liberation of fermentation gases CO_2, H_2, N_2O and CH_4.

The CH_4 gas which is formed in the rumen serves as a hydrogen sink for ruminants. Methane generation is a wasteful process in the rumen because it results in the loss of about 10–12 % of the gross energy consumed by the ruminants, which, otherwise, could have been used for the production purpose. Therefore, it has been the constant endeavour of scientists worldwide to reduce CH_4 emissions from ruminants as doing so would allow the animals to retain more energy and produce meat and milk more efficiently. Farm animals, mostly ruminants, are the prime source of food and animal protein (milk, meat) for human and are raised under different production/feeding systems prevailing in regions or countries as a whole. The type of feed offered to the animals along with other factors is responsible for the enteric CH_4 production; therefore, the feeding system plays an important role on enteric CH_4 production and, subsequently, its release to the atmosphere. Among the diverse factors associated with enteric CH_4 production in ruminants, nutrition plays an important role. Methane production will be lowered only if the feed that is offered to the animal is tailored to the metabolic requirements, with better digestibility, and significant portion of the nutrients are diverted towards production and less towards wastage and CH_4 emissions (Grainger and Beauchemin 2011). For instance, in concentrate-based feeding system, a high-grain diet will result in less CH_4 per unit of intake in ruminants, but a feeding system solely on concentrate will have other implications.

Therefore, a thorough understanding of nutritional principles along with proper nutritional management can promote optimum growth and will lead to higher levels of production than in the absence of such care. In grazing-based production system, a significant portion of CH_4 is produced by the animal from enteric fermentation if the grazing pasture is not managed scientifically (Berchielli et al. 2012). Therefore, executing proper grazing management practices to improve the quality of pastures may optimise animal productivity to a desired level, concomitantly with a reduction in enteric CH_4 production. The importance of soil health and plant composition in the grazing pasture is paramount in ensuring lower CH_4 and better production efficiency in animals in grazing-based feeding system. An in-depth effort has been made in this chapter to highlight different feeding systems in which livestock (ruminants) are reared, enteric CH_4 production and ways of lowering enteric CH_4 production for augmenting production in different ruminant species.

12.2 Brief History of Domestication and Different Feeding Systems for Livestock Production

The history of domestication of animals for the benefit of human beings dates back to more than 12,000 years. Humans relied on animals for food and associated by-products, work and a variety of other uses. To meet up these demands, they have tamed or held in captivity species of mammals, birds, etc. These animals are known as livestock and provide food for human beings with higher nutritive value, and rearing them has implications for occupational safety and health. Among the livestock species, sheep and goat were the first to be domesticated for human use, and this was followed by other livestock species (Myers 2011). The demand for animal products of late has increased, and it is driven by the rising human population and an increase in per capita consumption due to enhanced income.

The distribution and rearing pattern of livestock around the world depends on the geographical location and agro-climatic conditions. For instance, animal husbandry practices in sub-Saharan Africa (semiarid to arid) have evolved species that are more tolerant to poor nutrition, infectious diseases and long migrations. Similarly, in Asia and the Pacific region, nearly 76 % of the world's agricultural population exists on 30 % of the world's arable land (Myers 2011). About 85 % of the farmers use cattle (bullocks) and buffaloes to cultivate and thresh crops. Livestock rearing operations are mainly small-scale units in this region, but large commercial farms are establishing operations near urban centres. In rural areas, millions of people depend on livestock for meat, milk, eggs, hides and skins, draught power and wool. In Europe the number of people associated with agriculture, precisely livestock industry, has decreased over the years due to increased urbanisation and mechanisation. The livestock rearing in this region is based on pastures that have been developed due to better climatic conditions. More than 30 % of the population of the Near East is engaged in agriculture. This region is characterised by lower rainfall and majority of the area that is available is used for grazing of animals. Most of the livestock species that were domesticated in this region include goats, sheep, pigs, cattle, water buffaloes, dromedary camels and donkey/asses. Migration of livestock for longer distances in search of feed and water is practised in these regions.

The Latin American and Caribbean region differs from other regions in many ways. Large tracts of land remain to be exploited, the region has large populations of domestic animals, and much of the agriculture is operated as large operations. Livestock represents about one-third of the agricultural production, which makes up a significant part of the gross domestic product (Myers 2011). Agriculture is the major economic activity in North America (Canada and the United States), but a fewer proportion of the population is engaged in agriculture, and it is more intensive, with larger farms. Livestock and livestock products make up a major proportion of the population's diet, contributing 40 % to the total food energy. The livestock industry in this region has been very dynamic.

12.3 Different Feeding Systems for Livestock Production

12.3.1 Cattle and Buffalo

Domesticated large ruminants, namely, cattle and buffalos, are generally reared for milk and meat production and as a source of energy (draught animals) for agricultural activities (ploughing) and carrying loads mainly in the developing countries. The livestock contributes immensely to the gross domestic product (GDP) and food security to millions of human population round the world. The ruminant livestock in particular are unique in converting forage-based feed that are unsuitable for human consumption to valuable food (milk, meat, etc.) for teeming human population the world over. The feeding system for ruminant food animals round the globe is not uniform but heterogeneous and depends on the socio-economic condition, geographical locations, climatic conditions, human and livestock population, government policies and other factors associated with that particular country. In general, the feeding systems are moulded based on the targeted livestock product, viz. milk or meat.

12.3.1.1 Milk Production

Developed countries in general have livestock feeding systems which are adapted for large-scale (herd size) higher-yielding dairy cows that are concentrated in confinement production systems either seasonally or round the year (FAO, IDF and IFCN 2014). These countries show greater inconsistency in animal feeding systems which depends exclusively on roughage to high reliance on concentrates. Therefore, the feeding system relies on both the stored forage and the purchased grains and concentrate. Even in the developed countries, sometimes, the feeding system is wholly based on the pasture with no concentrate supplementation (Moss 2010). For example, animal feeding systems in New Zealand are predominately pasture based with a low dependence on purchased grains and concentrate (typically less than 10 % of the diet) even though the average herd size is relatively large compared with those in most other developed countries. For instance, in South America and South Africa, the milk yield may reach up to 7,000 kg energy-corrected milk per cow per year, whereas in Southeast Asian countries and India, the average annual yield is less than 3,000 kg energy-corrected milk per cow per year.

In contrast to the feeding system in developed countries, the developing countries have feeding systems adapted for small herd size and low-yielding dairy cows, where locally produced roughage represents the major source of feed utilised. A significant amount of the dry matter intake in these animals comes from grazing in unorganised community grazing lands, with marginal supplementation with concentrate. For example, animal feeding systems for dairy cows in some countries like Venezuela depend entirely on grass as the roughage source, whereas feeding systems in Southeast Asian countries like India and Thailand rely substantially on crop residues (cereal straw, stover, bagasses, etc.).

12.3.1.2 Meat Production

The feeding systems employed for meat production vary from country to country and it is not uniform. In developed countries, quality beef is produced from the feeding of high-energy rations to young animals in confinement; on the contrary, meat production in developing countries comes from pasture-based feeding system. Presently, the demand for meat from grass-fed animals is increasing due to health consciousness; in this direction some meat producers have also altered their feeding practices, whereby reducing or eliminating grain from the ruminant diet, producing a product referred to as 'grass fed' or 'grass finished' (Mathews and Johnson 2013).

Under intensive or specialised system of feeding, the meat animals are raised in organised farms, and the finishing stages before marketing are important as desired meat in terms of fat and marbling is curved. In this system the input includes grass, fodder, silage, grain or industrial by-products, which are extensively used.

In an extensive system of meat production, the animals are bred, raised and grown exclusively in grazing pasture and sent to the market for slaughter. These types of feeding system are observed in regions of the world where there are pastoral grazing land (Africa and Latin America) and in Asian countries where livestock are reared on community grazing land and crop on residues. Though live weight gain in extensive-based feeding system is small, but during dry seasons and in drought, a significant amount of production energy is wasted by the animals in search of feed and often losses considerable portion of live weight.

Mixed farming type of feeding management is practised in many parts of the world, wherein small farmers keep young male animals and some culled heifers for feeding and finishing and fed them on home-grown fodder. Under the mixed farming systems practised today, the feeder cattle are usually, but not always, produced on specialised breeding and raising farms located on poorer land or land unsuited to intensive farming.

12.3.2 Sheep and Goat

Sheep and goats are mostly raised for meat purpose, but in some countries goats are also reared for dairying as well as for meat. Both sheep and goats are grazing ruminants, though the feeding habit resembles to some extent, but differs considerably. The selection and intake of forage depend not only on the available plant resources but also on the feeding behaviour of animals. Goats prefer to consume a wide variety of feedstuffs and are more selective and browse more, especially under extensive conditions, than sheep. The selectivity of goats is reduced under intensive management. Goats generally have a better body condition compared to sheep under the same grazing conditions, mainly due to their ability to select a nutritious diet.

In extensive type of feeding system, the natural pastures contribute to the bulk of sheep and goat feed. The pasture may be composed of indigenous forage species and is often subjected to severe overgrazing. Sheep and goat may graze on permanent grazing pasture/areas, on fallow land and on cultivated land following harvest. Both fallow land and crop stubble provide poor grazing for a very short period just after harvest. The availability and quality of native pasture vary with altitude, rainfall, soil type and cropping intensity. In many areas, natural pastures are invaded by species of low palatability; therefore, optimum nutrients from the pasture may be limited (Mengistu 1985). Goats have affinity for browsing protein-rich plants, which are richer in protein and minerals than tropical grasses during the dry season. During the dry period, the browse often serves as an excellent source of supplemental protein in addition to dry grass.

In a semi-intensive type of feeding system, the small ruminants are grazed on cultivated grasses and sometimes on legumes, community grasslands and fallow lands for 8–12 h in a day (Sankhyan et al. 2010). Then in the evening, some concentrate mixture or supplemental grain or oil cakes are offered to the animals. Goats can efficiently use cultivated pastures for either meat or milk production. A hectare can support 16–60 goats depending on the type of pasture, the amount of fertiliser applied and the presence of legumes. Available farm by-products are sometimes used as supplement in addition to intake from pasture (Child et al. 1984).

Intensive type of feeding or stall feeding system is also known as ‘zero graze’ system and animals are confined in a pen and all the feeding management is done here. It requires huge capital investment and is labour intensive; thus, it is not extensively practised in many of the developing countries, and nevertheless, it has commercial potential. In this system the animals are fed mostly on cut forage (cereal hay, legume hay or cereal-legume hay mixtures), conserved hay and chaffed straw. Supplementary feeding is also carried out with concentrates, the quantity of which depends again on forage availability and the productive stage of animal. Short-term intensive feeding prior to marketing of sheep/goats for meat known as fattening is also practised in many countries (Sumberg and Cassaday 1985). Fattening/finishing involves intensive feeding of sheep and goats to slaughter weight with adequate finish (fat deposit) in feedlots. Fattening/finishing can be accomplished with rations containing different proportions of roughages and concentrates. The proportion depends on the type of feeds available, the desired length of feeding and the types of animals to be finished. Higher proportions of concentrate feeding shorten the time required for fattening. Grains and grain products commonly fed are corn, barley, sorghum, oats and wheat and grain by-products like wheat bran, and high protein concentrate ingredients include groundnut cake, soybean cake, cottonseed cake, linseed cake, sunflower cake, brewer's grains, distillers' grains and other similar feeds.

12.4 Methane Production from Livestock vis-à-vis Global Warming

Methane production in ruminants is a normal phenomenon, and it acts as a sink for the hydrogen gas which is formed in the rumen as a result of anaerobic fermentation by the microbes. Anaerobic fermentation by livestock is the outcome of the capability of ruminants to utilise large amounts of fibrous feeds (grass, straw, stover, crop residues) which cannot be utilised as human food. Ruminant livestock, such as cattle, sheep and goats, have a large anaerobic fermentation vat known as rumen, which harbours a large microbial population, which ferments and aids in the digestion of roughages. The end products of fermentation are mainly volatile fatty acids, acetate, propionate, butyrate and valerate with other branch fatty acids (iso-butyrate and iso-valerate) and fermentation gases CO_2 and hydrogen. The quality of feeds, mainly the roughage which constitutes the major bulk of the ruminant's diet, is responsible for CH_4 emissions per unit of feed energy consumed by the animal. Accordingly, when poor quality of feed is fed to the ruminants, there will be higher CH_4 production per unit of product than better fed animals.

Ruminant animals contribute significantly to human food chain as they have the ability to utilise complex polysaccharides in plant cell walls, viz. cellulose, hemicelluloses and pectin, which are otherwise non-digestible by any of the mammalian digestive enzyme and convert them to meat and milk for human consumption. In spite of their valuable contribution, ruminant animals are often considered as one of the major contributor to the global climate change due to the emission of CH_4 as a by-product of fermentative digestion of feedstuffs in the rumen. Domestic ruminants are one of the important anthropogenic sources of CH_4, contributing approximately 29 % of the total anthropogenic annual CH_4 production (Ripple et al. 2014). Approximately two-thirds of the total CH_4 production by domestic ruminants is contributed by cattle, and the rest is shared by other domestic ruminants like buffalo, sheep, goats, etc.

12.4.1 Enteric Fermentation and Methane Production in Ruminants

Enteric fermentation is the fermentation that takes place in the digestive systems of ruminant animals. A significant amount of fermentation takes place in the rumen of cattle, buffalo, sheep and goats resulting in the formation of volatile fatty acids along with fermentation gases CO_2 and hydrogen which are further reduced to CH_4. As far as pseudo-ruminants (like horses, mule and donkeys) and monogastric animals (pigs) are concerned, the emissions of CH_4 are relatively lower because the digestive tract does not support the same level of feed fermentation. Domestic ruminants with low levels of production efficiency have relatively high CH_4 emissions per unit of product because in these animals a significant fraction of the feed intake is solely used for maintenance (basic metabolic processes) rather than production. However, in animals with higher production efficiency, the maintenance emissions are spread out over a larger amount of production; therefore, the CH_4 emissions are lower per unit product.

In ruminants and pseudo-ruminants like camel, the major part of CH_4 production or methanogenesis occurs in the large fermentative vessel known as rumen, which is located at the beginning of the digestive tract. Methane is also produced in the hindgut of ruminants and monogastric animals, but in much smaller amounts. The rumen is a composite and diverse system and mostly houses obligatory anaerobic microbes where feedstuffs including fibrous plant material are broken down and fermented primarily to short-chain volatile fatty acids (VFA), CO_2, hydrogen (H_2) and CH_4 by large numbers of different genera and species of bacteria, protozoa, fungi and methanogens. Methanogens present in the rumen belong to a separate domain Archaea in the kingdom of Euryarchaeota and are found in a wide range of other anaerobic environments (Liu and Whitman 2008). Most rumen methanogens derive energy for their growth through a series of biochemical reduction of CO_2 with H_2, and some methanogens use acetate and methyl group-containing compounds to produce CH_4. Methanogens invariably play a key role by scavenging hydrogen gas which is liberated during the fermentation, thereby lowering the partial pressure of hydrogen so that fermentation can proceed efficiently (Song et al. 2011).

The microbial populations in the rumen have symbiotic relationships wherein the metabolites are exchanged between different microbial populations, and this promotes or compensates each other's growth (cross feeding). Methane synthesis is regarded as one such cross feeding between hydrogen-producing microbes and hydrogen-consuming methanogens (Wolin et al. 1997). Since the hydrogen-producing microbes include fibrolytic fungi and bacteria, their co-association with methanogens allows efficient removal of hydrogen, which facilitates continuous fibre degradation. There are about 70 methanogenic species belonging to 21 genera that have been reported, and a range of different methanogens also coexist in the rumen (Jarvis et al. 2000), but only seven ruminal species have been isolated and purified. These are *Methanobacterium formicicum*, *Methanobacterium bryantii*, *Methanobrevibacter ruminantium*, *Methanobrevibacter millerae*, *Methanobrevibacter olleyae*, *Methanomicrobium mobile* and *Methanoculleus olentangyi*. The population densities of methanogens in the rumen appear to be influenced by diet and in particular by the fibre content of the diet (Kirchgessner et al. 1995).

12.4.2 Class of Livestock Feed and Enteric Methane Production

Feed cost encompasses more than 70 % of the total cost of livestock production in organised sectors. Livestock feeds are broadly classified according to the amount of specific nutrient they provide in the ration. They are generally divided into two classes—concentrate and roughage. Concentrates are feeds which contain a relatively smaller amount of fibre (less than 18 %) and have a comparatively high digestibility and result in a higher nutritive value having more than 60 % total digestible nutrients (TDN). Roughages, on the other hand, are bulky feeds containing a relatively large amount of less digestible material (crude fibre more than 18 %) and with a lower energy value (up to 60 % TDN). In addition to the above, minerals (macro and micro), vitamins (water soluble and fat soluble) and water are important nutrients for farm animals.

A concentrate is a feed or mixture of feed which supplies primary nutrients (carbohydrate, protein and energy or fat) at higher level and at the same time contains less than 18 % CF with lower moisture content. On the basis of protein (crude protein, CP) content, they are further classified as either energy-rich concentrates (CP less than 18 %) or protein-rich concentrates when the CP content of the feed or feed mixture exceeds 18 %. Energy-rich concentrates include cereal grains and seeds (maize, barley, oats, sorghum, bajra, etc.), mill by-products (bran, flour, germ, gluten, grain screenings, groats, hulls, meal, middlings, polishing, shorts, etc.), molasses (molasses of cane, beet, citrus fruits, wood, etc.) and root crops (cassava).

Protein-rich concentrates on the other hand can be classified according to the source of origin as plant protein, animal protein, nonprotein nitrogen and single-cell proteins. Plant proteins include oil meals which are obtained by different processing methods like pressed or ghani, expeller and solvent extracted. Oil cakes and meals are good source of protein, and about 95 % of the nitrogen is present as true protein with higher digestibility (75–90 %) and is less methanogenic in ruminants. Some common oilseed meal (cakes)-based plant proteins used for feeding ruminants include peanut meals, linseed meals, mustard cake, cottonseed cake, copra meal, sesame meal and soybean meal. In addition to the above, brewer's grains and yeast are also a good source of protein for animals, but it contains high moisture. Animal protein supplement usually employed for farm animal feeding is derived from inedible portion of animal tissues mainly from the meat processing industries, milk processing industry and marine fish processing plants. They may include meat meal, meat and bone meal, blood meal, feather meal, hatchery by-product meal, fish meal, etc.

Feedstuffs containing nitrogen in form other than protein are known as nonprotein nitrogen (NPN). Organic NPN compounds include ammonia, amides, amines and amino acids, while inorganic NPN compounds may include a variety of ammonium salts and ammoniated by-products like urea. The microorganisms present in the rumen are able to degrade dietary proteins to synthesise microbial protein; in the same way, they degrade urea into ammonia and subsequently it is incorporated into amino acids. Single-cell protein (SCP) is obtained from single-cell organisms like yeast (*Saccharomyces cerevisiae*, *Torulopsis utilis*), bacteria (*Methanomonas methanica*) and algae (*Chlorella vulgaris*, *Spirulina maxima*, *Scenedesmus obliquus*) which are grown in specific growth media.

Roughages are generally bulky feedstuffs which have a low weight per unit of volume. Most feedstuffs that are classed as roughage have high crude fibre content with lower digestibility of nutrients. Most roughages have high content of cell wall material, the composition of which varies with the age of the plant, soil composition, etc. The cell wall contains an appreciable amount of cellulose, hemicelluloses, pectin, polyuronides, lignin, silica and other components. The nutrient content of plant materials reduces as the plant attains maturity, and the amount of lignin is a critical factor which affects digestibility of nutrients. The roughages can be classified as dry (hay, straw, stover, corn cobs, sugarcane bagasse and cottonseed hulls), and succulent roughage includes pasture, range plants, tree fodder, cultivated fodder, silages, root crops and tuber, brewery by-products, waste from food processing plants and fruit and vegetable waste.

Enteric CH_4 production in ruminants is a normal process, and major factors influencing its production are pH of rumen, diet, feeding strategy, volatile fatty acids, animal species and environmental stresses. The optimal pH range for CH_4 production is 7.0–7.2, but the same can be formed in the pH range of 6.6–7.6. But at lower pH, the activity of fibre degraders reduces considerably (Argyle and Baldwin 1988; Dijkstra et al. 1992); thereby, the nutrient digestibility gets affected. Methanogens present in rumen are responsible for CH_4 production, and diet has a prime role not only on methanogen numbers but also on CH_4 production, as both the quantity and quality of feed can alter the rumen fermentation pattern. Methane production may be higher when mature dried forages are fed or when they are thickly chopped rather than finely ground or pelleted and may decrease when forages are preserved in ensiled form (Moss et al. 2000). Because they stimulate the rumen degradation of plant cell walls, alkali treatments of poor-quality forages have been shown to increase the amount of CH_4 emissions. Volatile fatty acids, the main source of energy for ruminants, vary with different carbohydrates that are fermented in the rumen. The ratio of forage to concentrate also influences the ratio of acetate to propionate in the rumen, and CH_4 emission decreases drastically from 6–12 % (forage-based diet) to 2–3 % when concentrates (90 %) predominate a major portion of the ruminants' diet (Johnson and Johnson 1995).

Thus, feeding of a high concentrate to low roughage diet produces less enteric CH_4 vis-à-vis low concentrate to high roughage diet (Whitelaw et al. 1984). This lower CH_4 emission can be ascribed to lower portion of carbohydrates and faster passage rate, thus shifting the fermentation pattern towards higher propionate production (Johnson and Johnson 1995). Apart from diet, other factors like higher intake of feed and rate of passage of digesta can also influence CH_4 production in the rumen. The retention time of digesta in the rumen decreases with increased passage rate and feed intake, and the digestion occurs in the small intestine rather than in the rumen, which in turn reduces the extent and rate of ruminal dietary fermentation. Apart from dietary factors, CH_4 production is also influenced by species of livestock; in general crossbred cattle produce higher CH_4 than exotic breeds.

12.4.3 Contribution of Methane from Livestock

In ruminants, CH_4 is produced normally during the course of digestion process, and these species are the major source of anthropogenic CH_4, contributing approximately 23 % (81 Tg of CH_4) of the total anthropogenic annual CH_4 production, which is the second largest source of anthropogenic CH_4. The process of CH_4 production in ruminants is a complex microbiological anaerobic fermentation that breaks down cellulose and other macromolecules in the rumen, generating CH_4 in the process and expelling it via eructation through the mouth and nose (Moss et al. 2000). Among the domestic ruminants, cattle is responsible for two-thirds of the total CH_4 production (74 %), and the rest is shared by other domestic ruminants like buffalo (11.3 %), sheep (6.36 %), goats (4.86 %), etc. Methane is also produced variably from nonruminants (Patra 2014) like camels (1.11 %), mules (0.11 %) and asses (0.42 %), pigs (1.08 %) and horses (1.05 %). Pseudo-ruminants like camel share some features of their digestive anatomy and physiology with ruminants, but camelids produce less CH_4 than ruminants (Dittmann et al. 2014).

Several factors influence the enteric CH_4 emissions from ruminants, and they include daily dry matter intake, digestibility of feed, amount of fibres and soluble carbohydrate in diet, type of volatile fatty acids (VFAs) produced during fermentation (acetate to propionate ratio), etc., that affect the amount of enteric CH_4 production. Similarly, animal species, breed and composition of the ruminal microbial population and rumen pH also affect CH_4 production. Therefore, ruminants, when fed low-quality feed, have higher CH_4 emissions per unit of product than better fed animals. Ruminants with low levels of productivity use a large fraction of their feed intake (dietary energy intake) for maintenance, and as a result, the emissions are spread over a relatively small output, resulting in a high level of emission per unit of product. Conversely, productive animals on the other hand produce less CH_4 per unit of product. In addition to the above, feed quality has an important impact on the level of CH_4 emissions. Very low-quality feeds, such as straw, crop residues, stovers and poor forages, have low levels of digestibility, and therefore, higher emissions are observed per unit of feed intake.

In arid and semiarid regions where ruminant production is land based (grazing), a sizeable period of the year offers feed resources which are poor in quality, thereby resulting in lower productivity with higher enteric emission in these regions. Grazing and mixed systems in the tropics and subtropics are thus the main contributors to high CH_4 emission levels. Generally, temperate and highland zones have the best quality of grazing and other forage resources for ruminants and therefore lower emission levels. Further, in regions where fodders are grown in irrigated lands with proper management practices, the quality of fodders is better and results in lower enteric CH_4 emission. Manures originating from the livestock are a major source of anthropogenic CH_4. In big farms in developed countries where intensive type of feeding management is practised for a very large number of animals, manure management is very important because improper management (storing of liquid manure) will contribute significantly to higher CH_4.

In developing countries the demand of livestock products (milk and meat) are increasing at an increasing rate. So, with the increase in livestock population, the enteric CH_4 emission is likely to increase. The projected global enteric CH_4 emission from different livestock species will increase from 94.9×10^9 kg in 2010 to 105×10^9 and 120×10^9 kg in 2025 and 2050, respectively (Patra 2014). The increase in the concentration of CH_4 will affect the environment in the long run. With this trend, GHG emission could reach 3,528 million tonnes CO_2 eq. in 2050 (an increase of 27.2 % with respect to year 2010), which is expected due to animal population growth driven by increased demands of meat and dairy products, especially in the developing countries, unless proper GHG mitigation measures are adopted in these countries (Patra 2014). If proper efforts are put in place, it will help to reduce the global warming due to GHGs, and secondly, it will lower feed energy loss. Reduction in CH_4 emission will result in higher growth and productivity of ruminant and improve the efficiency of feed utilisation with the same amount of energy supplied.

12.5 Enteric Methane Production from Different Feeding Systems in Animals

Feeding systems on which livestock are reared have a bearing on the quantity of enteric CH_4 production, and for this reason a sound understanding of the fundamentals of feeding systems vis-à-vis enteric CH_4 production in ruminants is desired. The enteric CH_4 production revolves around the microbial population in the rumen, the hydrogen gas which is produced during the course of anaerobic fermentation of feedstuffs and the proportion of fermentation end products, i.e. volatile fatty acids (acetate, propionate, butyrate, valerate, iso-butyrate and iso-valerate) which are likely to be formed to provide energy to the animals for maintenance as well as for production.

The quantity of hydrogen produced during anaerobic fermentation is highly dependent on the diet, the type of rumen microbes acting on the substrate and the resulting end product (Leng and Preston 2010). For instance, the propionate formation process in the rumen consumes hydrogen, whereas the acetate and butyrate formation process releases hydrogen. Thus, any feeding system which will favour shifting of rumen fermentation from acetate to propionate will lower hydrogen release and CH_4 production (Basarab et al. 2013), and the association between CH_4 emissions and the ratio of the various volatile fatty acids have been demonstrated in many of the studies aimed at lowering CH_4 production to enhance ruminant production.

Methanogenesis is an essential-evil process in ruminant digestion system as it prevents the accumulation of excess hydrogen and thereby enables normal fermentation process to proceed smoothly. If hydrogen gas is allowed to accumulate in the rumen, then the fermentation process cannot continue and it will stop abruptly. The utilisation of hydrogen and carbon dioxide to produce CH_4 is a characteristic of methanogenic archaea. The positive interaction of methanogens with other rumen microorganisms helps in enhancing the energy efficiency as well as in feed digestion, thereby increasing animal performance (Hook et al. 2010). Positive interactions have been described for cellulolytic (*Ruminococcus albus* and *R. flavefaciens*) and non-cellulolytic bacteria (*Selenomonas ruminantium*), protozoa and fungi (O'Mara 2004; Mirzaei-Aghsaghali et al. 2008).

When we deliberate on enteric CH_4 production from different feeding systems, it is imperative to consider all the factors, intrinsic or extrinsic, which are related to the livestock production (milk or meat) as well as factors that are associated with CH_4 production. In this regard, life cycle assessment for different livestock products (milk or meat) for which they are raised needs to be considered. Life cycle assessment in cows for milk production showed that grazing cows in the USA emitted more GHG per unit of milk compared with confinement (Belflower et al. 2012). When carbon sequestration by grassland was considered, pasture systems reduced net GHG emissions (Fredeen et al. 2013). The type of feed used in pasture and confinement systems has potential implications on both enteric CH_4 and total GHG emissions (Fredeen et al. 2013).

12.5.1 Enteric Methane Production from Intensive Feeding System

The amount of enteric CH_4 emitted by farm animals depends on the feeding system on which the animals are being raised. The enteric CH_4 produced by the farm animals for different products (milk or meat) is not similar, but varies with the product for which the animals are raised. In general, an animal raised on intensive feeding regime will produce less CH_4 than their counterpart reared on extensive system or on pasture because the more fibrous the feed available to the animal, the greater the CH_4 emissions. For instance, if we compare beef production from two feeding systems, grazing or grain-fed system, it is very likely that grass-fed beef production systems will produce more CH_4 than grain-fed or feedlot beef systems. Grains, such as corn, barley and soybean, and oil cakes (soybean meal, peanut meal, etc.) are much easier for ruminants to digest, and the amount of CH_4 produced by cattle fed a grain-based diet is less (Knapp et al. 2014) than that of cattle fed grass-based diets (sometimes, feeding of excess grain-based diets may have harmful effects on the health of ruminants). As grains are made up of simple sugars and starch, they are much easier to break down and digest than fibrous forages, requiring less fermentation and thus resulting in less CH_4 production (Beauchemin and McGinn 2005). Methane production potential of common concentrates that are routinely used for the feeding of livestock is listed in Table 12.1.

In general oil cakes or oilseed meals are less methanogenic in comparison to cereal grains and agro-industrial by-products. The presence of secondary plant metabolites in many of the feed ingredients is responsible for lower CH_4 production as many of the methanogenic

Table 12.1 Methane production potential (MPP) of concentrates used for livestock feeding

Feed ingredients	Scientific name	CH_4 (ml/g)	References
Grains			
Maize	*Zea mays*	12.5	Personal communication
Bajra	*Pennisetum typhoides*	13.7	Personal communication
Jowar	*Sorghum bicolour*	13.1	Personal communication
Guar	*Cyamopsis tetragonoloba*	16.1	Personal communication
Barley	*Hordeum vulgare*	12.4	Personal communication
Oat	*Avena sativa*	6.87	Lee et al. (2003)
Cakes/meals			
Soybean	*Glycine max*	7.14	Personal communication
Peanut	*Arachis hypogaea*	3.7	Personal communication
Sunflower	*Helianthus annuus*	8.22	Personal communication
Sesame	*Sesamum indicum*	9.4	Personal communication
Mustard	*Brassica* spp.	4.5	Personal communication
Cottonseed	*Gossypium* spp.	4.48	Personal communication
Palm kernel meal	*Elaeis* spp.	3.93	Lee et al. (2003)
Coconut oilseed meal	*Cocos nucifera*	6.63	Lee et al. (2003)
Agro-industrial by-products brans/hulls			
Rice bran	*Oryza sativa*	5.41	Personal communication
Wheat bran	*Triticum aestivum*	15.09	Personal communication
Soybean hull	*Glycine max*	11.12	Lee et al. (2003)
Cottonseed hull	*Gossypium* spp.	0.86	Lee et al. (2003)
Lupin hull	*Lupinus* spp.	8.66	Lee et al. (2003)
Corn gluten meal	*Zea mays*	6.56	Lee et al. (2003)

MPP values of common feedstuffs listed above are based on in vitro incubation of feedstuffs microorganisms are inhibited, and propionic acid is the major volatile fatty acids formed when such feed are fed to the ruminants (Szumacher-Strabel and Cieślak 2010). Feeding of high-grain diets to rapidly growing ruminants will yield less CH_4 emission because of higher production of propionic acid, and CH_4 emission may fall drastically to as low as 2–3 % (Johnson and Johnson 1995).

Feeding or production system on which animals are reared plays an important role not only on improving growth rate or reproduction efficiency but enteric CH_4 production. Lowering of enteric CH_4 in ruminants will save dietary energy by about 8–10 % which is otherwise wasted. Factors such as dry matter intake and diet composition are critical to the amount of CH_4 produced in the rumen. Johnson and Johnson (1995) reported that there is a relationship between the level of dry matter intake and diet composition, so that providing carbohydrates of high digestibility associated with high ingestion levels might result in a decrease in gas production. The comparison between dry matter intake (DMI) and CH_4 emission (g/day) evidenced that gas emission was related to the increase in DMI in animals, and the treatments with concentrate addition resulted in higher CH_4 emission (Johnson and Johnson 1995). Protein supplementation in the diets increased the nutrient digestibility and significantly decreased CH_4 production in rumen (Mehra et al. 2006). The higher efficiency of energy utilisation is the most efficient strategy to reduce CH_4 emission per kilogram of milk or meat in ruminants (Herrero et al. 2013).

If enteric CH_4 emission is compared between intensively fed animals and feedlot-raised animals, it is imperative that the emissions from feedlots will be higher on a per acre basis than the equivalent sized grass-based production systems, because the feedlot will have many more animals packed more closely together. However, if comparisons are made in terms of unit livestock product, say meat production, then faster-growing animals intensively fed will produce less CH_4 than extensively raised animals for the same purpose. Grain-finished beef in Australia produced 38 % less CH_4 than grass-finished beef (Peters et al. 2010), and although the total CH_4 emissions were higher from the area of the feedlot, the animals gained weight faster and so were slaughtered at a younger age, emitting less gas on a per unit of meat basis.

12.5.2 Extensive System of Livestock Rearing

The feeding habits of ruminant animals are primarily based on grazing, but ruminants are raised under different feeding systems to hasten the time period required to produce food for humans and for the ease of managing livestock rearing. When we talk about extensive system of livestock rearing, the livestock as a whole are the largest user of land resources with grazing land and cropland dedicated to the production of feed representing almost 80 % of all agricultural land. To sum up these segment uses 3.4 billion hectares for grazing and 0.5 billion hectares for cultivating feed crops (Steinfeld et al. 2006). The management practices and use of grazing land for livestock are not uniform worldwide but vary widely, so does the productivity of livestock and enteric CH_4 production per hectare of grazing land.

The quality of grazing pasture also depends on the agro-climatic condition of different regions of the world. In arid and semiarid rangelands, where most of the world's grasslands are confined, intensification of pastures is technically unfeasible or unprofitable (Cassandro et al. 2013). The grazing pastures in Africa and Asia are not extensive like that of European countries but are small, and traditionally, they are of common property resources. Rising human population, especially in the developing countries, is disturbing the forest ecology, and these practices have severe implications to pasturelands: valuable ecosystems are being converted to pastureland (e.g. clearing of forest); pastureland is being converted to other uses (cropland, urban areas and forest); and pastureland is degrading. In this situation the livestock raised on grassland are deprived of quality pastures as there is a diminishing of grazing area and livestock have to compete for dry matter.

Research shows that different grasses and forages at different stages of development cause ruminants to produce different amounts of CH_4. Feeding of diets rich in forage will result in an acetate type of fermentation (methanogenic) and will result in an increase of CH_4 production compared to propionic-type fermentation which, on the other hand, is stimulated by concentrates (Rowlinson et al. 2008; Kingeston-Smith et al. 2010) fed to ruminants. Research has shown that increased quality and digestibility of forages result in reduced CH_4 production. Grazing systems which are managed properly and rotational grazing will have inclination to reduce forage maturity, thereby improving forage digestibility and reducing enteric CH_4 production. However, at high intake levels, the proportion of energy lost as CH_4 decreases as the digestibility of the diet increases (Johnson and Johnson 1995). Water-soluble carbohydrates (WSC) present in forage material affect the enteric CH_4 production in ruminants. There is also evidence that using clovers and grasses with high WSC in animal diets can directly reduce CH_4 emissions (Lovett et al. 2004). It has been demonstrated that increasing the WSC content in perennial ryegrass by 33 g per kg reduces CH_4 production by 9 % in vitro (Rowlinson et al. 2008). Kurihara et al. (1997) reported a CH_4 production of 33–75 g per kg digested organic matter intake for forage-based beef cattle in tropical Australia. However, selecting forages high in non-fibre carbohydrates could reduce CH_4 emissions.

Methane production potential (MPP) of some forage samples determined by in vitro gas production technique is listed in Table 12.2, and these forage materials are consumed by ruminants in the semiarid region part of India. These in vitro techniques can be used for the measurement of CH_4 produced under rumen-like conditions in the laboratory. The gas production technique uses rumen fluid as an inoculum, and the CH_4 produced

Table 12.2 Methane production potential (MPP) of some forages used for livestock feeding

Feed ingredients	Scientific name	CH_4 (ml/g)	References
Straws			
Jowar	*Sorghum bicolour*	9.79	Personal communication
Wheat	*Triticum aestivum*	7.86	Personal communication
Guar	*Cyamopsis tetragonoloba*	6.55	Personal communication
Barley	*Hordeum vulgare*	7.79	Personal communication
Groundnut	*Arachis hypogaea*	5.38	Personal communication
Paddy	*Oryza sativa*	2.42	Lee et al. (2003)
Fodder			
Guar	*Cyamopsis tetragonoloba*	9.67	Personal communication
Groundnut	*Arachis hypogaea*	7.08	Personal communication
Jowar	*Sorghum bicolour*	4.39	Personal communication
Vigna	*Vigna* sp.	3.89	Personal communication
Black gram	*Vigna mungo*	3.28	Personal communication
Bajra	*Pennisetum typhoides*	15.22	Personal communication
Tree fodders			
Khejri	*Prosopis cineraria*	2.27	Personal communication
Ardu	*Ailanthus excelsa*	9.48	Personal communication
Neem	*Azadirachta indica*	6.07	Personal communication
Babool	*Acacia nilotica*	7.01	Personal communication
Siris	*Albizia lebbeck*	9.70	Personal communication
Mango	*Mangifera indica*	3.58	Personal communication
Indian rosewood	*Dalbergia sissoo*	10.44	Personal communication
Pala	*Ziziphus racemosa*	5.56	Personal communication
Pasture grass			
Cenchrus	*Cenchrus ciliaris*	13.16	Personal communication
Sewan	*Lasiurus sindicus*	9.19	Personal communication
Mixed pasture grass		7.88	Personal communication

MPP values of forages listed above are based on in vitro incubation of feedstuffs following the incubation of a wide variety of feeds can be measured and quantified. Any method that can predict CH_4 output from specific feeds can be incorporated into a ration formulation system to enable the CH_4 output to be minimised (Tamminga et al. 2007). An adequate characterisation of feedstuffs is required for an efficient ration formulation in any livestock system. The addition of some measure of CH_4 potential for any basic feedstuff would be very valuable to enable other methods to be imposed to reduce CH_4 output, i.e. mixed diets could be formulated to minimise CH_4 production using a range of ingredients.

Another important factor that can influence enteric CH_4 production in ruminants raised on pasture is the stage of maturity of forage. Improving the forage quality, either through feeding forages with lower fibre and higher soluble carbohydrates (changing from C_4 to C_3 grasses) or even grazing less mature pastures, can lower CH_4 production (Beauchemin et al. 2008; Ulyatt et al. 2002) to a significant level. Celluloses present in feedstuffs are more methanogenic than hemicelluloses, and it is reported to produce CH_4 three times than that of hemicellulose (Moe and Tyrell 1979), while cellulose and hemicellulose are fermented at a slower rate than nonstructural carbohydrates, thus yielding more CH_4 per unit of substrate digested (McAllister et al. 1996). Supplementation of leguminous forage in the diet of ruminants lowers CH_4 emissions partly due to lower fibre contact, faster rate of passage and in some case the presence of condensed tannins (Beauchemin et al. 2008). Increasing forage quality and the management of stocking rates and rotational grazing strategies have been demonstrated to reduce enteric CH_4 emissions (FAO 2010) in ruminants that are raised on pasture.

Forage species of grazing pasture also have a role in influencing enteric CH_4 production in ruminants. Tropical grasses fed to ruminants are generally 13 % less digestible than temperate grasses which is due to differences in the anatomical structure of the plants and higher temperatures at which tropical species are grown (Minson 1990). Methane conversion rate of tropical forage species is probably related to the relatively high levels of fibre and lignin, low levels of non-fibre carbohydrate (Van Soest 1994) and low digestibility (Minson 1990) compared with temperate forage species. In developing countries like India, crop residues and straws are the staple roughages, which form bulk in the animal's diets; therefore, enteric CH_4 production will be invariably higher in such animals.

12.5.3 Semi-intensive System of Livestock Rearing

In semi-intensive type of feeding management, as practised in many parts of the world, the livestock species are allowed to graze for about 8–10 h in a day and concentrates are supplemented after grazing hours. Under this system of feeding management, the enteric CH_4 will be lower than under extensive system as supplemental concentrate will aid in a better synchronisation of energy and protein with optimum fermentation. The feeding of small amounts of concentrate feeds can increase the utilisation of roughage feeds by ruminant livestock in this feeding system. Improvements in the digestibility of roughages are due to the provision of necessary nutrients (especially degradable protein) to promote rumen fermentation, resulting in increased fibre digestion and intakes of roughages, reduced wastes from unconsumed and undigested feeds and increased animal productivity and efficiency. Diets with a high proportion of concentrates will promote propionate type of ruminal fermentation and ultimately lower enteric CH_4 production from such animals. The ratio of forage to concentrate in the ration influences rumen fermentation so as the ratio of acetate to propionate in the rumen. It would therefore be expected that CH_4 production would be less when high-concentrate diets are fed (Moss et al. 2000).

12.6 Augmenting Livestock Production by Reducing Enteric Methane Emission Under Different Feeding Systems

Enteric CH_4 production by ruminants is a wasteful process and results in wastage of 8–10 % of the feed energy. Decreasing the quantity of CH_4

produced by livestock will not only augment livestock performance in terms of milk and meat production but decrease the carbon footprint, increase the efficiency of feed/nutrient utilisation and possibly decrease production costs to a significant extent. One of the major outcomes of decrease in ruminal CH_4 production is an increase in the production of propionate by the ruminal microbial residents. Because propionate is used by the animal more efficiently than other volatile fatty acids, increases in propionate production can decrease the quantity of feed required per unit of weight gain. Details of the enteric CH_4 abatement have been dealt elaborately elsewhere in the book; however, some CH_4-lowering strategies suitable for different systems are stated briefly.

12.6.1 Intensive Feeding System

Under intensive system of livestock feeding, several strategies can be adopted to lower enteric CH_4 production from ruminants. If rumen fermentation can be modified for a more propionate type, then production will be enhanced. The following strategies can aid to enhance livestock performance by lowering the enteric CH_4 production in domesticated livestock species which are raised for human food.

12.6.1.1 Supplementation of Feed Enzymes

Fibre-degrading enzymes like cellulases and hemicellulases, when added to the diet of ruminants, have been shown to improve ruminal fibre digestion and productivity and are reported to be mediated through alteration of the acetate to propionate ratio and had reduced CH_4 by 28 % in vitro and 9 % in vivo. These feed grade cocktail enzyme products are available in the market, and further research is still required to screen a large number of enzymes which have a significant CH_4 abatement potential (O'Mara 2004; Beauchemin et al. 2008).

12.6.1.2 Organic Acids (Dicarboxylic Acids)

Supplementation of dicarboxylic acids (fumarate, malate and acrylate), which are precursors for propionate production in the rumen, can act as an alternative H_2 sink, thereby lowering methanogenesis. Supplementation of fumaric acid in the diet has been reported to lower enteric CH_4 from 0 to 75 % (McAllister and Newbold 2008), but the high cost associated with its feeding limits its applicability under farm condition.

12.6.1.3 Supplementation of Fat and Oils

Inclusion of fat in the diets of ruminants causes a decrease in enteric CH_4 production, and it is dependent on the dose or levels of fat supplementation, fat sources, forms of fat supplementation and types of diet. Irrespective of fat sources, CH_4 emissions were calculated to be reduced by 5.6 % with each 1 % addition of fats (Beauchemin et al. 2008). A decrease in CH_4 production by fat supplementation may be mediated through combined influences on the inhibition of growth of methanogens and protozoal numbers and reduction of ruminal organic matter (OM) fermentation and hydrogenation of unsaturated fatty acids, thereby acting as alternative H_2 sink in the rumen (Bhatt et al. 2011). Oil supplementation in the diet can lower CH_4 production in the rumen, and in sheep a decrease up to 27 % has been reported (Fievez et al. 2003; Machmüller et al. 2003). Methane-lowering effect is due to two factors, namely, hydrogenation of the fatty acids competing for substrate with methanogens and direct inhibition of methanogens by the fatty acids themselves (Chaves et al. 2008).

12.6.1.4 Use of Ionophore Compounds

The practice of supplementing ionophore antibiotics like monensin in the diet of ruminants is widely practised in many of the developed countries to improve the efficiency of meat and milk production. Their supplementations have also been shown to depress CH_4 production in ruminants (Beauchemin et al. 2008), and the positive effect exhibited by their supplementation is dose dependent in many of the studies. The CH_4 production has been reported to decrease up to 76 % in vitro and to an average of 18 % in vivo (Van Nevel and Demeyer 1996). Ionophores do not alter the quantity and diversity of methanogens

(Hook et al. 2009), but they change the bacterial population from Gram-positive to Gram-negative organisms with a concomitant change in the fermentation from acetate to propionate. This fermentation shift lowers the availability of H_2 for CH_4 production by methanogens, but these additives are now forbidden in the European Union.

12.6.1.5 Defaunation

Removal of protozoa (defaunation) has often been reported to lower CH_4 emissions, primarily due to the decrease in the amount of H_2 transferred from protozoa to methanogens. An average reduction of approximately 13 % has been suggested by Hegarty (1999). However, protozoa numbers are strongly affected by diet, and defaunation has achieved more dramatic reductions in CH_4 emissions from ruminants on a concentrate-based diet, with CH_4 reductions ranging from 20 to 42 % (Whitelaw et al. 1984; McAllister and Newbold 2008; Morgavi et al. 2008). Most common methods to achieve defaunation in farm animals can be done by feeding a high-grain diet for a short period, and this practice will result in a drop of pH which ultimately inhibits protozoa. Chemical defaunation (usually with detergents) is the commonly used experimental defaunation. The use of secondary plant metabolites like saponin-rich plant or essential oils can be more effective in inhibiting rumen protozoa.

12.6.1.6 Supplementation of Probiotics

The term ‘probiotics’ is defined as ‘a live microbial feed supplement that may beneficially affect the host animal upon ingestion by improving its intestinal microbial balance’ (Fuller 1989). Probiotics are living microorganisms that confer health benefits to the host when administered in adequate amounts. The term probiotic describes viable microbial cultures, culture extracts, enzyme preparations or various combinations of these. Common probiotic organisms used as additives are *Saccharomyces*, *Lactobacillus*, *Aspergillus*, etc. Methane-lowering effect has been shown by some of these species, mostly in vitro. Mutsvangwa et al. (1992) showed that addition of *S. cerevisiae* to an in vitro system suppressed CH_4 formation by 10 %. Similarly, a 20 % reduction in CH_4 after 48 h of incubation of mixed rumen microorganisms in the presence of alfalfa and a live yeast product was reported (Lynch and Martin 2002). *A. oryzae* has been found to lower CH_4 production to the extent of 50 % (Frumholtz et al. 1989), which was directly related to a reduction in the protozoal population.

12.6.2 Extensive Feeding System

Under extensive system of feeding management, the ruminant animals are raised exclusively on pasture, and CH_4 mitigation strategies from ruminants in pasture-based systems can be challenging because of the lack of methods to estimate feed intake of the animals. In ruminants, dry matter intake (DMI) is the main factor driving CH_4 production (g CH_4/day), and generally, a strong positive relationship of DMI and CH_4 production is observed (Moss et al. 1995; Molano and Clark 2008). The strategies should involve grazing pasture management, use of plant secondary metabolites and similar approaches that are related to the feeding system.

12.6.2.1 Grazing Pasture Management

As pasture is the main source of nutrients for the grazing ruminants, therefore, proper pasture management practices will prevent pasture degradation and excessive nutrient loss from the pasture. Pasture management, including forage species selection, stocking rate and continuous vs. rotational grazing strategies have all been shown to influence enteric CH_4 emissions. Perhaps the most promising pasture management strategy identified to date for mitigation of enteric emissions is the inclusion of legumes in the forage species mix.

Intensive rotational grazing systems serve as a better way to increase forage production per unit area. In conventional grazing systems, the animals are allowed to graze continuously on a single field. General characteristics of a conventional system usually include a single water source such as a stream, sporadic and inconsistent pasture rest periods and inconsistent manure spreading. On the other hand, rotational grazing systems have multiple, smaller fields (paddocks) for rotation of livestock, management-dependent forage rest periods, better water distribution within paddocks and more investment in capital such as fencing and watering systems. Rotational grazing leads to increased soil water holding capacity and reduced sheet and gully erosion. Another potential benefit may involve a reduction in GHG emissions, primarily enteric CH_4 production. Improved forage quality and animal health may reduce animal CH_4 emissions and increase the carbon sequestration potential of pasture soils.

12.6.2.2 Plant Secondary Metabolites

Plant secondary metabolites (PSM) were earlier considered as anti-nutritive factors in animal nutrition because of their antibacterial properties and adverse effect on nutrient utilisation. Currently, numerous studies have attempted to exploit these PSM as natural feed additives to improve the rumen fermentation efficiency (enhancing protein metabolism, decreasing CH_4 production), reducing nutritional stress such as bloat and improving animal health and productivity (McIntosh et al. 2003; Patra et al. 2006; Benchaar et al. 2007). Many phytochemicals such as saponins, tannins, essential oils and many other unknown metabolites from a wide range of plant sources show potential for CH_4 mitigation options (Kamra et al. 2008; Patra and Saxena 2010). These metabolites lessen CH_4 production through a direct effect on methanogens and/or elimination of protozoa, reduction of OM digestion and modification of fermentation in the rumen (Patra and Saxena 2010). In pasture-based systems, CH_4 mitigation strategies that require daily supplementation of basal diet are not feasible, and manipulation of pasture species composition seems the only alternative for mitigation strategies.

The anti-methanogenic activity of tanniniferous plants has been studied mainly for condensed tannin-rich plants or extracts because of their lower risk of toxicity to the animal than hydrolysable tannins (Beauchemin et al. 2008). There are two modes of action of tannins on methanogenesis, firstly, the activity or methanogen population is directly affected, and secondly tannins reduce hydrogen production by lowering feed degradation (Tavendale et al. 2005). Alternately, tannins are also known to decrease protozoal numbers (Makkar et al. 1995), and the decrease in CH_4 production could also be mediated through the decrease in protozoal number. Tannin-containing forages and tannin extracts have been demonstrated to decrease CH_4 production both in vitro and in vivo experiments.

Saponins are glycosides that occur in wide variety of plants. Saponins are natural detergents, chemically defined as high molecular weight glycosides in which sugars are linked to a triterpene or steroidal aglycone moiety. The important common forages known to contain saponins are lucern, white clover, red clover and soybean. In ruminants saponins form bloat by changing surface tension of rumen contents contributing to a frothy blot by entrapment of numerous bubbles of fermentative gases in the digesta. These compounds also affect rumen protozoa and cause cell death by forming complex with sterols in protozoal cell membranes (Cheeke 2000). They also modify ruminal fermentation by suppressing protozoa and selectively inhibiting some bacteria. Rumen protozoa are particularly sensitive to saponins which reduce their level in the rumen, resulting in the depression of methanogens associated with protozoa (Kobayashi 2010). Supplementation of saponin-rich plant extracts to ruminants decreased ruminal protozoa counts and lowered methanogenesis (Wallace et al. 1994; Takahashi et al. 2000; Wang et al. 2000; Mwenya et al. 2004; Santoso et al. 2004), and in all the studies, lower methane production was accompanied by a decrease in the ruminal acetate to propionate ratio in both in vitro and in vivo experimentation.

Essential oils (EO) are steam-volatile or organic solvent extracts of plants (Gershenzon and Croteau 1991). The term ‘essential’ derives from ‘essence’, which means smell or taste, and relates to the property of these substances of providing specific flavours and odours to many plants (Calsamiglia et al. 2007). The most important active compounds present in essential oils are broadly included in two chemical groups, namely, terpenoids (monoterpenoids and sesquiterpenoids) and phenylpropanoids. They are mostly obtained from herbs and spices and also present to some extent in many plants for their protective role against microbes (bacterial, protozoa or fungal) or insect attack. Structurally, they are mainly cyclic hydrocarbons and their alcohol, aldehyde or ester derivatives. The use of essential oils and their active ingredients in enteric CH_4 mitigation has been reported mostly from in vitro experiments (Calsamiglia et al. 2008; Bodas et al. 2008; Benchaar et al. 2009; Soren et al. 2010, 2011). Many of the studies pertaining to the use of essential oils in CH_4 reduction have been demonstrated to be dose dependent. McIntosh et al. (2003) demonstrated that the reduction in the number of *Methanobrevibacter smithii* occurred only after using the highest concentration (1,000 ppm) of the commercial mixture of essential oils, while the lower doses (5, 10, 20, 40, 80, 160 ppm) did not adversely affect the population of *Methanobrevibacter smithii*. A similar dose-related phenomenon has also been reported by Macheboeuf et al. (2008), who studied the effect of the essential oils extracted from *Thymus vulgaris*, *Origanum vulgare*, *Cinnamomum verum* and *Anethum graveolens*.

12.6.3 Semi-intensive Feeding System

In semi-intensive or mixed type of feeding system, the animals are allowed to graze for about 8–10 h in the pasture followed by supplementation in the evening. The grazing pasture or community grazing lands are not uniform round the year but vary seasonally. Majority of the interventions are required during the lean period when the availability of nutrients is poor and there are possibilities that enteric CH_4 production will be higher. Some of the nutritional strategies pertaining to the feeding system in question are as follows:

12.6.3.1 Nutritional and Diet Management

Nutritional management includes feeding or supplementation of quality forage to ruminants with lower fibre and higher soluble carbohydrates, changing of tropical grasses (C_4 species) of the pasture to temperate type (C_3 species) or grazing less mature pastures that may be fruitful for reducing enteric CH_4 (Beauchemin et al. 2008). Addition of grains to a forage diet will increase the starch content, thus reducing fibre intake, reducing rumen pH and promoting the production of propionate in the rumen (McAllister and Newbold 2008). Propionate production tends to reduce methanogenesis in the rumen. Methane emissions are also commonly lower with higher proportions of forage legumes in the diet, partly due to lower fibre content, faster rate of passage and, in some cases, the presence of condensed tannins (Beauchemin et al. 2008). Plant breeding therefore offers some potential to improve the efficiency of digestion, while reducing CH_4 production.

12.6.3.2 Concentrate Supplementation

Enteric CH_4 production can be lowered by supplementing concentrate in the diet of ruminants with higher genetic merit because the nutritional requirements are not met only with the feeding of forages. Compared to forages, concentrates are usually lower in cell wall components, and the presence of nonstructural carbohydrates (starch and sugars) will allow faster fermentation with the production of elevated levels of propionate in comparison to acetate. Thus, CH_4 production can be lowered by almost 40 % concentrates when a forage-rich diet is replaced by a concentrate-rich diet (Veen 2000). Increasing the proportion of concentrates is to be done judiciously; otherwise, clinical acidosis may ensue, and therefore, there is a need to supplement structural carbohydrates also.

12.6.3.3 Ration Balancing

Dairy animals in developing countries produce more CH_4 because of feeding rations which are imbalanced in nutrients. Animals on imbalanced rations not only yield less milk at a higher cost but also are reported to produce more CH_4 per litre of milk (Capper et al. 2009; Garg 2011). A balanced ration should provide protein, energy, minerals and vitamins from dry fodders, green fodders, concentrates, mineral supplements, etc., in appropriate quantities to enable the animal to perform optimally and remain healthy. Enteric CH_4 emission from animals fed on balanced ration is 12–15 % lower (Kannan et al. 2011).

12.7 Conclusions

Methane is one of the GHGs which have a significant role in greenhouse effect. Methane production in ruminants is unique and serves as a hydrogen sink. Around 10–12 % of the gross energy is wasted as CH_4 in ruminants; thus, the animals cannot exhibit optimum production performance. Livestock feeding system is not uniform worldwide and may vary depending on the socio-economic condition, geographical locations, climatic conditions and human and livestock population and in turn may affect enteric CH_4 production and animal performance as a whole. A sound knowledge and understanding of different feeding systems on which ruminants thrive will help to improve livestock performance and lower enteric CH_4 yield. Suitable mitigation strategy(s), most appropriate for a particular feeding system, will help in better abatement of enteric CH_4 for a clean and green environment for humans in years to come.

12.8 Future Prospect

Research works involving different feeding systems existing worldwide for lower enteric CH_4 production, along with evolving mitigation strategies that are simple and practicable, need to be developed for increasing the production from ruminant animals. Lowering CH_4 emission from ruminants by different interventions will not only lead to a clean and green environment but healthy environment for humans to live.

References

Argyle JL, Baldwin RL (1988) Modeling of rumen water kinetics and effects of rumen pH changes. J Dairy Sci 71:1178–1188

Basarab JA, Beauchemin KA, Baron VS, Ominski KH, Guan LL, Miller SP, Crowley JJ (2013) Reducing GHG emissions through genetic improvement for feed efficiency: effects on economically important traits and enteric methane production. Animal 7:303–315

Beauchemin KA, McGinn SM (2005) Methane emissions from feedlot cattle fed barley or corn diets. J Anim Sci 83:653–661

Beauchemin KA, Kreuzer M, O'Mara F, McAllister TA (2008) Nutritional management for enteric methane abatement: a review. Aust J Exp Agric 48:21–27

Belflower JB, Bernard JK, Gattie DK, Hancock DW, Risse LM, Rotz CA (2012) A case study of the potential environmental impacts of different dairy production systems in Georgia. Agric Syst 108:84–93

Benchaar C, Petit HV, Berthiaume R, Ouellet DR, Chiquette J, Chouinard PY (2007) Effects of essential oils on digestion, ruminal fermentation, rumen microbial populations, milk production, and milk composition in dairy cows fed alfalfa silage or corn silage. J Dairy Sci 90:886–897

Benchaar C, Hristov AN, Greathead H (2009) Essential oils as feed additives in animal nutrition. In: Steiner T (ed) Phytogenics in animal nutrition. Nottingham University Press, Nottingham, pp 111–146

Berchielli TT, Messana JD, Canesin RC (2012) Enteric methane production in tropical pastures. Rev Bras Saude Producao Anim 13:954–968

Bhatt RS, Soren NM, Tripathi MK, Karim SA (2011) Effects of different levels of coconut oil supplementation on performance, digestibility, rumen fermentation and carcass traits of Malpura lambs. Anim Feed Sci Technol 164:29–37

Bodas R, López S, Fernandez M, Garcia-González R, Rodríguez AB, Wallace RJ, González JS (2008) *In vitro* screening of the potential of numerous plant species as antimethanogenic feed additives for ruminants. Anim Feed Sci Technol 145:245–258

Calsamiglia S, Busquet M, Cardozo PW, Castillejos L, Ferret A (2007) Invited review: essential oils as modifiers of rumen microbial fermentation. J Dairy Sci 90:2580–2595

Calsamiglia S, Busquet M, Cardozo PW, Castillejos L, Ferret A (2008) Essential oils as modifiers of rumen microbial fermentation. J Dairy Sci 90:2580–2595

Capper JL, Cady RA, Bauman DE (2009) The environmental impact of dairy production: 1944 compared with 2007. J Anim Sci 87:2160–2167

Cassandro M, Mele M, Stefanon B (2013) Genetic aspects of enteric methane emission in livestock ruminants. Ital J Anim Sci 12:450–458

Chaves AV, He ML, Yang WZ, Hristov AN, McAllister TA, Benchaar C (2008) Effects of essential oils on proteolytic, deaminative and methanogenic activities of mixed ruminal bacteria. Can J Anim Sci 88:117–122

Cheeke PR (2000) Actual and potential applications of *Yucca schidigera* and *Quillaja saponaria* saponins in human and animal nutrition. J Anim Sci 77:1–10

Child RD, Heady HF, Hickey WC, Petecson RA, Pieper RD (1984) Arid and semiarid lands: sustainable use and management in developing countries. Winrock International Morrilton, Washington, DC

Dijkstra J, Neal HDSC, Beever DE, France J (1992) Simulation of nutrient digestion, absorption and outflow in the rumen: model description. J Nutr 122:2239–2256

Dittmann MT, Runge U, Lang RA, Moser D, Galeffi C, Kreuzer M, Clauss M (2014) Methane emission from camelids: a comparison of measured data with literature data from ruminants. Proc Soc Nutr Physiol 23:30

FAO (2010) Greenhouse gas emissions from the dairy sector-a life cycle assessment. Animal Production and Health Division, Food and Agriculture Organization of the United Nations, p 94

FAO, IDF, IFCN (2014) World mapping of animal feeding systems in the dairy sector. Rome, pp 155–160. http://www.fao.org/3/a-i3913e.pdf

Fievez V, Dohme F, Danneels M, Raes K, Demeyer D (2003) Fish oils as potent rumen methane inhibitors and associated effects on rumen fermentation *in vitro* and *in vivo*. Anim Feed Sci Technol 104:41–58

Fredeen A, Juurlink S, Main M, Astatkie T, Martin RC (2013) Implications of dairy systems on enteric methane and postulated effects on total greenhouse gas emission. Animal 7:1875–1883

Frumholtz PP, Newbold CJ, Wallace RJ (1989) Influence of *Aspergillus oryzae* fermentation extract on the fermentation of a basal ration in the rumen simulation technique (Rusitec). J Agric Sci (Camb) 113:169–172

Fuller R (1989) Probiotics in man and animals. J Appl Bacteriol 66:365–378

Garg MR (2011) Methane emission reduction in lactating animals through balanced feeding. In: Proceedings of recent advances in methane estimation and mitigation strategies in ruminants. NIANP, Bangalore, 5–18 August 2011, pp 9–13

Gershenzon J, Croteau R (1991) Terpenoids. In: Rosenthal GA, Berenbaum MR (eds) Herbivores: their interactions with secondary plant metabolites, vol 1. Academic, San Diego, pp 165–219

Grainger C, Beauchemin KA (2011) Can enteric methane emissions from ruminants be lowered without lowering their production? Anim Feed Sci Technol 166–167:308–320

Hegarty RS (1999) Reducing rumen methane emissions through elimination of rumen protozoa. Aust J Agric Res 50:1321–1327

Herrero M, Havlík P, Valin H, Notenbaert A, Rufino MC, Thornton PK, Blümmel M, Weiss F, Grace D, Obersteiner M (2013) Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. Proc Natl Acad Sci U S A 110:20888–20893

Hook SE, Northwood KS, Wright ADG, McBride BW (2009) Long-term monensin supplementation does not significantly affect the quantity or diversity of methanogens in the rumen of the lactating dairy cow. Appl Environ Microbiol 75:374–380

Hook SE, Wright AG, McBride BW (2010) Methanogens: methane producers of the rumen and mitigation strategies. Archaea, Article ID 945785. doi:10.1155/2010/945785

Jarvis GN, Strompl C, Burgess DM, Skillman LC, Moore ERB, Joblin KN (2000) Isolation and identification of ruminal methanogens from grazing cattle. Curr Microbiol 40:327–332

Johnson KA, Johnson DE (1995) Methane emissions from cattle. J Anim Sci 73:2483–2492

Kamra DN, Patra AK, Chatterjee PN, Kumar R, Agarwal N, Chaudhary LC (2008) Effect of plant extracts on methanogenesis and microbial profile of the rumen of buffalo: a brief overview. Aust J Exp Agric 48:175–178

Kannan A, Garg MR, Mahesh Kumar BV (2011) Effect of ration balancing on milk production, microbial protein synthesis and methane emission in crossbred cows under field conditions in Chittoor district of Andhra Pradesh. Indian J Anim Nutr 28:117–123

Kingeston-Smith AH, Edwards JE, Huws SA, Kim EJ, Abberton M (2010) Plant-based strategies towards minimising livestock's long shadow. Proc Nutr Soc 69:613–620

Kirchgessner M, Windisch W, Muller HL (1995) Nutritional factors affecting methane production by ruminants. In: Engelhardt WV, Leonhard-Marek S, Breves G, Giesecke D (eds) Ruminant physiology: digestion, metabolism, growth and reproduction. Ferdinand Enke Verlag, Stuttgart, pp 333–343

Knapp JR, Laur GL, Vadas PA, Weiss WP, Tricarico JM (2014) Enteric methane in dairy cattle production: quantifying the opportunities and impact of reducing emissions. J Dairy Sci 97:3231–3261

Kobayashi Y (2010) Abatement of methane production from ruminants: trends in the manipulation of rumen fermentation. Asian-Australas J Anim Sci 23:410–416

Kurihara M, Magner T, Hunter RA, McCrabb GJ (1997) Methane emissions of cattle fed on tropical forage and high grain diets. Proc Nutr Soc Aust 21:169

Lee HJ, Lee SC, Kim JD, Oh YG, Kim BK, Kim CW, Kim KJ (2003) Methane production potential of feed ingredients as measured by *in vitro* gas test. Asian-Australas J Anim Sci 16:1143–1150

Leng RA, Preston TR (2010) Further considerations of the potential of nitrate as a high affinity electron acceptor to lower enteric methane production in ruminants. Livest Res Rural Dev 22:Article #221. Retrieved September 2, 2014, from http://www.lrrd.org/lrrd22/12/leng22221.htm

Liu Y, Whitman WB (2008) Metabolic, phylogenetic, and ecological diversity of the methanogenic archaea. Ann N Y Acad Sci 1125:171–189

Lovett DK, Bortolozzo A, Conaghan P, O'Kiely P, O'Mara FP (2004) *In vitro* total and methane gas production as influenced by rate of nitrogen application, season of harvest and perennial ryegrass cultivar. Grass Forage Sci 59:227–232

Lynch HA, Martin SA (2002) Effects of *Saccharomyces cerevisiae* culture and *Saccharomyces cerevisiae* live cells on *in vitro* mixed ruminal microorganism fermentation. J Dairy Sci 85:2603–2608

Macheboeuf D, Morgavi DP, Papon Y, Mousset JL, Arturo-Schaan M (2008) Dose-response effects of essential oils on *in vitro* fermentation activity of the rumen microbial population. Anim Feed Sci Technol 145:335–350

Machmüller A, Soliva CR, Kreuzer M (2003) Methane-suppressing effect of myristic acid in sheep as affected by dietary calcium and forage proportion. Br J Nutr 90:529–540

Makkar HPS, Blummel M, Becker K (1995) *In vitro* effects of and interactions between tannins and saponins and fate of tannins in the rumen. J Sci Food Agric 69:481–493

Mathews KH Jr, Johnson RJ (2013) Alternative beef production systems: issues and implications. A report from the economic research service, United States Department of Agriculture, LDPM-218-01. http://www.ers.usda.gov/media/1071057/ldpm-218-01.pdf

McAllister TA, Newbold CJ (2008) Redirecting rumen fermentation to reduce methanogenesis. Aust J Exp Agric 48:7–13

McAllister TA, Okine EK, Mathison GW, Cheng KJ (1996) Dietary, environmental and microbiological aspects of methane production in ruminants. Can J Anim Sci 76:231–243

McIntosh FM, Williams P, Losa R, Wallace RJ, Beever DA, Newbold CJ (2003) Effects of essential oils on ruminal microorganisms and their protein metabolism. Appl Environ Microbiol 69:5011–5014

Mehra UR, Khan MY, Murari L, Hasan QZ, Asit D, Bhar R, Verma AK, Dass RS, Singh P (2006) Effect of source of supplementary protein on intake, digestion and efficiency of energy utilization in buffaloes fed wheat straw based diets. Asian-Australas J Anim Sci 5:623–638

Mengistu A (1985) Feed resources in Ethiopia. In: Kategile JA, Said AN, Dzowela BH (eds) Animal feed resources for small-scale livestock producers. Proceedings of the second PANESA workshop, held in Nairobi, 11–15 November 1985

Minson DJ (1990) Forages in ruminant nutrition. Academic, New York, p 350

Mirzaei-Aghsaghali A, Maheri-Sis N, Mirza-Aghazadeh A, Ebrahimnezhad Y, Dastouri MR, Aghajanzadeh-Golshani A (2008) Estimation of methane production in sheep using nutrient composition of the diet. J Anim Vet Adv 7:765–770

Moe PW, Tyrell HF (1979) Methane production in dairy cows. J Dairy Sci 62:1583–1586

Molano G, Clark H (2008) The effect of level of intake and forage quality on methane production by sheep. Aust J Exp Agric 48:219–222

Morgavi DP, Jouany JP, Martin C (2008) Changes in methane emissions and rumen fermentation parameters induced by refaunation in sheep. Aust J Exp Agric 48:69–72

Moss N (2010) Where are the feeding systems heading to in Australia? In: Celi P, Garcia S (eds) Current topics in dairy production, vol 15. University Printing Service, Sydney, pp 30–43

Moss AR, Givens DI, Garnsworthy PC (1995) The effect of supplementing grass silage with barley on digestibility, *in sacco* degradability, rumen fermentation and methane production in sheep at two levels of intake. Anim Feed Sci Technol 55:9–33

Moss AR, Jouany JP, Newbold J (2000) Methane production by ruminants: its contribution to global warming. Ann Zootech 49:231–253

Mutsvangwa T, Edwards IE, Topps JH, Paterson GFM (1992) The effect of dietary inclusion of yeast culture (Yea-Sacc) on patterns of rumen fermentation, food intake and growth of intensively fed bulls. Anim Prod 55:35–40

Mwenya B, Sar C, Gamo Y, Kobayashi T, Morikawa R, Kimura K, Mizukoshi H, Takahashi J (2004) Effects of *Yucca schidigera* with or without nisin on ruminal fermentation and microbial protein synthesis in sheep fed silage- and hay-based diets. Anim Sci J 75:525–531

Myers ML (2011) Livestock rearing: its extent and health effects. In: Myers ML (ed) Encyclopaedia of occupational health and safety. International Labor Organization, Geneva

O'Mara F (2004) Greenhouse gas production from dairying: reducing methane production. Adv Dairy Technol 16:295–309

Patra AK (2014) Trends and projected estimates of GHG emissions from Indian livestock in comparisons with GHG emissions from world and developing countries. Asian-Australas J Anim Sci 27:592–599

Patra AK, Saxena J (2010) A new perspective on the use of plant secondary metabolites to inhibit methanogenesis in the rumen. Phytochemistry 71:1198–1222

Patra AK, Kamra DN, Agarwal N (2006) Effect of plant extracts on *in vitro* methanogenesis, enzyme activities and fermentation of feed in rumen liquor of buffalo. Anim Feed Sci Technol 128:276–291

Peters GM, Rowley HV, Wiedemann S, Tucker R, Short MD, Schulz M (2010) Red meat production in Australia: life cycle assessment and comparison with overseas studies. Environ Sci Technol 44:1327–1332

Ripple WJ, Smith P, Haberl H, Montzka SA, McAlpine C, Boucher DH (2014) Ruminants, climate change and climate policy. Nat Clim Chang 4:2–5

Rowlinson P, Steele M, Nefzaoui A (2008) Livestock and global climate change. In: Proceedings of the international conference in Hammamet, Cambridge University Press, 17–20 May, pp 216–216

Sankhyan SK, Soren NM, Bhatt RS, Shinde AK, Karim SA (2010) Performance, rumen fermentation pattern and blood biochemical characteristics of pregnant ewes grazing on semi-arid pastures during winter season. Ind J Small Rumin 16:39–44

Santoso B, Mwenya B, Sar C, Gamo Y, Kobayashi T, Morikawa R, Kimura K, Mizukoshi H, Takahashi J (2004) Effects of supplementing galacto-oligosaccharides, *Yucca schidigera* or nisin on rumen methanogenesis, nitrogen and energy metabolism in sheep. Livest Prod Sci 91:209–217

Song MK, Li XZ, Oh YK, Lee C, Hyun Y (2011) Control of methane emission in ruminants and industrial application of biogas from livestock manure in Korea. Asian-Australas J Anim Sci 24:130–136

Soren NM, Pareek L, Jain PK, Sahoo A (2010) *In vitro* ruminal gas production and fermentation attributes of different spices straws and tree forages. In: Proceedings of 7th biennials conference of Animal Nutrition Association, vol II, Bhubaneswar, Animal Nutrition Association of India, 17–19 December, p 150

Soren NM, Sahoo A, Kumawat P (2011) Spices straw as additives to concentrate mixture and cenchrus grass on *in vitro* ruminal gas production and fermentation attributes. In: Datt C, Kundu SS, Tiwari DP, Thakur SS (eds) Livestock productivity with available feed resources. Book of abstract. Excel India Publishers, New Delhi, pp 173–175

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow: environmental issues and options. Food and Agriculture Organization of the United Nations, Rome. Available at: ftp://ftp.fao.org/docrep/fao/010/a0701e/a0701e00.pdf

Sumberg JE, Cassaday K (1985) Sheep and goats in humid West Africa. In: Sumberg JE, Cassaday K (eds) Proceedings of the workshop on small ruminant production systems in the humid zone of West Africa, held in Ibadan, 23–26 January 1984

Szumacher-Strabel M, Cieślak A (2010) Potential of phytofactors to mitigate rumen ammonia and methane production. J Anim Feed Sci 19:319–337

Takahashi J, Miyagawa Y, Kojima Y, Umetsu K (2000) Effects of *Yucca schidigera* extract, probiotics, monensin and L-cysteine on rumen methanogenesis. Asian-Australas J Anim Sci 13:499–501

Tamminga S, Bannink A, Dijkstra J, Zom R (2007) Feeding strategies to reduce methane loss in cattle. Animal Science Group Report, Wageningen

Tavendale MH, Meagher LP, Pacheco D, Walker N, Attwood GT, Sivakumaran S (2005) Methane production from *in vitro* rumen incubations with *Lotus pedunculatus* and *Medicago sativa*, and effects of extractable condensed tannin fractions on methanogenesis. Anim Feed Sci Technol 123–124:403–419

Ulyatt MJ, Lassey KR, Shelton ID, Walker CF (2002) Methane emission from dairy cows and wether sheep fed subtropical grass-dominant pastures in midsummer in New Zealand. N Z J Agric Res 45:227–234

Van Nevel CJ, Demeyer DI (1996) Influence of antibiotics and a deaminase inhibitor on volatile fatty acids and methane production from detergent washed hay and soluble starch by rumen microbes *in vitro*. Anim Feed Sci Technol 37:21–31

Van Soest PJ (1994) Nutritional ecology of the ruminant, 2nd edn. Cornell University Press, Ithaca, p 476. ISBN 13: 9780801427725

Veen WAG (2000) Veevoedermaatregelen ter vermindering van methaanproductie door herkauwers. Schothorst Feed Research proefverslag. www.robklimaat.nl

Wallace RJ, Arthaud L, Newbold CJ (1994) Influence of *Yucca Schidigera* extract on ruminal ammonia concentrations and ruminal microorganisms. Appl Environ Microbiol 60:1762–1767

Wang Y, McAllister TA, Yanke LJ, Xu ZJ, Cheeke PR, Cheng KJ (2000) *In vitro* effects of steroidal saponins from *Yucca schidigera* extract on rumen microbial protein synthesis and ruminal fermentation. J Sci Food Agric 80:2114–2122

Whitelaw FG, Eadie JM, Bruce LA, Shand WJ (1984) Methane formation in faunated and ciliate-free cattle and its relationship with rumen volatile fatty acid production. Br J Nutr 52:261–275

Wolin MJ, Miller TL, Stewart CS (1997) Microbe-microbe interactions. In: Hobson PJ, Stewart CS (eds) The Rumen microbial ecosystem, 2nd edn. Blackie Academic and Professional Publishers, London, pp 467–491

Estimation Methodologies for Enteric Methane Emission in Ruminants

13

Laura M. Cersosimo and André-Denis G. Wright

Abstract

As enteric methane emissions from ruminants contribute to feed inefficiency and global warming, methodologies to measure the enteric methane from either the individual ruminant or the herd are needed. Therefore, methane emission estimations in ruminants may provide insight into potential methane mitigation strategies. Furthermore, the use of methane emission methodologies enables researchers to compare and contrast methane emissions from different diets, breeds, and geographical locations and to evaluate mitigation strategies. This chapter describes key methane estimation methodologies previously and currently used in research and highlights the advantages and disadvantages of each methodology. Key in vivo techniques include open- and closed-circuit respiration chambers, open-circuit hood systems, sulfur hexafluoride (SF_6) tracer, polythene tunnel system, methane/carbon dioxide ratio, GreenFeed, infrared (IR) thermography, laser methane detector, and the intraruminal gas measurement device. Furthermore, the in vitro gas technique (IVGT) estimates the methane emissions from different dairy rations. Theoretical methodologies include the rumen fermentation balance, COWPOLL ruminant digestion model, and the Cattle Enteric Fermentation Model (CEFM). Although there are several different types of methane estimation methodologies, the cost, species, accuracy of the technique, maintenance, and the environment of the ruminant are all contributing factors in choosing which technique to apply to a study.

Keywords

Enteric methane emissions • Estimation methodologies

L.M. Cersosimo
Department of Animal Science, College of
Agriculture and Life Sciences, University of Vermont,
570 Main St., Burlington, VT 05401, USA

A.-D.G. Wright (✉)
Department of Animal Science, College of
Agriculture and Life Sciences, University of Vermont,
570 Main St., Burlington, VT 05401, USA

School of Animal and Comparative Biomedical
Sciences, The University of Arizona, 1117 E. Lowell
Street, Tucson, AZ 85721, USA
e-mail: adwright@email.arizona.edu

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_13, © Springer India 2015

13.1 Introduction

Globally, enteric fermentation accounts for 28 % of the estimated anthropogenic methane emissions (EPA 2013). With an expanding global population and demand for beef and dairy products, methane emissions are projected to significantly increase by year 2020 (Global Methane Emissions and Mitigation Opportunities 2014). Because methane has a 12-year lifespan in the atmosphere, it is a short-term climate forcer. While methane is in the atmosphere shorter, and is produced in smaller quantities than carbon dioxide, it has a global warming potential (GWP) 25 times that of carbon dioxide, making it one of the most important greenhouse gases contributing to climate change (EPA 2010).

As a response to global and country-specific enteric methane emissions, scientists have come up with several methane mitigation strategies and methodologies for estimating enteric methane emissions from ruminants. Emphasis on the latter will be the focus of this chapter. If the overall goal is to mitigate methane, then it is important to understand how much methane ruminants are producing and how much is being abated on an individual and whole herd basis. This chapter will focus on a variety of popular methods for estimating individual animal enteric methane emissions. A description of the functionalities of each method and the advantages and disadvantages of each methodology will be presented.

13.2 Closed-Circuit Respiration Chamber

Turner and Thorton (1966) developed a closed-circuit respiration chamber in 1966 that was completely sealed and measured the change in air composition. The closed-circuit chamber has air conditioning, a cage to hold the animal, and feed and water bins. Gas analysis occurs as air is pumped continuously from the chamber through a sampling circuit that contains a dust trap, solenoid, and relief valves. An infrared analyzer is used to record methane and carbon dioxide concentrations. According to Turner and Thorton (1966), each run can range from 30 to 100 min and is dependent upon animal size and state. Wright et al. (2004) described placing sheep in closed-circuit chambers for 13.5 h for 5 consecutive days. The sheep on this study also received 30 min of acclimation. Because the system was closed, the chamber was raised or “opened” for approximately 12 min every 2–3 h to expel the carbon dioxide. When the chamber is lowered again, the system is then considered “closed.”

Cost is the biggest disadvantage to this methane emission estimation methodology. Because carbon dioxide can build up in the closed system, an operator needs to be present to open the system, making it more difficult to measure total exchange over a long period of time (Turner and Thorton 1966; Wright et al. 2004). By opening up the system, Turner and Thorton (1966) noted that it could become more difficult to keep ambient air in. Although the closed-circuit system has several disadvantages, it still is highly precise in comparison to other techniques. If researchers prefer to use an open-circuit respiration chamber, then the closed-circuit respiration chamber can be easily converted into one.

13.3 Open-Circuit Whole Animal Respiration Chambers

The use of whole animal open-circuit respiration chambers has been the gold standard method to estimate individual methane emissions of small and large ruminants. In fact, the validity of other methodologies presented in this chapter is determined by comparing results to data collected with the use of whole animal respiration chambers (Johnson et al. 1994; Chagunda et al. 2009; Montanholi et al. 2008).

With the open-circuit indirect calorimeter, a known flow of air is circulated around the animal’s head, nose, and mouth, and expired air is collected (McClean and Tobin 1987). Methane emissions can be determined by measuring the total airflow through the system and calculating differences between inhaled and expired air (Johnson and Johnson 1995). Both carbon dioxide and methane are determined with an infrared analyzer, while oxygen concentrations are determined by a paramagnetic analyzer (Miller and Koes 1988). The chamber is completely sealed and has a negative pressure created by outside air to ensure that all potential leaks that could affect methane emissions go inward. The chamber temperature is maintained by circulating air going through the evaporator assembly (Miller and Koes 1988). Before going through the infrared and paramagnetic analyzers, all moisture from the air samples is removed by a desiccant.

Although the design of respiration chambers varies by experiment and facility, all chambers typically have similar components. The respiration chamber contains a cage to house an individual animal (e.g., cattle or sheep). Within the cage, waterers, feeders, fecal and urine collectors, air conditioning, and dehumidifiers are all necessary for animal comfort (Chagunda et al. 2009). Before starting an experiment, the animal must be acclimated to the chamber. Typically, the animal gets acclimated to the chamber for 4–6 h, multiple times. Once the animal becomes acclimated to the chamber, then gas measurements can be calculated.

Johnson and Johnson (1995) noted that respiration chambers can measure both enteric and hindgut methane emissions in an individual, giving a more accurate estimate of the total methane produced by the animal. The biggest disadvantages to using a respiration chamber are the cost due to construction and maintenance and the lack of a comfortable, normal environment for the animal. The chambers attempt to create a comfortable environment, but changes in animal behavior could be an issue as ruminants like sheep and cattle are herd animals that like to socialize with other members of their herd. It is proposed that by creating an artificial environment, the animal's dry matter intake (DMI) will be altered. DMI is a key component that drives methane emissions (Ellis et al. 2007) and would decrease under these chamber conditions (Johnson and Johnson 1995). Therefore, it is believed that the use of an immobile respiration chamber cannot be applied to animals on pasture. Although cost is the major drawback to using respiration chambers, this technique is still considered the gold standard for the most accurate estimates in comparison to the other techniques that will be discussed below.

13.4 Open-Circuit Ventilated Hood System

The ventilated hood systems use the same principles as the whole animal chambers to measure methane concentrations, but are less expensive and portable. Kelly et al. (1994) developed a mobile, open-circuit indirect calorimetry system that contains a hood system with an airtight headbox. The system uses two separate but linked sampling lines. The mainline involves the movement of gas across a ventilated hood worn around the animal's neck with subsequent measurements of airflow, absolute pressure, relative humidity, and temperature. The hood fits small ruminants and was originally made primarily of plywood (Kelly et al. 1994). The hoods have acrylic windows and a removable rear panel for feeding and watering that is sealed with butterfly clips and foam to prevent leakage. The front of the hood has an opening for the animal to put its head in. A nylon drape attached to the hood is secured around the animal's neck with an adjustable string.

Odongo et al. (2008) also used the same principles of the whole animal chamber along with the previous hood system to create an open-circuit ventilated hood system for estimating methane emitted from lactating Holstein dairy cattle under two diet treatments. Furthermore, Place et al. (2011) utilized basic dimensions and design from both Kelly et al. (1994) and Odongo et al. (2008) to construct a ventilated hood system that measures greenhouse gases and volatile organic compound emissions. Because the headboxes are made out of clear polycarbonate material, cattle can have a full range of vision while they are temporarily placed in the headboxes for sampling (Place et al. 2011). By having a full range of vision and movement, the animal can be more comfortable and less stressed.

The biggest advantage of using ventilated hood systems is that it is less expensive than a whole animal chamber. It also requires less space and is mounted on a cart with wheels so that it can be moved from one location to another. According to Place et al. (2011), the ventilated hood systems are more accurate than the SF_6 tracer technique that will be explained later in the chapter. The biggest critique of the technique is that the animal is restrained and therefore needs to adapt to the system.

13.5 Rumen Fermentation Balance

Using a series of assumptions about fermentation and volatile fatty acids (VFAs), Wolin (1960) came up with an equation, called the theoretical rumen fermentation balance for predicting methane and carbon dioxide in ruminants in correspondence to the molar distribution of VFAs in the rumen. The following assumptions were made: (1) there is no hydrogen associated with microbial cell synthesis; (2) the fermentation of noncarbohydrate substrates results in no VFAs; (3) the molar proportions of VFAs in a rumen fluid sample are 65 acetic acid: 20 propionic acid: 15 butyric acid, representing the proportions in which they are produced from substrates; and (4) all the carbohydrates are of the same empirical formula, $C_6H_{12}O_6$. The fermentation balance is evaluated with experimental data with product-substrate relationships to determine theoretical methane to carbon dioxide ratio. Furthermore, Ørskov et al. (1968) explored the VFAs, acetic, propionic, and butyric acids and stated that the fermentation balance suggests that there is a correlation between methane losses and acetic acid. For example, with an increase in acetic acid production, more hydrogen is available to reduce carbon dioxide to methane. In contrast, propionic acid has an inverse effect, while butyric acid has an intermediate effect on methane.

Since this technique uses equations to indirectly estimate methane emissions, it has received several criticisms. The technique was established in 1960 when the other methodologies revealed in this chapter were not yet developed. Considering the age of the technique and the lack of other techniques during this time, the rumen fermentation balance was a start to establishing methods to estimating methane emissions.

13.6 In Vitro Gas Technique

The in vitro gas production technique (IVGPT) or in vitro gas test was originally used to predict the fermentation of ruminant feedstuffs. With methane's contribution to greenhouse gas emissions and methane's inability to be used as an energy substrate, the IVGPT has been applied to examine methane production from different feed ingredients predominantly seen in dairy rations (Lee et al. 2003). The overall goal of using this method would be to quantify the methane produced from the ration, compare rations from commercial farms, and to alter rations to be more feed efficient for the animal and contribute less methane into the environment.

Although there are several different methods and alterations to measuring gas production, the basic principles of all the techniques are the same: ferment feed with naturally occurring rumen microorganisms. A fresh rumen digesta sample is collected and filtered through cheesecloth to remove any large feed particles. To avoid a change in the microbial population, carbon dioxide is flushed into the containers holding the experimental samples. Over a series of time points, from 0 h up to 144 h, the feedstuff, buffer, mineral solution, and rumen fluid are incubated at 39 °C in a water bath (Lee et al. 2003; Storm et al. 2012; Getachew et al. 2005). The total amount of gas produced during the incubation is measured and analyzed to predict the amount of methane produced. Methane can be determined by injecting 100 ml of the gas from a glass syringe with an outlet containing a gastight septum into a gas chromatograph (GC) with a thermal conductivity detector (Getachew et al. 2005). Getachew et al. (2005) ran each incubation in duplicate, and gas samples were collected from each syringe at 6, 24, 48, and 72 h from the syringe septum. The amount of gas produced by fermentation of the substrates in the feed can estimate digestibility and metabolizable energy. The IVGPT measures the fractional degradation ratio of feed matter disappearance per unit time and the amount of methane produced per gram dry matter (Storm et al. 2012).

Although the basis of the technique is consistent, there are some variations to the methods used to measure in vitro gas. Menke et al. (1979) described an IVGPT where gas produced from fermentation was used to estimate digestibility, but 0.2 g of air-dry material or feedstuff was added to a 150 ml glass syringe with a buffered medium and rumen fluid inoculum that was incubated at 39 °C in a water bath. The total gas production was measured by reading the position of a piston at different time intervals (Mauricio et al. 1999). In contrast to Menke et al.'s (1979) technique, Wilkins (1974) incubated the substrates and rumen fluid in a sealed serum flask with fermentation gases building up in the oxygen-free headspace of the flask. A technique employed by both Pell and Schofield (1993) and Tedeschi et al. (2008) uses an in vitro fermentation chamber where the substrates, buffer, and rumen fluid are within flasks that had pressure sensors attached. Other techniques include fully automated systems and the rumen simulation technique (RUSITEC) that uses rumen effluent from simulated rumen fermentation, but has lower microbial activity than natural rumen fluid (Storm et al. 2012).

Some advantages to using the IVGPT technique are that it is relatively inexpensive to other methane estimation techniques such as respiration chambers. Typically, the duration of these experiments is 1–4 weeks and can compare multiple feedstuffs from different commercial farms at a time. Aside from the initial collection of rumen fluid in vivo, the technique resides in the laboratory without the use of live animals, thereby decreasing the labor intensity of the procedure.

The biggest criticism of using the IVGPT is that it is a simulation of how the feedstuff is fermented in the rumen and not a technique that gives the individual animal's methane emission estimates and total digestibility in the whole animal (Storm et al. 2012). The gas release captured by this technique is related to degradation, but gives no information about the extent of degradation or the quantity of fermentation products (i.e., microbial proteins and volatile fatty acids) (Mauricio et al. 1999). This technique does not account for the long-term adaption of the rumen microorganisms to feedstuffs under a normal rumen environment. For example, bacteria are estimated to adapt to a change in feedstuff within 4 weeks, while methanogens adapt between 4 and 12 weeks (Williams et al. 2009). Although this technique has several flaws, it is a good basis for testing new feedstuffs and comparing rations that could potentially launch an in vivo experiment using live animals.

13.7 Sulfur Hexafluoride (SF_6) Tracer

The SF_6 tracer procedure designed by Johnson et al. (1994) estimates methane emission rates from cattle and sheep in their natural environments. SF_6 is used to simulate the methane emission rates from the mouth and nostrils, as the dilution rates are very similar to methane and are nontoxic to the animal. Before measuring the methane emissions in vivo, small permeation tubes containing liquid SF_6 are prepared in the laboratory. The tubes are placed in a 39 °C water bath and weighed until accurate loss rates are determined. Permeation rates of 500–1,000 ng of SF_6/min are suggested (Johnson et al. 1994).

Before the permeation tubes are inserted into the rumen, the animals go through an acclimation period that is dependent upon the individual animal being sampled, ranging from 1 day to a week. A balling gun inserts the permeation tube containing SF_6 into the rumen. Contrary to the Johnson et al.'s (1994) acclimation period and tube insertion procedure, Pinares-Patiño and Clark (2008) and Pinares-Patiño et al. (2008) used a 10-day acclimation period and used fistulated cattle so that a balling gun was unnecessary. Although acclimation periods and routes of permeation tube insertions vary by study, the action of the sulfur hexafluoride (SF_6) is the same. Once in the rumen, the permeation tube will release SF_6 at a constant rate, and both SF_6 and methane concentrations can be measured at the mouth of the animal. Once SF_6 release rates and methane and SF_6 concentrations are measured, the following equation can be used to determine the methane emission rate (Sheppard et al. 1982):

$$Q_{\mathrm{methane}} = Q_{SF_6} \times [CH_4]/[SF_6]$$

In their original article, a 1-L stainless steel collection vessel and a capillary tube extending from the collection canister were used above the animal's mouth and nostrils for sample collection (Johnson et al. 1994). There is a collar around the animal's neck for the canister to attach to a transfer line. Prior to sample collection, the canister is evacuated. To start sample collection, a valve on the collection vessel is opened as the evacuated canister is filled at a constant rate until it reaches 0.5 atmospheres (atm). Once this occurs, the canister valve is closed to stop sampling. The air that is collected in the canister passes through a sample loop with a flame ionization detector (FID) that is attached to a calibrated GC. Quantification of methane production is observed comparing the peak heights and retention times of the samples to a set of standards (Johnson and Johnson 1995).

Although the SF_6 tracer method enables researchers to estimate the methane emissions from ruminants in their natural settings, such as pasture and free stalls, there are several flaws displayed by this technique. Both McGinn et al. (2006) and Pinares-Patiño et al. (2008) noted that although the method does measure the methane eructated by the animal, it fails to measure the 5–10 % of the methane from the rectum (Johnson and Johnson 1995). Furthermore, in comparison to the chamber method, the SF_6 tracer technique both underestimates and overestimates methane emissions when compared to open-circuit indirect calorimetry techniques, making it a less accurate technique (Pinares-Patiño and Clark 2008; Pinares-Patiño et al. 2008; Grainger et al. 2007). Pinares-Patiño et al. (2008) also noted that there is an uncertainty about the permeation rate of the tubes associated with length of time between calibration and trial use. Some researchers argue that the SF_6 tracers generate inaccurate readings and are highly variable in data recorded from the same animal in consecutive days. This variability is from dust and water blocking the capillary tubing, from leaks in the polyvinyl chloride (PVC) yolks used around the animal's neck or from poor ventilation (Pinares-Patiño et al. 2008; Wright et al. 2013).

13.8 Polythene Tunnel Systems

A polythene tunnel system was designed to draw air through a large tunnel and measure methane concentrations in air entering and leaving the tunnel with gas chromatography. Lockyer and Champion (2001) used the polythene tunnel, previously explained by Lockyer and Jarvis (1995), to measure methane production in sheep in relation to changes in grazing behaviors. While measuring methane, video recordings of the animals' eating and ruminating behavior were observed.

The polythene tunnel consists of one large tunnel that is portable and can be placed out on pasture, unlike whole animal respiration chambers. The animals contained in the tunnel are still able to graze on pasture, while their methane emissions are measured. Within the large tunnel, variable speed coaxial fan and two smaller tunnels blow air into and out from the larger tunnel. An apparatus inside the tunnel measures and records the methane in air entering and leaving the tunnel while monitoring the airspeed, humidity, and temperature.

Some of the challenges of using the tunnel system are that different dietary treatments cannot be used as the animals in the tunnel are grazing on the pasture under the tunnel (Bhatta et al. 2007). It was observed by Lockyer and Champion (2001) that animals contained in the tunnel for 10 days had consistent methane emissions to other studies using the polythene tunnel, but had decreased methane emissions in comparison to studies with open-circuit indirect calorimetry.

13.9 Methane/Carbon Dioxide Ratio

With the use of carbon dioxide as an internal marker to estimate methane emissions, the methane/carbon dioxide ratio determines how efficient microbial fermentation is on feed and therefore uses feeds or cattle with the great energy conversion abilities and low methane emissions. From data collected from metabolizable energy (ME) intake or from heat-producing units (HPU), the total concentration of carbon dioxide can be estimated. The intake ME minus the weight gain or milk produced by the animal will yield the amount of carbon dioxide excreted. To determine the methane/carbon dioxide ratio, a portable device called a Gasmet (Gasmet Technologies, Oy, Helsinki, Finland) samples air in barns or around individual animals, while the amount of carbon from fat, carbohydrates, or proteins not metabolized to carbon dioxide can be estimated as methane emissions (Madsen et al. 2010). To calculate the amount of methane emitted, the same equation from the SF_6 tracer method is used with carbon dioxide replacing SF_6.

When cows eructate carbon dioxide and methane, the respective concentrations are 100 and 1,000 times higher than the concentrations found naturally in air (Storm et al. 2012). Therefore, Madsen et al. (2010) state that a low amount of an animal's breath needs to be sampled (i.e., 2–3 %). Another benefit of this methodology is that it is versatile. Since the device that measures the gases in the breath and air is portable, both individual and whole herds can have their methane emissions estimated in different environments. Although this method does not measure the methane emissions from the rectum, it still measures the majority of the methane emitted from the animal (Murray et al. 1976).

One of the challenges of this technique is that both CO_2 production and the animal's energy requirements are influenced by the same factors: size, production, and activity (Storm et al. 2012). In comparison to the respiration chamber technique, this method also has more variation between day-to-day measurements, leading to an increased standard error. To address this variation, larger sample numbers are required and are easier to obtain as this method is noninvasive and does not disturb the animal in an unfamiliar environment like the respiration chamber does.

13.10 GreenFeed

Another means of measuring methane emissions in cattle is the GreenFeed system, created by Zimmerman and C-Lock Incorporated (Zimmerman 1993). The system is versatile in that it can measure methane and carbon dioxide emissions from both dairy and beef cattle in different environments such as pasture, free stalls, and tie stalls. The GreenFeed system is a "turnkey-based system" with a "baiting station" that can quantitatively measure both methane and carbon dioxide.

GreenFeed works when an animal sticks its head into the instrument and receives a small amount of food as an award. To prevent any discrepancies in methane measurements due to a varying diet and frequency of animal visits to the instrument, the typical food reward (150–300 g) that the animal receives is allotted to 3–5 times per day and is similar to the ration that the animal consumes on a daily basis. Once the animal sticks its head into the instrument, a radio frequency identification (RFID) system identifies the animal. A fan draws air over the animal's nose, mouth, and head into an air-handling system where airflow rates, gas concentrations, and the volumetric flux (liters/minute) of gases emitted by the animal are calculated. Once the volumetric flux is calculated, the mass flux (grams/minute) can be calculated in conjunction with the ideal gas law ($PV=nRT$) where P is the pressure of the gas, V is the volume of the gas, n is the amount in moles of the gas, R is the ideal gas constant, and T is the absolute temperature. After an animal's emissions are measured, the information goes to the analyzing station, and the unit resets for the next animal to enter (Zimmerman 1993; Waghorn et al. 2013).

As of 2012, there have been 18 GreenFeed units installed in seven countries, and they have been tailored to the environment in which it is to be used. In the United States, a GreenFeed system at Washington State University (WSU) can still operate during a harsh winter and only requires a low amount of power (i.e., 50 watts). At Pennsylvania State University (USA), the unit moves on wheels, between cows housed in tie stalls. To get an estimate of the methane emitted from each cow in a tie-stall operation, the cow's methane is measured for 5–7 min, 5 times per day. Another one at Michigan State University (USA) is installed into a robotic milker at the Kellogg Biological Research Station.

There are several pros of using the GreenFeed unit versus other techniques. The unit itself is standardized and is low maintenance in that it takes 15 min per week to change out the air filters and calibrate the unit. Unlike respiration chambers or headboxes, the animals can be measured under grazing conditions. The unit also uses a low amount of energy and receives its power supply by the solar panel connected to it. However, it was noted that WSU had to use an AC adapter to help power the unit in the winter.

One of the biggest challenges with the GreenFeed method of measuring methane is that methane emissions are taken at all times of the day for each animal. For example, cow A could enter the unit and receive bait before a meal when methane emissions are typically low and cow B could tend to enter the unit after a meal when methane emissions are high (Montanholi et al. 2008). Multiple time points during the course of the day are supposed to make up for this potential disparity, but the animal's ability to enter the unit cannot be controlled. There is a potential that an animal will not have any interest in the unit or that a dominant animal may prevent a more submissive animal from entering.

Although, the unit measures the methane that exits the animal's mouth and nose, it does not get a complete estimate of methane emissions as it does not measure the 5–10 % of the methane that is emitted from the rear of the animal (Murray et al. 1976). The majority of the methane would be measured with this unit, but does not collect 100 % of the methane emitted from the animal as a closed respiration chamber does.

13.11 Infrared Thermography

It has been suggested that there is a correlation between decreased body surface temperatures and increased feed efficiency in cattle (Montanholi et al. 2006, 2007). The production of methane results in an estimated 2–12 % gross energy intake that makes the animal less feed efficient (Johnson and Johnson 1995). Knowing this information about feed efficiency and there being insufficient comparisons made between infrared (IR) thermography and actual methane and heat production, Montanholi et al. (2008) demonstrated that methane emissions from cattle could be estimated by comparing thermal images captured with an IR camera from the right and left flanks of dairy cattle to methane emissions measured by an open-circuit indirect calorimetry system.

The IR camera is portable and can be used without coming into contact with the animal. Before use, the camera is calibrated with the current room temperature and humidity. To get more accurate readings, it is suggested that the animal's body surfaces be free from excess debris and that measurements be taken with the animal out of direct sunlight (Poikalainen et al. 2012). When aiming the camera at a body surface of the animal, such as the left flank, the camera sits atop a tripod, 1.5 m away from the body surface, and an image is captured (Huntington et al. 2012). The camera converts the skin surface's emitted radiation from wavelengths to an electrical signal that is converted into a thermal image. It is suggested that thermal images be captured every 20 min for a total of 20 time points, indicating that it takes 6.5 h to generate data from one animal.

In the study by Montanholi et al. (2008), it was noted that there was only a 0.1 °C difference between the left and right flanks, and temperature fluctuations coincided with feeding. The temperature difference detected by the IR camera between the left and right flanks coincided with the methane emission pattern that was observed from the animals in the open-circuit calorimeter. Furthermore, it was concluded that differences between the left and right flank temperatures are good indictors of methane estimates, but only at certain times of the day. The postprandial period, roughly 100 min after a meal, was advised to be the best time to assess the methane production via IR thermography and demonstrates fluctuations in rumen temperatures (Montanholi et al. 2008). Some advantages to using IR thermography are that the technique is fast, noninvasive, and less expensive in comparison to other methane estimation technologies and enables the animals to be in their normal environments (e.g., free stalls, pasture, or tie stalls). The IR camera also provides instant results that are stored in computer files so that the researchers can better manage the large amount of data they are collecting on farm.

Although there are several benefits to IR thermography, there are some issues and parameters that must be followed to get accurate results. As mentioned before, thermal images must be taken out of direct sunlight and out of the wind, as these factors can alter the body surface temperatures (Poikalainen et al. 2012). Because it takes 6.5 h to generate data from one animal, the technique can become time consuming and labor intensive with increased herd sizes. Another issue is that there needs to be a way to calibrate methane with temperature. This technology does not quantify the methane that is produced so there is a need to calibrate temperature with methane.

13.12 Laser Methane Detector

Originally, the laser methane detector (LMD) was created by the Tokyo Gas Co. for measuring methane emissions in sewage systems, mines, and demolition sites. However, it was recently suggested by Chagunda et al. (2009) that this device could be used on commercial farms to estimate methane emissions in individual cattle and sheep that could benefit greenhouse gas mitigation strategies and feed efficiency concerns. The LMD is a handheld device that uses infrared absorption spectroscopy and uses second harmonic detection of wavelength modulation spectroscopy to determine the methane concentration.

To use the handheld device, a semiconductor laser beam is directed at the preferred area of detection (i.e., the nostrils). The data that are obtained from each measurement are stored on a memory card that can then download readings onto a computer. Measurements are obtained via gas column density, and methane concentrations are given in part per million (ppm). Chagunda et al. (2009) used LMD to measure methane emitted by four sheep and two dairy cows that were housed for 8 h in an open-circuit respiration chamber. Every 30 min, samples were collected from each animal with methane measurements taken every 0.5 s within a 5-min window. While measuring each animal, researchers note the activity of the animal (e.g., ruminating, standing, eating, lying) along with the weather conditions (Chagunda et al. 2013). By noting these conditions, a correlation of methane and activity was made by Chagunda and Yan (2011), indicating that methane emissions in ppm increased directly after feeding.

The use of a LMD to detect methane is safe for the operator of the device to use because no animal contact is needed, and it is ideal for the animal, in that it is a noninvasive, stress-reducing technique that predicts methane emissions of individual animals in their natural environments. Because it is portable, methane emissions can be estimated in different production systems such as pasture based, tie stalls, or free stalls. This device has demonstrated that it can be used to estimate methane emissions in real time from sheep, cattle, and possibly other ruminants. Since the data are stored in the memory card, no samples are required to be immediately transferred to the lab, and data can be obtained quickly.

Although Chagunda and Yan (2011) revealed the positive outcomes of using LMD, the author also points out several challenges of using the technology. The first issue is extracting the methane emission data from the animal. Because ruminants are eructating methane from their mouths and respiring methane from their nostrils, the laser beam on the LMD is only measuring one of these emissions at a time. To compensate for this issue, it is suggested that both are measured over longer durations. Unlike respiration chambers, the LMD does not account for the 5–10 % methane emitted from the rectum (Johnson and Johnson 1995). Taking the above issues into account and measuring methane emissions every hour for 24 h in conjunction with documenting the animals' activities, this technique could become labor intensive.

13.13 Intraruminal Gas Measurement Device

As an alternative to using SF_6 tracers or respiration chambers to estimate enteric methane emissions from cattle on pasture, an intraruminal gas measurement device has been developed at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia. The proposed gas measurement device is capable of being housed in the rumen as it is impermeable to liquid and is swallowed by the ruminant as a bolus with a tubular body. When first swallowed, the device has wings that are held in position by dissolvable bands. Once in the stomach, the bands dissolve and the wings expand outward to prevent it from being expelled from the rumen. The bolus is permeable to gases and has gas sensors in the form of miniaturized infrared sensors that can detect the methane in the rumen. A controller is coupled to the gas sensor so that it can periodically process and output data that provides the amount of methane in the rumen (Wright et al. 2013). Although this device is not yet available, it is believed to be an alternative to the SF_6 tracers. The intra-stomach device is considered more desirable because it does not significantly impede the animal in its natural environment. Lastly, this device has an advantage in that it can be applied to a wide variety of ruminants (e.g., cattle, sheep, giraffes), while other methodologies are typically species specific.

13.14 Intergovernmental Panel on Climate Change (IPCC)

In 1988, the IPCC was created by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) to act as an international body to assess climate change (IPCC 2007). To estimate enteric methane emissions, the IPCC uses three tiers: tier 1, 2, and 3. In general, tier 1 is a less accurate approach for determining enteric methane emissions from different regions of the world and does not take into account variations in animal physiology production level (Yan et al. 2006). Instead, it relies on a default emission factor given in the *IPCC Guidelines* that is multiplied by the number of animals for each livestock group to calculate the total methane emissions. In the United States, all livestock excluding cattle are part of tier 1, and a less detailed approach is taken in comparison to tier 2.

The tier 2 method is more accurate and is country specific for countries that have large cattle and sheep populations and have documented records of diet and animal populations. An appropriate methane emission factor is determined and multiplied by the number of animals for each animal type. To do this, animal population data and animal and feed characteristics are needed. The latter are obtained either from a government organization like the Environmental Protection Agency (EPA) or from interviews of key people in the industry. In the United States, the EPA developed the Cattle Enteric Fermentation Model (CEFM) that divides the cattle population into subcategories. For dairy cattle, subcategories include calves, replacement heifers, and cows, while beef cattle subcategories include steers, bulls, cows, feedlot cattle, and calves (EPA 2010). Along with the subcategories, the specific diets are also analyzed, and the COWPOLL ruminant digestion model evaluates the methane conversion rates (Y_m) from respiration chambers that represent the gross energy converted to methane (EPA 2010; Montanholi et al. 2008).

Tier 3 also uses the Y_m calculations, but is a more complex method than tier 2. To be part of the tier 3 method, there needs to be a scientific documentation in an article published in an international journal.

13.15 Conclusion

Several different methane estimation methodologies exist, and choosing which one to utilize is dependent upon various factors such as cost, maintenance, accuracy, or the environment in which the ruminant lives in. With these methane emission estimation methodologies present, it is possible to calculate how much methane an individual ruminant or a herd is producing under specific diets, by certain species, or breed. Although this chapter highlighted several strategies used to estimate methane emissions from ruminants, new methodologies or improvements on the present methodologies will be created. Each methodology has its own advantages and disadvantages that need to be considered before use in an experiment and after experimental data are retrieved and interpreted.

References

Bhatta R, Enishi O, Kurihara M (2007) Measurement of methane production from ruminants. Asian-Australas J Anim Sci 20:1305–1318

Chagunda M, Yan T (2011) Do methane measurements from a laser detector and an indirect open-circuit respiration calorimetric chamber agree sufficiently closely? Anim Feed Sci Technol 165:8–14

Chagunda M, Ross D, Roberts D (2009) On the use of a laser CH_4 detector in dairy cows. Comp Electron Agric 68:157–160

Chagunda M, Ross D, Rooke J, Yan T, Douglaus J-L, Poret L, McEwan N, Teeranavattanakul P, Roberts D (2013) Measurement of enteric methane from ruminants using a hand-held laser methane detector. Acta Agric Scand Sect A Anim Sci 63:68–75

Ellis J, Kebreab E, Odonto N, McBride B, Okine E, France J (2007) Prediction of methane production from dairy and beef cattle. J Dairy Sci 90:3456–3467

EPA (2010) Inventory of U.S. greenhouse gas emissions and sinks: 1990–2010: Ch. 6 Agriculture. U.S. Environmental Protection Agency, Washington, DC

EPA (2013) U.S. Environmental Protection Agency: ruminant livestock. In: Methane sources emiss. http://www.epa.gov/rlep/faq.html

Getachew G, Robinson P, DePeters E, Taylor S, Gisi D, Higginbotham G, Riordan T (2005) Methane production from commercial dairy rations estimated using an in vitro gas technique. Anim Feed Sci Technol 123:391–402

Global Methane Emissions and Mitigation Opportunities (2014) In: Global Methane Initiative. www.global-methane.org/documents/analysis_fs_en.pdf

Grainger C, Clarke T, McGinn SM, Auldist MJ, Beauchemin KA, Hannah MC, Waghorn GC, Clark H, Eckard RJ (2007) Methane emissions from dairy cows measured using the sulfur hexafluoride (SF6) tracer and chamber techniques. J Dairy Sci 90:2755–2766

Huntington G, Cassady J, Gray K, Poore M, Whisnant S, Hansen G (2012) Use of digital infrared thermal imaging to assess feed efficiency in Angus bulls. Prof Anim Sci 28:166–172

IPCC (2007) Intergovernmental Panel on Climate Control Fourth Assessment Report. http://www.ipcc.ch/publications_and_data/ar4/wg2/en/ch15s15-3.html

Johnson K, Johnson D (1995) Methane emissions from cattle. J Anim Sci 73:2483–2492

Johnson K, Huyler M, Westberg H, Lamb B, Zlmmerman P (1994) Measurement of methane emissions from ruminant livestock using a SF6 tracer technique. Environ Sci Technol 28:359–362

Kelly JM, Kerrigant B, Milligan LP, Mcbride BW (1994) Development of a mobile, open-circuit indirect calorimetry system. Can J Anim Sci 74:65–71

Lee H, Lee S, Kim J, Oh Y, Kim B, Kim C, Kim K (2003) Methane production potential of feed ingredients as measured by in vitro gas test. Asian-Australas J Anim Sci 16:1143–1150

Lockyer D, Champion R (2001) Methane production by sheep in relation to temporal changes in grazing behaviour. Agric Ecosyst Environ 86:237–246

Lockyer D, Jarvis S (1995) The measurement of methane losses from grazing animals. Environ Pollut 90:383–390

Madsen J, Bjerg BS, Hvelplund T, Weisbjerg MR, Lund P (2010) Methane and carbon dioxide ratio in excreted air for quantification of the methane production from ruminants. Livest Sci 129:223–227

Mauricio RM, Mould FL, Dhanoa MS, Owen E, Channa KS, Theodorou MK (1999) A semi-automated in vitro gas production technique for ruminant feedstuff evaluation. Anim Feed Sci Technol 79:321–330

McClean J, Tobin G (1987) Animal and human calorimetry. Cambridge University Press, Cambridge

McGinn S, Beauchemin K, Iwaasa K, McAllister A (2006) Assessment of the sulfur hexafluoride tracer technique for measuring enteric methane emissions from cattle. J Environ Qual 35:1686–1691

Menke K, Raab L, Salewski A, Steingass H, Fritz D, Schneider W (1979) The estimation of the digestibility and metabolizable energy content of ruminant feeding-stuffs from the gas production when they are incubated with rumen liquor in vitro. J Agric Sci 93:217–222

Miller W, Koes R (1988) Construction and operation of an open-circuit indirect calorimetry system for small ruminants. J Anim Sci 66:1042–1047

Montanholi Y, Schenkel F, Miller S, Swanson K, Mandell I (2006) Infrared images taken in beef cows: repeatability of the measurements. In: Proceedings of the eighth world congress on genetics applied to livestock production

Montanholi Y, Swanson K, Miller S, Palme R, Schenkel F (2007) Relationship between residual feed intake and infrared thermography and glucocorticoid levels in feedlot steers from three different sire breeds. In: Proceedings of the Canadian Nutrition Congress, p 36

Montanholi YR, Odongo NE, Swanson KC, Schenkel FS, McBride BW, Miller SP (2008) Application of infrared thermography as an indicator of heat and methane production and its use in the study of skin temperature in response to physiological events in dairy cattle (*Bos taurus*). J Therm Biol 33:468–475

Murray R, Bryant A, Leng R (1976) Rates of production of methane in rumen and large-intestine of sheep. Br J Nutr 36:1–14

Odongo NE, AlZahal O, Las JE, Kramer A, Kerrigan B, Kebreab E, France J, McBride BW (2008) Data capture: development of a mobile open-circuit ventilated hood system for measuring real-time gaseous emissions in cattle. In: France J, Kebreab E (eds) Mathematical modeling in animal nutrition. CABI Publishing, Wallingford, pp 225–240

Ørskov ER, Flatt WP, Moe PW (1968) Fermentation balance approach to estimate extent of fermentation and efficiency of volatile fatty acid formation in ruminants. J Dairy Sci 51:1429–1435

Pell A, Schofield P (1993) Computerized monitoring of gas production to measure forage digestion in vitro. J Dairy Sci 76:1063–1073

Pinares-Patiño CS, Clark H (2008) Reliability of the sulfur hexafluoride tracer technique for methane emission measurement from individual animals: an overview. Aust J Exp Agric 48:223

Pinares-Patiño C, Holmes C, Lassey K, Ulyatt M (2008) Measurement of methane emissions from sheep by sulphur hexafluoride tracer technique and by the calorimetric chamber: failure and success. Animal 2:141–148

Place SE, Pan Y, Zhao Y, Mitloehner FM (2011) Construction and operation of a ventilated hood system for measuring greenhouse gas and volatile organic compound emissions from cattle. Animals 1:433–446

Poikalainen V, Praks J, Veermae I, Kokin E (2012) Infrared temperature patterns of cow's body as an indicator for health control at precision cattle farming. Agron Res 10:187–194

Sheppard J, Westberg H, Hopper J, Ganesan K, Zimmerman P (1982) Inventory of global methane sources and their production rates. J Geophys Res 87:1305–1312

Storm I, Hellwing ALF, Nielson NI, Madsen J (2012) Methods for measuring and estimating methane emission from ruminants. Animals 2:160–183

Tedeschi LO, Schofield P, Pell AN (2008) Determining feed quality for ruminants using in vitro gas production technique. Evaluating different models to assess gas production measurements. Fourth Work. Model Rumin Nutr Juiz de Fora 1–15

Turner H, Thorton R (1966) A respiration camber for cattle. Proc Aust Soc Anim Prod 6:413–419

Waghorn G, Garnet E, Pinares-Patiño C, Zimmerman S (2013) Implementation of GreenFeed for estimating methane in a dairy herd grazing pasture. Greenhouse gases from animal agriculture conference, Dublin, p 80

Wilkins J (1974) Pressure transducer method for measuring gas production by microorganisms. Appl Microbiol 27:135–140

Williams YJ, Popovski S, Rea SM, Skillman LC, Toovey AF, Northwood KS, Wright A-DG (2009) A vaccine against rumen methanogens can alter the composition of archaeal populations. Appl Environ Microbiol 75:1860–1866

Wolin MJ (1960) A theoretical rumen fermentation balance. J Dairy Sci 43:1452–1459

Wright A-DG, Kennedy P, O'Neill C, Toovey A, Popovski S, Rea S, Pimm C, Klein L (2004) Reducing methane emissions in sheep by immunization against rumen methanogens. Vaccine 22:3976–3985

Wright A-DG, Ellis K, Dempsey J, Overs L, Valencia P, Paull D, McSweeney C (2013) System, method, and device for measuring a gas in the stomach of a mammal. World Intellectual Property Organization. Patent: WO 2013/003892 A1

Yan T, Mayne C, Porter M (2006) Effects of dietary and animal factors on methane production in dairy cows offered grass silage based diets. Int Congr Ser 1293:123–126

Zimmerman P (1993) Measuring metabolic gas emissions from animals. US Patent 5,265,618, 30 Dec 1993

14

Metagenomic Approaches in Understanding the Rumen Function and Establishing the Rumen Microbial Diversity

K.M. Singh, M. Bagath, S.K. Chikara, C.G. Joshi,
and R.K. Kothari

Abstract

Livestock production in developing countries is subsidiary to plant agriculture. In tropical countries, ruminants are fed on lignocellulosic by-products like cereal straws, tree foliages, and cakes of oilseeds. The rumen harbors complex microbial communities which play a critical role in efficient utilization of such complex plant materials. The metagenome of the rumen is considered a determining factor for the efficiency of the particular digestive metabolism of ruminants as well as the accompanying environmental problems. Gene signature and biological fingerprinting of microorganisms present in ruminants is an important area of scientific research. Recent advances in the ruminant gut microbiology and genomics now offer new opportunities to conduct a more holistic examination of the structure and function of rumen ecology. The importance of rumen microbial signature and diversity of microorganisms in the ruminant forestomach has gained increasing attention in response to recent trends in global livestock production. Applied metagenomics has the potential for providing insight into the functional dynamics of the ruminomics database and will help to achieve a major goal of rumen ecosystem; microbial communities function and interact among these microbes as well as with the host. In this book chapter, we highlight recent studies of the buffalo rumen microbiome in rumen ecology, nutrition, animal efficiency, and microbial function.

K.M. Singh (✉) • S.K. Chikara
Xcelris Genomics, Xcelris Labs Ltd,
Ahmedabad, Gujarat, India
e-mail: kmsingh18@gmail.com

M. Bagath
Animal Nutrition Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi, Hosur
Road, Bangalore, Karnataka 560030, India

C.G. Joshi
Department of Animal Biotechnology,
College of Veterinary Science and Animal Husbandry,
Anand Agricultural University,
Anand 388001, Gujarat, India

R.K. Kothari
Department of Bioscience, Saurashtra University,
Rajkot 360 005, Gujarat, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_14, © Springer India 2015

Keywords

Microbiota • Rumen • 16S rRNA gene • 18S rRNA gene • Pyrosequencing • Shotgun

14.1 Introduction

Rumen microbial diversity is composed of bacteria, archaea, fungi, protozoa, and virus in definite proportions, based on various factors influencing the rumen ecosystem. Modification and changes in rumen microbial ecosystem have a major impact on meeting the challenge of reducing enteric methane emission in ruminant livestock as well as in enhancing production using the hydrogen sink. The stability and the dynamics of the rumen play a vital role in maintaining the balance within the rumen ecosystem. There exists equilibrium between the microbial community and their metabolism. The equilibrium is altered, when new feed type or new organisms enter into the rumen ecosystem. The change is possible only if the entering new microbes fit into the rumen environment, if not the microbes are eliminated. Rumen is anaerobic in nature; the feed particles in rumen trap small air pockets containing oxygen which are used by the facultative anaerobes ensuring perfect anaerobic condition. Rumen ecosystem diversity, anaerobiosis, pH, and various other factors make it difficult to culture the organism with the present technology. In tropical countries like India, where livestock production is subsidiary to plant agriculture, ruminants are fed on lignocellulosic by-products, tree foliages, and cakes of oilseeds. The efficiency of ruminants to utilize such a wide variety of feeds depends on the prevailing microbes like bacteria, ciliate protozoa, methanogens, anaerobic fungi, and bacteriophages (Dehority et al. 1997; Hespell et al. 1997; Klieve and Bauchop 1988; Klieve and Swain 1993). The synergetic and antagonistic effect on account of feeding different type of feeds makes it difficult to quantify the role played by any particular group of microbes among the consortia inside the rumen. The conventional technique of culture-dependent cloning gives a limited and biased knowledge about the prevailing rumen microbial population. The knowledge about the prevailing organism in the rumen and an insight of the rumen microbial changes during different conditions can be studied with the help of next-generation sequencing (NGS) technique – metagenomics. Recently metagenomics has emerged as a very powerful tool for microbial community analysis irrespective of individual microbial culturing conditions. Metagenomics isolates DNA from the whole community, to sequence and to analyze the obtained data to provide intervention, microbial understanding, therapeutic and biotechnological applications.

14.2 16SrRNA Sequencing Methodology

14.2.1 Bacterial Diversity in the Rumen

The small subunit 16S rRNA gene is most commonly chosen because of its highly conserved and variable regions, extensive database of reference sequences, and precedent set by previous work. Sequencing of 16S amplicons is currently limited by the capability of available sequencing platforms. Therefore, several variable regions are typically selected from the 16S rRNA gene. Bacterial communities in buffalo rumen were characterized using a culture-independent approach (Singh et al. 2010a). Buffalo rumen includes species of various bacterial phyla, hence 16S rDNA sequences were amplified and cloned from the sample. A total of 191 clones were sequenced and similarities to known 16S rDNA sequences were examined. About 62.82 % sequences (120 clones) had >90 % similarity to the 16S rDNA database sequences. Furthermore, about 34.03 % of the sequences (65 clones) were 85–89 % similar to 16S rDNA database sequences. For the remaining 3.14 %, the similarity was lower than 85 %. Phylogenetic analyses were also used to infer the makeup of bacterial communities in the rumen of Surti buffalo. The study distinguished 42 operational taxonomic units (OTUs) based on unique 16S rDNA sequences: 19 OTUs affiliated to an unidentified group (45.23 % of total OTUs); 11 OTUs of the phylum *Firmicutes*, also known as the low G+C group (26.19 %); 7 OTUs of the *Cytophaga–Flexibacter–Bacteroides* phylum (16.66 %); 4 OTUs of *Spirochaetes* (9.52 %); and 1 OTU of *Actinobacteria* (2.38 %). These include 10 single-clone OTUs, hence good coverage (94.76 %) of 16S rRNA libraries indicated that sequences identified in the libraries represent the majority of bacterial diversity present in ruminal fluid.

The microbiome of buffalo rumen plays an important role in animal health and productivity. The rumen bacterial composition of both liquid and solid fraction was surveyed using pyrosequencing of the 16S rRNA gene. Sequences were analyzed using taxonomy-dependent clustering methods and revealed that the dominant ruminal bacteria shared by all samples belonged to phyla *Bacteroidetes*, *Firmicutes*, *Fibrobacteres*, and *Proteobacteria*. The core rumen microbiome of the rumen consisted of 10 phyla, 19 classes, 22 orders, and 25 families. However, the relative abundance of these bacterial groups was markedly affected by diet composition as well as in type of biomaterial (liquid and solid). In animals fed with a green and dry roughage diet, the cellulolytic bacteria, *Ruminococcaceae* and *Fibrobacteraceae*, were found in highest abundance, in all biomaterials, which reflected the need for enhanced fiber-digesting capacity in buffalo. The polysaccharide-degrading *Prevotellaceae* bacteria were most abundant in buffalo rumen. In taxonomic comparison of rumen bacteria, about 26 genera were differentially abundant among liquid and solid fraction of ruminal fluid. These results highlight the buffalo ruminal microbiome's ability to adapt to feed with different composition.

14.2.2 Methanogen Diversity in the Rumen

The rumen is characterized by its high microbial population density and complexity of microecological interactions. Methane is biologically produced by the metabolism of the diverse group of methanogenic microorganisms.

They inhabit typical anaerobic environments, such as wetlands, sediments, geothermal springs, and the digestive tracts of mammals (Garcia et al. 2000). Methane is an important greenhouse gas which significantly contributes to global warming. Livestock is a major anthropogenic source of methane emission from agriculture and contributes about 18 % of the global greenhouse gas (GHG) emissions, and as much as 37 % of anthropogenic methane, mostly from enteric fermentation by ruminants (FAO 2009). Livestock rearing has been an integral part of the agricultural system in India. Currently, India possesses the world's largest livestock population of 485 million, which accounts for 13 % of the global livestock population (MOA 2003). It has 57 % of the world's buffalo and 16 % of the cattle population. Contribution of methane emission in India by buffalo is 42 % (Chhabra et al. 2009).

Several species of methanogens have been isolated from ruminants, but few have been consistently found in high numbers (Stewart et al. 1997), and it is likely that major species of rumen methanogens are yet to be identified (Rocheleau et al. 1999; Wright et al. 2004). The most common species of methanogens isolated from the rumen are strains of *Methanobrevibacter*, *Methanomicrobium*, *Methanobacterium*, and *Methanosarcina* (Wright et al. 2004; Jarvis et al. 2000). Methanogens are difficult to study through culture-based methods, and therefore many researchers have instead used culture-independent techniques to study methanogen populations. The 16S rRNA gene is the most widely used target for gene surveys, and a number of primers and probes have been developed to target methanogen groups (Purdy et al. 2003; Saengkerdsub et al. 2007; Shin et al. 2004; Tatsuoka et al. 2004). Methanogens are frequently found in association with protozoa (Tajima et al. 2001; Sizova et al. 2003).

Methane emissions from ruminant livestock are considered to be one of the most potent forms of greenhouses gases contributing to global warming. Many strategies to reduce emissions are targeting the methanogens that inhabit the rumen, but such an approach can only be successful if it targets all the major groups of ruminant methanogens. Therefore, a basic knowledge of the diversity of these microbes in different breeds of buffalo is required. Singh et al. (2010b) studied the methanogenic community in rumen of Surti buffaloes by using PCR amplification, cloning, and sequencing of methyl coenzyme M reductase (mcrA) gene. A total of 76 clones were identified revealing 14 different sequences (OTUs). All 14 sequences were similar to methanogens belonging to the order Methanobacteriales. Within Methanobacteriales, six OTUs (12 clones) were similar to *Methanosphaera stadtmanae*, seven OTUs (63 clones) were similar to unclassified Methanobacteriales, and the remaining one OTU (1 clone) belonged to unknown methanogen. Overall, members of the Methanobacteriales dominated the mcrA clone library in the rumen of Surti buffalo. Further studies and effective strategies can be made to inhibit the growth of Methanobacteriales to reduce the methane emission from rumen which would help in preventing global warming.

In another study, the methanogenic communities in rumen were characterized using a culture-independent method. 16S rDNA sequences were amplified and cloned from the sample. A total of 171 clones were sequenced to examine 16S rDNA sequence similarity. About 52.63 % sequences (90 clones) had ≥90 % similarity, whereas 46.78 % of the sequences (81 clones) were 75–89 % similar to 16S rDNA database sequences, respectively. Phylogenetic analyses were also used to infer the makeup of methanogenic communities in the rumen of Surti buffalo. The study distinguished 23 operational taxonomic units (OTUs) based on unique 16S rDNA sequences: 12 OTUs (52.17 %) affiliated to Methanomicrobiales order, 10 OTUs (43.47 %) of the order Methanobacteriales, and one OTU (4.34 %) of *Methanosarcina barkeri*-like clone, respectively. In addition, the population of Methanomicrobiales and Methanobacteriales orders was also observed, accounting for 4 and 2.17 % of total archaea. This study has revealed the largest assortment of hydrogenotrophic methanogen phylotypes ever identified from rumen of Surti buffaloes (Singh et al. 2012a).

14.3 Assessment of Protozoa Rumen Based on 18S rDNA Sequences

Protozoa are unicellular eukaryotic microorganisms which are ubiquitous in nature and human-made environment. The rumen ciliates are potentially an agriculturally important group of protozoa found in domestic and wild ruminants (Williams and Coleman 1992). Compared to other ecosystems, little information is available on protozoa in buffalo rumen. The relative lack of information on ruminal protozoa may be due to difficulties in isolation, culture, or maintenance. Rumen isolates often lose viability for unknown reasons during purification or subculturing of pure isolates. More than 42 genera of ruminal protozoa have been described based on cultivation and morphological studies (Williams 1986; Dehority 1993). Most genera are representatives of typical bovine rumen populations, viz., *Entodinium*, *Diplodinium*, *Eudiplodinium*, *Ostracodinium*, *Metadinium*, *Enoploplastron*, *Polyplastron*, *Epidinium*, *Ophryoscolex*, *Isotricha*, and *Dasytricha* (Karnati et al. 2003).

The molecular diversity of rumen protozoa in Surti buffalo (*Bubalus bubalis*) was investigated using 18S rRNA gene library prepared from the pooled sample of rumen fluid from three adult animals. A total of 172 clones were sequenced and similarities to known 18S rDNA sequences were examined. About 12 OTUs had ≥91 % similarity to 18S rDNA data sequences. Furthermore, about 27 OTUs of the sequences were 86–90 % similar to 18S rDNA database sequences, and for the remaining 14 OTUs, the similarity was less than 85 %. Phylogenetic analyses were also used to infer the makeup of protozoal communities in the rumen of Surti buffalo. As a result, 40 OTUs (123 of 172 clones) belonged to Entodiniomorphid protozoa, indicating that this group is the most dominant component of protozoal populations in Surti buffaloes (*Bubalus bubalis*). 12 OTUs (45 clones) belonged to the Holotrich protozoa. Among Holotrich, 12 clones isolated from rumen fluid fell into two species identified as *Dasytricha ruminantium*-like clone (7 clones) and *Isotricha prostoma*-like clone (5 clones). One OTU (4 clones) belonged to the Haptorida protozoa (Singh et al. 2013a).

14.4 Real-Time PCR Technique in Determination of Microbes in Rumen

14.4.1 Bacterial Community

The digestion of plant material and subsequent conversion for energy requirements of the host ruminant are performed through a complex symbiotic relationship of microbiota with the rumen (Mackie 1997). The composition and proportion of microorganisms are influenced by external factors, such as diet, feeding frequency, age, geographical location, and ruminant–host interaction (Hungate 1969). Bacteria are considered important for the biological degradation of dietary fibers due to their fibrolytic activity and biomass in the rumen. Although fibrolytic species such as *Fibrobacter succinogenes*, *Ruminococcus albus*, and *Ruminococcus flavefaciens* play a key role in plant fiber degradation (Forsberg et al. 1997), positive interactions between them and non-fibrolytic bacteria such as *Selenomonas ruminantium* and *Treponema bryantii* have been reported (Kudo et al. 1987). In an early study, the synergism between *R. flavefaciens* and *S. ruminantium* was suggested to enhance propionate production (Scheifinger and Wolin 1973). Sawanon and Kobayashi in the year 2006 reported that fiber digestibility and propionate production significantly increased in coculture of *R. flavefaciens* and *S. ruminantium* compared to monoculture of *R. flavefaciens*. These findings indicate that non-fibrolytic bacteria may also be important to facilitate plant fiber degradation in the rumen.

In milk industry in India, buffalo breeds are most commonly used for milk production. Efficiency of fiber digestion in ruminants is critical for animal productivity. Bacteria play an important role in fiber digestion and utilization. Assessment of bacterial population size needs to be characterized further. Traditional methods for enumerating microbial populations within the buffalo rumen can be time-consuming and cumbersome. Real-time PCR approach was used to determine the population of major ruminal microbial species (fibrolytic bacteria and non-fibrolytic bacteria) present in rumen fluid of Surti buffalo fed with green fodder, dry roughage, and compound concentrate mixture. Among the cellulolytic bacterial species considered to be the major ones in the rumen, *Ruminococcus albus* is the dominant cellulolytic bacterial representative in Indian buffalo, accounting for 5.66 % of total bacteria. In non-fibrolytics, *Streptococcus bovis* was prevalent accounting for 0.11 % of total bacteria (Singh et al. 2013b).

A study was conducted to determine the major bacterial population present in rumen microbiota with respect to different diet using qPCR. Animals were acclimatized to a diet of roughage-to-concentrate ratio in the proportion of 100:00 (T1), 75:25 (T2), 50:50 (T3), and 25:75 (T4), respectively, for 6 weeks. At the end of each treatment, rumen fluid was collected at 0 and 2 h after feeding. It was found that among fibrolytic bacteria, *R. flavefaciens* (2.22×10^8 copies/ml) were highest in T2 group, followed by 1.11×10^8 copies/ml for *F. succinogenes* (T2), 2.56×10^7 copies/ml for *Prevotella ruminicola* (T1), and 1.25×10^7 copies/ml for *Ruminococcus albus* (T4). In non-fibrolytic bacteria, the *Selenomonas ruminantium* (2.62×10^7 copies/ml) was predominant in group T3, followed by *Treponema bryantii* (2.52×10^7 copies/ml), *Ruminobacter amylophilus* (1.31×10^7 copies/ml) in group T1, and *Anaerovibrio lipolytica* (2.58×10^6 copies/ml) in group T4, respectively. It is most notable that *R. flavefaciens* were the highest in population in the rumen of Surti buffalo fed on wheat straw as roughage source (Singh et al. 2014a).

14.4.2 Protozoa

The genetic diversity of protozoa in Surti buffalo rumen was studied by amplified ribosomal DNA restriction analysis, 18S rDNA sequence homology, and phylogenetic and real-time PCR analysis methods. Three animals were fed on a diet comprised of green fodder Napier bajra 21 (*Pennisetum purpureum*), mature pasture grass (*Dichanthium annulatum*), and concentrate mixture (20 % crude protein, 65 % total digestible nutrients). A protozoa-specific primer (P-SSU-342f) and a eukaryote-specific primer (Medlin B) were used to amplify a 1,360 bp fragment of DNA encoding protozoal small subunit (SSU) ribosomal RNA from rumen fluid. A total of 91 clones were examined, and 14 different 18S RNA sequences based on PCR–RFLP pattern were identified. These 14 phylotypes were distributed into four genera-based 18S rDNA database sequences and identified as *Dasytricha* (57 clones), *Isotricha* (14 clones), *Ostracodinium* (11 clones), and *Polyplastron* (9 clones). Phylogenetic analyses were also used to infer the makeup of protozoal communities in the rumen of Surti buffalo. Out of 14 sequences, 8 sequences (69 clones) were clustered with the *Dasytricha ruminantium-like* clone, and 4 sequences (13 clones) were also phylogenetically placed with the *Isotricha prostoma*-like clone. Moreover, 2 phylotypes (9 clones) were related to Polyplastron multivesiculatum-like clone. In addition, the number of 18S rDNA gene copies of *Dasytricha ruminantium* (0.05 % to ciliate protozoa) was higher than *Entodinium* sp. (2.0 9 105 vs. 1.3 9 104) in per ml ruminal fluid (Singh et al. 2011).

14.4.3 Methanogens

Interest in ruminal methanogen is on account of the role of methane in global warming and from the fact that enteric methane emission is a major source of greenhouse gas in agriculture sector. India possesses the world's largest livestock population of 485 million, which accounts for 13 % of the global livestock population.

High roughage diet causes more methane emissions; however, the total methanogen abundance is not influenced by roughage proportion. Technologies to reduce methane emissions are lacking, and development of inhibitors and vaccines that mitigate rumen-derived methane by targeting methanogens relies on present knowledge of the methanogens. In this work, the molecular diversity of rumen methanogens of Surti buffalo was investigated. DNA from rumen fluid was extracted, and 16S rRNA-encoding genes were amplified using methanogen-specific primer to generate 16S rDNA clone libraries. Seventy-six clones were randomly selected and analyzed by RFLP resulting in 21 operational taxonomic units (OTUs). BLAST analysis with available sequences in database revealed sequences of 13 OTUs (55 clones) showing similarity with *Methanomicrobium* sp. and 3 OTUs (15 clones) with *Methanobrevibacter* sp. The remaining 5 OTUs (6 clones) belonged to uncultured archaea. The phylogenetic analysis indicated that methanogenic communities found in the library were clustered in the order of Methanomicrobiales (18 OTUs) and Methanobacteriales (3 OTUs). The population of Methanomicrobiales, Methanobacteriales, and Methanococcales were also observed, accounting for 1.94 %, 0.72 %, and 0.47 % of total archaea, respectively (Singh et al. 2014b).

14.5 High-Throughput Whole Rumen Microbiome

The complex microbiome of the rumen functions as an effective system for the conversion of plant cell wall biomass to microbial proteins, short-chain fatty acids, and gases. In this study (Singh et al. 2012b), metagenomic approaches were used to study the microbial populations and metabolic potential of the microbial community. DNA was extracted from Surti buffalo rumen samples (four-treatment diet) and sequenced separately using a 454 GS FLX Titanium system. Comparative metagenomics was used to examine metabolic potential and phylogenetic composition from pyrosequence data generated in four samples; considering phylogenetic composition and metabolic potentials in the rumen may remarkably be different with respect to nutrient utilization.

The sequencing of the genomes from several hundred microbial and numerous eukaryotic species has laid the foundation for generating genomic sequence data from whole environments avoiding a culturing step. This approach, also known as "metagenomics," is defined as the genomic analysis of microorganisms by direct extraction and cloning of DNA from an assemblage of microorganisms (Handelsman 2004). Pyrosequencing is the base for a promising new-generation sequence technology developed by 454 Life Sciences Technologies (http://www.454.com/) (Margulies et al. 2005) and is now being applied to metagenomics. One approach has been the use of the pyrosequence technology to increase the depth of SSU rDNA surveys by sequencing amplicons from the variable region of the SSU molecule. This has been applied to ocean microbial samples (Sogin et al. 2006), soils (Roesch et al. 2007), and human (Larsen et al. 2010). The second approach uses random sample pyrosequencing to generate environmental gene tags (EGTs) and protein families (Tringe et al. 2005) from microbiomes. This approach, applied to environmental biomes (Edwards et al. 2007), allows one to highlight significant differences in metabolic potential in each environment.

14.6 Resistome Analysis in Rumen

The increasing occurrence of antibiotic-resistant bacteria has become a notorious threat to human health. Bacteria become resistant through resistance genes that can move between cells using horizontal gene transfer. Since antibiotics are naturally produced by microorganisms in the environment, therefore, bacterial communities maintain a large collection of resistance genes called the resistome. The resistome, therefore, is a complex array of genes, and they function directly or indirectly to block the activity of antibiotics.

There is a concern that antibiotic resistance can potentially be transferred from animals to humans through the food chain. The relationship between specific antibiotic-resistant bacteria and the genes they carry is yet not studied. Little details are known about the ecology of antibiotic resistance genes and bacteria in food production systems or how antibiotic resistance genes in food animals can be compared to antibiotic resistance genes in other ecosystems.

World consumers and producers, including India, are increasingly aware of concerns over antibiotic resistance in food. In animal agriculture, the specific concern is that the use of antibiotics in food animals promotes the growth of antibiotic-resistant bacteria that can then be transferred to humans via food processing and distribution systems (Collignon et al. 2009).

The gastrointestinal tract is an open system, which every day encounters a myriad of bacterial acquisitions originating from the environment (e.g., from food, water, soil, and other humans or animals; Baquero 2012). These incoming bacteria often harbor antibiotic resistance genes. In the case of opportunistic pathogens of environmental or food-borne origin, such antimicrobial-resistant (AMR) bacteria can pose a direct threat to the host. Alternatively, these incoming microbes might transfer their resistance elements through horizontal gene transfer (HGT) to the indigenous microbial communities. HGT can occur between different species and genera, and as such between commensals and (opportunistic) pathogens.

Application of metagenomic functional selections to study antibiotic resistance genes is revealing a highly diverse and complex network of genetic exchange between bacterial pathogens and environmental reservoirs, which likely contributes significantly to increasing resistance levels in pathogens. In some cases, clinically relevant resistance genes have been acquired from organisms where their native function is not antibiotic resistance and which may not even confer a resistance phenotype in their native context (Singh et al. 2012c).

Reddy et al. (2014) studied the rumen microbiota to understand the presence of mobilome, resistome, and stress responses in the rumen ecology. However, knowledge of metagenomic responses to such conditions is still rudimentary. On the analysis of metagenomes of buffalo rumen in the liquid and solid phase of the rumen biomaterial, from river buffalo, using high-throughput sequencing to know the occurrence of antibiotic resistance genes, genetic exchange between bacterial population and environmental reservoirs showed adaption to varying proportions of concentrate to green or dry roughages. A total of 3,914.94 MB data were generated from all three treatment groups. The data were analyzed with metagenome rapid annotation system tools (MGRAST). At the phylum level, *Bacteroidetes* were dominant in all the treatments followed by *Firmicutes*. Genes coding for functional responses to stress (oxidative stress and heat shock proteins) and resistome genes (resistance to antibiotics and toxic compounds (RATC), phages, transposable elements, and pathogenicity islands) were prevalent in similar proportion in liquid and solid fraction of rumen metagenomes. The fluoroquinolone resistance, MDR efflux pumps, and methicillin resistance genes were broadly distributed across 11, 9, and 14 bacterial classes, respectively. Bacteria responsible for phage replication and prophage and phage packaging and rlt-like streptococcal phage genes were mostly assigned to phyla *Bacteroides*, *Firmicutes*, and *Proteobacteria*. Also, more reads matching the sigma B genes were identified in the buffalo rumen. This study underscores the presence of diverse mechanisms of adaptation to different diet, antibiotics, and other stresses in buffalo rumen, reflecting the proportional representation of major bacterial groups.

14.7 Metagenome Analysis of Dormancy and Sporulation Genes in Rumen

Bacteria have the ability to adapt to different growth conditions and to survive in various environments. They also have capacity to enter into dormant states. Some bacteria form spores when exposed to stresses such as starvation and oxygen deprivation (Bhupender et al. 2010). Endospores are dormant, nonreproductive, and enzymatically inert forms of bacterial vegetative cells. Endospore-producing bacteria are also conventionally termed as "sporulating bacteria" (Cano and Borucki 2012).

The spores serve to protect the bacterium from harmful environmental conditions by reducing into a desiccated, cryptobiotic, and highly defensive state, which provides resistance to many environmental conditions that would otherwise harm and kill the vegetative form of the bacterium. These environmental conditions include extreme temperatures, radiation, extreme pH levels, extreme pressures, and harmful chemical agents (Cano and Borucki 2012). Breaking of the dormant state of bacterial spores is the initiating event in germination. Glucose, certain amino acids, nucleosides, and even salts are among the many agents which induce initiation; however, the mechanism is not understood (Woese et al. 1968). Uncultured bacteria are predicted to be a significant reservoir of novel small-molecule biosynthetic machinery (Brady et al. 1998; Rondon et al. 2000). Functional metagenomics is one of the approaches by which one can access the biosynthetic potential contained within the genomes of uncultured bacteria (Brady et al. 1998). Despite of the importance of the rumen microbial population to host health and productivity, knowledge about dormancy and sporulation and cell wall and capsule genes of bacteria remains relatively rudimentary.

Buffalo rumen microbiome experiences a variety of diet stress and represents a reservoir of dormancy and sporulation genes. However, the information on genomic responses to such conditions is very limited. The Ion Torrent PGM next-generation sequencing technology was used to characterize general microbial diversity and the repertoire of microbial genes present, including genes associated with dormancy and sporulation in Mehsani buffalo rumen metagenome. The research findings revealed the abundance of bacteria at the domain level and presence of dormancy and sporulation genes which were predominantly associated with the *Clostridia* and *Bacilli* taxa belonging to the phylum *Firmicutes*.

Genes associated with sporulation cluster and sporulation orphans were increased from 50 to 100 % roughage treatment, thereby promoting sporulation all along the treatments. The spore germination is observed to be the highest in the 75 % roughage treatment both in the liquid and solid rumen fraction samples with respect to the decrease in the values of the genes associated with spore core dehydration, thereby facilitating spore core hydration which is necessary for spore germination (Singh et al. 2014c).

14.8 Biomass Degradation Enzyme Discovery from Rumen

Singh et al. (2014d) identified many biomass degradation enzymes from buffalo rumen. The complex microbiome of the rumen functions as an effective system for plant cell wall degradation and biomass utilization and provides genetic resource for degrading microbial enzymes that could be used in the production of biofuel. Therefore, the buffalo rumen microbiota was surveyed using shotgun sequencing. This metagenomic sequencing generated 3.9 GB of sequences, and data were assembled into 137,270 contiguous sequences (contigs). A potential 2,614 contigs encoding biomass-degrading enzymes including glycoside hydrolases (GH: 1,943 contigs), carbohydrate-binding module (CMB: 23 contigs), glycosyltransferase (GT: 373 contigs), carbohydrate esterases (CE: 259 contigs), and polysaccharide lyases (PE: 16 contigs) were identified in the study. The hierarchical clustering of buffalo metagenomes demonstrated the similarities and dissimilarity in microbial community structures and functional capacity. This demonstrates that buffalo rumen microbial metagenome is considerably enriched in functional genes involved in polysaccharide degradation with great prospects to obtain new molecules that may be applied in the biofuel industry.

Livestock production in India is subsidiary to plant production. In tropical countries, the ruminants are fed on lignocellulosic agricultural by-products. Ruminants digest such plant materials by virtue of the extensive microbial community (Pope et al. 2012; Miron et al. 2001), which are found in the rumen and provide the host with nutrients, predominantly in the form of volatile fatty acids and microbial protein (Jami and Mizrahi 2012). The rumen habitat contains a consortium of microorganisms that harbor the complex lignocellulosic degradation system for the microbial attachment and digestion of plant biomass. However, the complex chemical processes required to break down the plant cell wall are rarely carried out by a single species. Evidence also suggests that the most important organisms and gene sets involved in the most efficient hydrolysis of plant cell wall are associated with the fiber portion of the rumen digesta (Forsberg and Lam 1977). Plant cell walls have a basic structure of cellulose surrounded by a complex matrix of hemicellulose, pectin, and protein (Cosgrove 2005). *Ruminococcus flavefaciens*, *Ruminococcus albus*, *and Fibrobacter succinogenes* are considered to be the most important cellulose-degrading bacteria in the rumen (Flint et al. 2008), and they produce a set of cellulolytic enzymes, including endoglucanases, exoglucanases, glucosidases, as well as hemicellulases. In addition, the predominant ruminal hemicellulose-digesting bacteria such as *Butyrivibrio fibrisolvens* and *Prevotella ruminicola* degrade xylan and pectin and utilize the degraded soluble sugars as substrates (Flint et al. 2008). In recent years, rumen metagenomics studies have revealed the vast diversity of fibrolytic enzymes, multiple domain proteins, and the complexity of microbial composition in the ecosystem (Hess et al. 2011; Brulc et al. 2009). The glycoside hydrolases (GHs) are modular enzymes that hydrolyze glycosidic bonds of carbohydrates, with classification based on amino acid sequence and predicted three-dimensional structure. Such enzymes may contain single or multiple catalytic modules (GH) together with single or multiple non-catalytic carbohydrate-binding modules (CBMs) (Cantarel et al. 2009). Conversely, hitting upon the polysaccharide-degrading enzyme machineries from metagenomic data is scarce (Bera-Maillet et al. 2005; Qi et al. 2011). The microbes present in the rumen cannot be cultured; moreover, if cloning is opted, enormous screening of clones will be required for covering the entire metagenome (Tilman et al. 2009; Qi et al. 2011). However, there are limitations to metagenome mining (Henne et al. 1999), and the number of clones needed to represent the entire metagenome is staggering (Handelsman et al. 1998). It has been reported that the nature of diet is one of the factors that shapes the composition of the gut microbiota (Thomas et al. 2011). Therefore, in order to improve the digestibility, the modulations of microbial consortia have also been attempted by dietary interventions (Calsamiglia et al. 2007; Stiverson et al. 2011).

Next-generation sequencing technologies have been used to characterize the microbial diversity and functional capacity of a range of microbial communities in the gastrointestinal tracts of humans (Gill et al. 2006; Turnbaugh et al. 2009) as well as in several animal species (Qu et al. 2008; Swanson et al. 2011; Lamendella et al. 2011; Tun et al. 2012; Xu et al. 2013).

The bovine rumen provides a unique genetic resource for the discovery of plant cell wall-degrading microbial enzymes (CAZymes) for use in biofuel production, presumably because of coevolution of microbes and plant cell wall types (Hess et al. 2011). Identification of potent cellulolytic and other carbohydrate-active enzymes is of great interest for industrial applications (Tilman et al. 2009).

Livestock play an essential role in the economy of developing countries like India. Livestock production has been shown to make an important contribution to national economies as well as to increasing incomes and security at the community and individual levels. About 70 % of the world's 1.4 billion extreme poor population depends, at least in part, on livestock for their livelihood (FAO 2009). Proper feed and feeding is imperative for achieving high and sustained livestock productivity. The success of animal reproduction and health programs rests on proper animal nutrition and digestion. Proper animal nutrition could play an important role in addressing ongoing and emerging challenges imposed by increasing human population and global warming. The importance of rumen microbial ecology has gained increasing attention in response to livestock production. The microorganisms in the digestive tracts of ruminant livestock have a profound influence on the conversion of feed into end products which can impact on the animal health. In developing countries like India, there will be an increasing need to understand these processes for better management and use of both the feed base and other natural resources that underpin the development of sustainable feeding systems. Metagenomics is a rapidly growing field of research that aims at studying uncultured organisms to understand the true diversity of microbes, their functions, cooperation, and evolution, in environments such as soil, water, ancient remains of animals, or the digestive system of animals and humans (Huson et al. 2009).

Applied metagenomics which can be used to characterize complex microbial communities and their potential without incubation are now being employed regularly in ruminant nutrition studies. Conventional culture-based methods for enumerating rumen microorganisms have been superseded and are now used mainly to obtain pure isolates of novel organisms. The foundation of the molecular ecology techniques is RNA gene sequence analysis which has provided a phylogenetically based classification scheme for enumeration and identification of microbial community members. The use of this marker gene in assays involving the use of single nucleic acid probes or primer sets is rapidly evolving to high-throughput approaches such as microarray analysis and new-generation sequencing technologies. While these analyses are very informative for determining the composition of the microbial community and monitoring changes in population size, they can only infer function based on these observations. The focus of nucleic acid research is now shifting to the functional analysis of the ecosystem which involves the measurement of functional genes and their expression in the predominant or specific members of the rumen microbial community. Functional gene studies are less developed than 16S rDNA-based analysis of community structure. Also for gene expression studies, there are inherent problems involved in extracting high-quality RNA from digesta and priming cDNA synthesis from bacterial mRNA.

Many of the biotechnological approaches employed in the rumen focused on direct genetic modification of microbes to enhance processes like cell wall digestion, toxin degradation, and the balance of nutrients delivered to the ruminant. To date, the most significant contribution of biotechnology has been to define the diversity, density, and dynamics of the ruminal ecosystem which was previously a little possible using traditional culture techniques. Modern techniques have identified myriad genes encoding a variety of unique enzyme activities, many of which may have potential applications in livestock production and industry. Undoubtedly, gene discovery will continue to accelerate as genome sequencing of cultivated rumen bacteria continues and uncultivated genomes become available with the production of metagenome libraries. Such approaches may provide detailed knowledge of ruminal enzyme systems, the absence of which has hampered rumen scientists in solving challenges such as improving the digestion of low-quality forages and the efficiency of ruminal nitrogen utilization. Comparative and metagenomics and metatranscriptomics are providing a clear-cut idea of complete dynamics of microbiota, host interaction, and functions. Next-generation sequencing technologies are playing an important role in animal nutrition for solving biological problems in dairy industry worldwide.

The rumen provides a unique genetic resource for the discovery of plant cell wall-degrading microbial enzymes for use in biofuel production, presumably because of coevolution of microbes and plant cell wall types. It is well studied that microbial community inhabiting in the rumen is characterized by its high population density, wide diversity, and interactive complexity (Duan et al. 2009). This microbial community is responsible for the bioconversion of lignocellulosic feeds into volatile fatty acids (Kamra 2005). The goal of rumen biotechnologists is to manipulate the ruminal microbial ecosystem to improve the efficiency of feed. It is well known that biotechnology has a continuous demand for novel genes and enzymes and compounds (Christel et al. 2007).

14.9 Metagenomics to Improving Animal Productivity

Many animals across a wide range of orders have a portion of their digestive tract adapted to accommodate a microbial population which aids in digestion and provides a variety of nutritional and health benefits. These complex microbes form a closely integrated ecological unit with each other and the host animal as well as play a vital role in the nutritional, physiological, immunological, and protective functions of the host. The rumen is one of the most extensively studied and well-documented gut ecosystems because of the importance of ruminants to human nutrition and the major role played by rumen microbes in nutrition of the ruminant animal.

Fiber Digestion

The degradation of plant cell walls by ruminants is of major economic importance in the developed as well as developing countries. Plant cell wall hydrolysis is carried out by specialist bacteria (*Ruminococcus* and *Fibrobacter*), ciliate protozoa, and anaerobic fungi. Cellulase enzyme systems are complex and have a number of endo- and exocellulases, cellodextrinases, and β-glucosidase activities. The first step in the degradation of an insoluble substrate, such as the plant cell wall or cellulose, is attachment, and factors that regulate this are under investigation. Also, molecular mechanisms involved in adherence of fiber-degrading bacteria and their enzymes to insoluble substrates are being determined (Morgavi et al. 2012).

Determination of Biomass

Important application of microbial metagenomics in animal nutrition is the quantitative determination of total rumen microbial biomass and differentiating the bacterial and protozoal biomass. Rapid profiling procedures, such as real-time PCR assay, can be used to infer likely differences in community structure of bacteria and archaea present in animals and times after feeding diets.

Starch and Pectin Degradation

Starch is rapidly and extensively degraded in the rumen. Starch granules are rapidly engulfed by the Entodiniomorphid protozoa and converted to an iodophilic storage polymer, as are soluble sugars by the Holotrich protozoa. Degradation of dietary starch by bacteria, protozoa, and fungi occurs by combined activity of debranching, α-linked endoand exoamylase, and glucosidase enzymes. Maltodextrins and glucose are the products of enzymatic starch hydrolysis. Pectin is hydrolyzed by pectin esterase and polygalacturonase enzymes of bacteria and protozoa. Anaerobic fungi are weakly pectinolytic.

Ruminal Nitrogen Metabolism

A better understanding of mechanistic process altering the production and uptake of amino nitrogen will help the livestock nutritionists to improve the overall conversion of dietary nitrogen into microbial protein. It will provide key information needed to further improve the mechanistic models describing the rumen function and evaluating dietary conditions that influence the efficiency of conversion of dietary nitrogen into milk protein (Firkins et al. 2007).

Rumen Lipolysis and Biohydrogenation

Despite the fact that the ruminant diet is rich in polyunsaturated fatty acids (PUFA), ruminant products – meat, milk, and dairy – contain mainly saturated fatty acids (SFA) because of bacterial lipolysis and subsequent biohydrogenation of ingested PUFA in the rumen. In contrast, ruminant products also contain fatty acids that are known to be beneficial to human health, namely, conjugated linoleic acids (CLAs). The metagenomes of research in this field have been to understand the microbial ecology of lipolysis and biohydrogenation and to find ways of manipulating ruminal microbes to increase the flow of PUFA and CLA from the rumen into meat and milk. The quantity and composition of dietary lipids have a major effect because of the FA that escape ruminal metabolism. FA may also have a direct manipulating effect, however, whereby they inhibit biohydrogenation. Biohydrogenation is affected indirectly too when other activities are changed, because FA metabolism is inextricably linked to other areas of ruminal metabolism, through a common reliance on H_2 metabolism and/or the microbial species that are involved in multiple metabolic processes (Lourenço et al. 2010).

Rumen Microbes of Animals Fed with Phenol-Rich Forage

The most complete description of a ruminal microbial response to a plant secondary compound like tannin-rich diets (Makkar et al. 1995). Recent research has therefore focused on the inhibitory effects of condensed tannins on microbial populations, their mode of action, and the adaptive responses of the ruminal community to these compounds (Molan et al. 2001). Metagenome studies have confirmed that Gram-negative bacteria groups (*Enterobacteriaceae* and *Bacteroides* species) predominate in the presence of dietary tannins and that there is a corresponding decrease in the Gram-positive *Clostridium leptum* group and other Gram-positive bacteria (Smith and Mackie 2004).

Increasing the performance of the dairy cow milk production remains a priority for research. The global demand for dairy is steadily rising. With increases in population, incomes, and urbanization, the demand in developing countries such as India and China is particularly strong (Gerosa and Skoet 2012). Also greenhouse gas emissions from livestock are an environmental problem worldwide, which may be intensified with increases in milk production, so any strategy employed must strike the right balance between food production and greenhouse gas emissions. Methanogenesis in the rumen is a result of some forms of interspecies hydrogen transfer, whereby the methanogens can remove gaseous forms of hydrogen (H_2) produced during the anaerobic schemes of fermentation used by many heterotrophic bacteria. This maintains a relatively low partial pressure of H_2 (pH_2) within the rumen, which allows the fermentative bacteria to continue to use fermentative processes that yield ATP. Numerous feeding trials with various feed additives that reduce methanogenesis have also offered promising evidence that gain in ruminant (Moate et al. 2011). Therefore, looking for differences in microbial populations, which may be linked to changes in the feed conversion efficiency (FCE) or their methane emissions, gives us the opportunity to find rumen phenotypes that identify more efficient and productive animals (Wallace et al. 1997). Bacteria dominate in the rumen and play the most important role in converting ingested feed to nutrients into acetic, propionic, and butyric acids that can be assimilated by the ruminant hosts. Cellulolytic bacteria are the focus of many studies on the ruminal microbiome because degradation of cellulose, which is recalcitrant, is often the limiting step in feed digestion. *Fibrobacter succinogenes*, *Ruminococcus albus*, and *R. flavefaciens* are major cellulolytic bacteria present in the rumen. Strains tested of *F. succinogenes* degrade fiber and even crystallize cellulose more actively than those of *R. albus* or *R. flavefaciens* (Kobayashi et al. 2008). *Ruminococcus flavefaciens*, which is a Gram-variable and coccus-shaped anaerobe, produces a yellow pigment and is more abundant than *R. albus* (Kongmun et al. 2010; Mosoni et al. 2011).

14.10 Conclusion

In this book chapter, we provided a concise note on current research on rumen microbiome especially in Indian buffalo. The rumen is swarm with high abundant and diverse microbial community. The rumen microbiome is the fingerprinting factor of all ruminants, and improved understanding of this complex community will lead to more efficient animal production. Advancing nucleic acid-based technology has redefined our ability to describe the rumen microbiome and created new opportunities to investigate the complex relationships and niches within the microbial community. However, we are lagging behind in the development of bioinformatics and biostatistics tools that enable us to perform correlations between them.

References

Baquero F (2012) Metagenomic epidemiology: a public health need for the control of resistance. Clin Microbiol Infect 18:67–73

Bera-Maillet C, Devillard E, Cezette M, Jouany JP, Forano E (2005) Xylanases and carboxymethylcellulases of the rumen protozoa Polyplastron multivesiculatum, Eudiplodinium maggii and Entodinium sp. FEMS Microbiol Lett 244:149–156

Bhupender SJG, Islam NM, Santanu D, Leif AK (2010) Growth, cell division and sporulation in mycobacteria. Antonie Van Leeuwenhoek 98:165–177

Brady R, Clardy J, Goodman RM (1998) Molecular biological access to the chemistry of unknown soil microbes. Chem Biol 5:245–249

Brulc JM, Antonopoulos DA, Miller ME, Wilson MK, Yannarell AC, Dinsdale EA, Edwards RE, Frank ED, Emerson JB, Wacklin P, Coutinho PM, Henrissat B, Nelson KE, White BA (2009) Gene-centric metagenomics of the fiber-adherent bovine rumen microbiome reveals forage specific glycoside hydrolases. Proc Natl Acad Sci 106:1948–1953

Calsamiglia S, Busquet M, Cardozo PW, Castillejos L, Ferret A (2007) Invited review: essential oils as modifiers of rumen microbial fermentation. J Dairy Sci 90:2580–2595

Cano J, Borucki MK (2012) Revival and identification of bacterial spores in 25- to 40-million-year-old Dominican amber. Science 268:1060–1064

Cantarel BL, Coutinho PM, Rancurel C, Bernard T, Lombard V, Henrissat B (2009) The Carbohydrate-Active EnZymes database (CAZy): an expert resource for Glycogenomics. Nucleic Acids Res 37:233–238

Chhabra A, Manjunath KR, Panigrahy S, Parihar JS (2009) Spatial pattern of methane emissions from Indian livestock. Curr Sci 96:5–10

Christel S, Helen S, Wolfgang RW (2007) Metagenomics, biotechnology with non-culturable microbes. Appl Microbiol Biotechnol 75:955–962

Collignon P, Powers JH, Chiller TM, Aidara-Kane A, Aarestrup AFM (2009) World Health Organization ranking of antimicrobials according to their importance in human medicine: a critical step for developing risk management strategies for the use of antimicrobials in food production animals. Clin Infect Dis 49:132–141

Cosgrove DJ (2005) Growth of the plant cell wall. Nat Rev Mol Cell Biol 6:850–861

Dehority BA (1993) Laboratory manual for classification and morphology of ruminal ciliate protozoa. CRC Press, Boca Raton

Dehority BA, Orpin CG (1997) Development of, and natural fluctuations in, rumen microbial populations. In: Hobson PN, Stewart CS (eds) The rumen microbial ecosystem. Chapman & Hall, London, pp 196–245

Duan CJ, Xian L, Zhao GC, Feng Y, Pang H, Bai XL, Tang JL, Ma QS, Feng JX (2009) Isolation and partial characterization of novel genes encoding acidic cellulases from metagenomes of buffalo rumens. J Appl Microbiol 107:245–256

Edwards JE, Huws SA, Kim EJ, Kingston-Smith AH (2007) Characterization of the dynamics of initial bacterial colonization of nonconserved forage in the bovine rumen. FEMS Microbiol Ecol 62:323–335

FAO, FAOSTAT (2009) Online Statistical Service. Food and Agriculture Organization of the United Nations, Rome

Firkins JL, Yu Z, Morrison M (2007) Ruminal nitrogen metabolism: perspectives for integration of microbiology and nutrition for dairy. J Dairy Sci 90:1–16

Flint HJ, Bayer EA, Rincon MT, Lamed R, White BA (2008) Polysaccharide utilization by gut bacteria: potential for new insights from genomic analysis. Nat Rev Microbiol 6:121–131

Forsberg CW, Lam K (1977) Use of adenosine 5′-triphosphate as an indicator of the microbiota biomass in rumen contents. Appl Environ Microbiol 33:528–537

Forsberg CW, Cheng KJ, White BA (1997) Polysaccharide degradation in the rumen and large intestine. In: Mackie RI, White BA (eds) Gastrointestinal microbiology. Chapman & Hall, New York, pp 319–379

Garcia JL, Patel BKC, Olliver B (2000) Taxonomic, phylogenetic, and ecological diversity of methanogenic Archaea. Anaerobe 6:205–226

Gerosa S, Skoet J (2012) Milk availability: trends in production and demand and medium-term outlook. ESA Working paper No. 12-01, February 2012, Agricultural Development Economics Division, Food and Agriculture Organization of the United Nations. www.fao.org/economic/esa

Gill SR, Pop M, Deboy RT, Eckburg PB, Turnbaugh PJ, Samuel BS, Gordon JI, Relman CM, Fraser L, Nelson KE (2006) Metagenomic analysis of the human distal gut microbiome. Science 312:1355–1359

Handelsman J (2004) Metagenomics: application of genomics to uncultured. Microbiol Mol Biol Rev 68:669–685

Handelsman J, Rondon MR, Brady SF, Clardy J, Goodman RM (1998) Molecular biological access to the chemistry of unknown soil microbes: a new frontier for natural products. Chem Biol 5:R245–R249

Henne A, Daniel R, Schmitz RA, Gottschalk G (1999) Construction of environmental DNA libraries in Escherichia coli and screening for the presence of genes conferring utilization of 4-hydroxybutyrate. Appl Environ Microbiol 65:3901–3907

Hespell RB, Akin DE, Dehority BA (1997) Bacteria, fungi and protozoa of the rumen. In: Mackie RI, White BA, Isaacson R (eds) Gastrointestinal microbiology, vol 2. Chapman and Hall, New York, pp 59–186

Hess M, Sczyrba A, Egan R, Kim TW, Chokhawala H, Schroth G, Luo S, Clark DS, Chen F, Zhang T, Mackie RI, Pennacchio LA, Tringe SG, Visel A, Woyke T, Wang Z, Rubin EM (2011) Metagenomic discovery of biomass-degrading genes and genomes from cow rumen. Science 331:463–467

Hungate RE (1969) A roll tube method for cultivation of strict anaerobes. In: Norris JR, Ribbons DW (eds) Methods in microbiology, vol 3B. Academic, London/New York, pp 117–132

Huson DH, Richter DC, Mitra S, Auch AF, Schuster SC (2009) Methods for comparative. BMC Bioinform 10(Suppl 1):S12

Jami E, Mizrahi I (2012) Composition and similarity of bovine rumen microbiota across individual animals. PLoS One 7(3):e33306

Jarvis GN, Strompl C, Burgess DM, Skillman LC, Moore ER, Joblin KN (2000) Isolation and identification of ruminal methanogens from grazing cattle. Curr Microbiol 40:327–332

Kamra DN (2005) Rumen microbial ecosystem. Curr Sci 89:124–135

Karnati SKR, Yu Z, Sylvester JT, Dehority BA, Morrison M, Firkins JL (2003) Technical note: specific PCR amplification of protozoal 18S rDNA sequences from DNA extracted from ruminal samples of cows. J Anim Sci 81:812–815

Klieve AV, Bauchop T (1988) Morphological diversity of ruminal bacteriophages from sheep and cattle. Appl Environ Microbiol 54:1637–1641

Klieve AV, Swain RA (1993) Estimation of ruminal bacteriophage numbers by pulsed field gel electrophoresis and laser densitometry. Appl Environ Microbiol 59:2299–2303

Kobayashi Y, Shinkai T, Koike S (2008) Ecological and physiological characterization shows that Fibrobacter succinogenes is important in rumen fiber digestion. Folia Microbiol 53:195–200

Kongmun P, Wanapat M, Pakdee P, Navanukraw C (2010) Effect of coconut oil and garlic powder on in vitro fermentation using gas production technique. Livest Sci 127:38–44

Kudo H, Cheng KJ, Costerton JW (1987) Interactions between *Treponema bryantii* and bacteria in the in vitro degradation of straw cellulose. Can J Microbiol 33:244–248

Lamendella R, Domingo JW, Ghosh S, Martinson J, Oerther DB (2011) Comparative fecal metagenomics unveils unique functional capacity of the swine gut. BMC Microbiol 11:103

Larsen N, Vogensen FK, Van den Berg FWJ, Nielsen DS, Andreasen AS, Pedersen BK, Abu Al-Soud WMAF, Sorensen SJ, Hansen LH, Jakobsen M (2010) Gut microbiota in human adults with type 2 diabetes differs from non-diabetic adults. PLoS ONE 5:e9085

Lourenço M, Ramos-Morales E, Wallace RJ (2010) The role of microbes in rumen lipolysis and biohydrogenation and their manipulation. Animal 4:1008–1023

Mackie RI (1997) Gut environment and evolution of mutualistic fermentative digestion. In: Mackie RI, White BA (eds) Gastrointestinal microbiology, vol 1. Chapman & Hall, New York, pp 13–35

Makkar HPS, Becker K, Abel HJ, Szegletti C (1995) Degradation of condensed tannins by rumen microbes exposed to quebracho tannins (QT) in rumen simulation technique (RUSITEC) and effects of QT on fermentation processes in the RUSITEC. J Sci Food Agric 69:495–500

Margulies M, Egholm M, Altman WE, Attiya S, Bader JS, Bemben LA, Berka J, Braverman MS, Chen YJ, Chen Z, Dewell SB, de Winter A, Drake J, Du L, Fierro JM, Forte R, Gomes XV, Godwin BC, He W, Helgesen S, Ho CH, Hutchison SK, Irzyk GP, Jando SC, Alenquer MLI, Jarvie TP, Jirage KB, Kim JB, Knight JR, Lanza JR, Leamon JH, Lee WL, Lefkowitz SM, Lei M, Li J, Lohman KL, Lu H, Makhijani VB, McDade KE, McKenna MP, Myers EW, Nickerson E, Nobile JR, Plant R, Puc BP, Reifler M, Ronan MT, Roth GT, Sarkis GJ, Simons JF, Simpson JW, Srinivasan M, Tartaro KR, Tomasz A, Vogt KA, Volkmer GA, Wang SH, Wang Y, Weiner MP, Willoughby DA, Yu P, Begley RF, Rothberg JM (2005) Genome sequencing in microfabricated high-density picolitre reactors. Nature 441:7089

Miron J, Ben-Ghedalia D, Morrison M (2001) Invited review: adhesion mechanisms of rumen cellulolytic bacteria. J Dairy Sci 84:1294–1309

MOA (2003) 17th livestock census of India. Department of Animal Husbandry and Dairying, Ministry of Agriculture, Government of India

Moate PJ, Williams SRO, Grainger C, Hannah MC, Ponnampalam EN, Eckard RJ (2011) Influence of cold-pressed canola, brewers grains and hominy meal as dietary supplements suitable for reducing enteric methane emissions from lactating dairy cows. Anim Feed Sci Technol 166:254–264

Molan AL, Attwood GT, Min BR, McNabb WC (2001) The effect of condensed tannins from Lotus pedunculatus and Lotus corniculatus on the growth of proteolytic rumen bacteria in vitro and their possible mode of action. Can J Microbiol 47:626–633

Morgavi DP, Kelly WJ, Janssen PH, Attwood GT (2012) Rumen microbial (meta)genomics and its application to ruminant production. Animal http://dx.doi.org/10.1017/S1751731112000419

Mosoni P, Martin C, Forano E, Morgavi DP (2011) Long-term defaunation increases the abundance of cellulolytic ruminococci and methanogens but does not affect the bacterial and methanogen diversity in the rumen of sheep. J Anim Sci 89:783–791

Pope PB, Mackenzie AK, Gregor I, Smith W, Sundset MA, McHardy AC, Morrison M, Eijsink VGH (2012) Metagenomics of the Svalbard reindeer rumen microbiome reveals abundance of polysaccharide utilization loci. PLoS ONE 7:e38571

Purdy KJ, Nedwell DB, Embley TM (2003) Analysis of the sulfate-reducing bacterial and methanogenic archaeal populations in contrasting Antarctic sediments. Appl Environ Microbiol 69:3181–3191

Qi M, Wang P, O'Toole N, Barboza PS, Ungerfeld E, Leigh MB, Selinger B, Butler G, Tsang A, McAllister TA, Forster RJ (2011) Snapshot of the eukaryotic gene expression in muskoxen rumen-a metatranscriptomic approach. PLoS ONE 6:e20521

Qu A, Brulc JM, Wilson MK, Law BF, Theoret JR, Joens LA, Konkel ME, Angly F, Dinsdale EA, Edwards RA, Nelson KE, White BA (2008) Comparative metagenomics reveals host specific metavirulomes and horizontal gene transfer elements in the chicken cecum microbiome. PLoS ONE 3:e2945

Reddy B, Singh KM, Patel AK, Antony A, Panchasara HJ, Joshi CG (2014) Insights into resistome and stress responses genes in Bubalus bubalis rumen through metagenomic analysis. Mol Biol Rep 2014 Jul 2 [Epub ahead of print]

Rocheleau S, Greer CW, Lawrence JR, Cantin C, Laramee L, Guiot SR (1999) Differentiation of *Methanosaeta concilii* and *Methanosarcina barkeri* in anaerobic mesophilic granular sludge by fluorescent in situ hybridization and confocal scanning laser microscopy. Appl Environ Microbiol 65:2222–2229

Roesch LFW, Fulthorpe RR, Riva A, Casella G, Hadwin AKM, Kent AD, Daroub S, Camargo FAO, Farmerie WG, Triplett EW (2007) Pyrosequencing enumerates and contrasts soil microbial diversity. ISME J 1:283–290

Rondon MR, August PR, Bettermann AD, Brady SF, Grossman TH, Liles MR, Loiacono KA, Lynch BA, MacNeil IA, Minor C, Tiong CL, Gilman M, Osburne MS, Clardy J, Handelsman J, Goodman RM (2000) Cloning the soil metagenome: a strategy for accessing the genetic and functional diversity of uncultured. Appl Environ Microbiol 66:2541–2547

Saengkerdsub S, Anderson RC, Wilkinson HH, Kim WK, Nisbet DJ, Ricke SC (2007) Identification and quantification of methanogenic archaea in adult chicken ceca. Appl Environ Microbiol 73:353–356

Sawanon S, Kobayashi Y (2006) Synergistic fibrolysis in the rumen by cellulolytic *Ruminococcus flavefaciens* and noncellulolytic *Selenomonas ruminantium*: evidence in defined cultures. Anim Sci J 77:208–214

Scheifinger CC, Wolin MJ (1973) Propionate formation from cellulose and soluble sugars by combined cultures of *Bacteroides succinogenes* and *Selenomonas ruminantium*. J Appl Microbiol 26:789–795

Shin EC, Choi BR, Lim WJ, Hong SY, An CL, Cho KM (2004) Phylogenetic analysis of archaea in three fractions of cow rumen based on the 16S rDNA sequence. Anaerobe 10:313–319

Singh KM, Pandya PR, Parnerkar S, Tripathi AK, Ramani U, Koringa PG, Rank DN, Joshi CG, Kothari RK (2010a) Methanogenic diversity studies within the rumen of Surti buffaloes based on methyl coenzyme M reductase A (mcrA) genes point to Methanobacteriales. Pol J Microbiol 59:175–178

Singh KM, Parnerkar S, Tripathi AK, Mehta HH, Rank DN, Kothari RK, Joshi CG (2010b) Bacterial diversity in the rumen of Indian Surti buffalo (Bubalus bubalis), assessed by 16S rDNA analysis. J Appl Genet 51:395–402

Singh KM, Tripathi AK, Pandya PR, Rank DN, Kothari RK, Joshi CG (2011) Dasytricha dominance in Surti buffalo rumen revealed by 18S rRNA sequences and real-time PCR assay. Curr Microbiol 63:281–288

Singh KM, Tripathi AK, Pandya PR, Parnerkar S, Rank DN, Kothari RK, Joshi CG (2012a) Methanogen diversity in the rumen of Indian Surti buffalo (Bubalus bubalis), assessed by 16S rDNA analysis. Res Vet Sci 92:451–455

Singh KM, Ahir V, Tripathi AK et al (2012b) Metagenomic analysis of Surti buffalo 400 366 (Bubalus bubalis) rumen: a preliminary study. Mol Biol Rep 39(4):4841–4848

Singh KM, Jakhesara SJ, Koringa PG, Rank DN, Joshi CG (2012c) Metagenomic analysis of virulence associated and antibiotic resistance genes of microbes in rumen of Indian buffalo (Bubalus bubalis). Gene 507:146–151

Singh K, Pandya P, Tripathi A, Patel G, Parnerkar S, Kothari R, Joshi C (2013a) Molecular diversity of protozoa in rumen of Indian buffalo (Bubalus bubalis). Agric Res 2:360–366

Singh KM, Tripathi AK, Pandya PR, Parnerkar S, Rank DN, Kothari RK, Joshi CG (2013b) Use of real-time PCR technique in determination of major fibrolytic and non fibrolytic bacteria present in Indian Surti buffaloes (Bubalus bubalis). Pol J Microbiol 62:195–200

Singh KM, Pandya PR, Tripathi AK, Patel GR, Parnerkar S, Kothari RK, Joshi CG (2014a) Study of rumen metagenome community using qPCR under different diets. Meta Gene 2:191–199

Singh KM, Tripathi AK, Pandya PR, Parnerkar S, Kothari RK, Joshi CG (2014b). Molecular genetic diversity and quantitation of methanogen in ruminal fluid of buffalo (Bubalus bubalis) fed ration (Wheat Straw and Concentrate Mixture Diet). Genet Res Int 2013 (2013), Article ID 980191, 7 p. ONLINE Journal

Singh KM, Reddy B, Patel AK, Panchasara H, Parmar N, Patel AB, Shah TM, Bhatt VD, Joshi CG (2014c) Metagenomic analysis of buffalo rumen microbiome: effect of roughage diet on Dormancy and Sporulation genes. Meta Gene 2:252–268

Singh KM, Reddy B, Patel D, Patel AK, Parmar N, Patel A, Patel JB Joshi CG (2014d) High potential source for biomass degradation enzyme discovery and environmental aspects revealed through metagenomics of Indian buffalo rumen. Biomed Res Int 2014 (2014), Article ID 267189, 10 p

Sizova MV, Panikov NS, Tourova TP, Flanagan PW (2003) Isolation and characterization of oligotrophic acido-tolerant methanogenic consortia from a sphagnum peat bog. FEMS Microbiol Ecol 45:301–315

Smith AH, Mackie RI (2004) Effect of condensed tannins on bacterial diversity and metabolic activity in the rat gastrointestinal tract. Appl Environ Microbiol 70:1104–1115

Sogin ML, Morrison HG, Huber JA, Welch DM, Huse SM, Neal PR, Arrieta JM, Herndl GJ (2006) Microbial diversity in the deep sea and the underexplored "rare biosphere". Proc Natl Acad Sci USA 103:12115–12120

Stewart CS, Flint HJ Bryant MP, Stewart CS, Flint HJ, Bryant MP (1997) The rumen bacteria. In: Hobson PN, Stewart CS (eds) The rumen microbial ecosystem, 2nd edn. Blackie Academic and Professional, New York, pp 467–491

Stiverson J, Morrison M, Yu Z (2011) Populations of select cultured and uncultured bacteria in the rumen of sheep and the effect of diets and ruminal fractions. Int J Microbiol 2011:750613

Swanson KS, Dowd SE, Suchodolski JS, Middelbos IS, Vester BM, Barry KA, Nelson KE, Torralba M, Henrissat B, Coutinho PM, Cann IK, White BA, Fahey GC (2011) Phylogenetic and gene-centric metagenomics of the canine intestinal microbiome reveals similarities with humans and mice. ISME J 5:639–649

Tajima K, Nagamine T, Matsui H, Nakamura M, Aminov RI (2001) Phylogenetic analysis of archaeal 16S rRNA libraries from the rumen suggests the existence of a novel group of archaea not associated with known methanogens. FEMS Microbiol Lett 200:67–72

Tatsuoka N, Mohammed N, Mitsumori M, Hara K, Kurihara M, Itabashi H (2004) Phylogenetic analysis of methyl coenzyme-M reductase detected from the bovine rumen. Lett Appl Microbiol 39:257–260

Thomas F, Hehemann JH, Rebuffet E, Czjzek M, Michel G (2011) Environmental and gut bacteroidetes: the food connection. Front Microbiol 2:93

Tilman D, Socolow R, Foley JA, Hill J, Larson E, Lynd L, Stephen P, Reilly J, Tim S, Chris S, Robert W (2009) Energy. Beneficial biofuels – the food, energy, and environment trilemma. Science 325:270–271

Tringe SG, Von Mering C, Kobayashi A, Salamov AA, Chen K, Chang HW, Podar M, Short JM, Mathur EJ, Detter JC, Bork P, Hugenholtz P, Rubin EM (2005) Comparative metagenomics of microbial communities. Science 308:554–557

Tun HM, Brar MS, Khin N, Jun L, Hui RK, Dowd SE, Leung FC (2012) Gene-centric analysis of feline intestinal microbiome using 454 junior pyrosequencing. J Microbiol Methods 88:369–376

Turnbaugh PJ, Hamady M, Yatsunenko T, Cantarel BL, Duncan A, Ley RE, Sogin ML, Jones WJ, Roe BA, Affourtit JP, Egholm M, Henrissat B, Heath AC, Knight R, Gordon JI (2009) A core gut microbiome in obese and lean twins. Nature 457:480–484

Wallace RJ, Onodera R, Cotta MA (1997) Metabolism of nitrogen-containing compounds. In: Hobson PN, Stewart CS (eds) The rumen microbial ecosystem, 2nd edn. Chapman and Hall, London, pp 283–328

Williams AG (1986) Rumen holotrich ciliate protozoa. Microbiol Rev 50:25–49

Williams AG, Coleman GS (1992) The rumen protozoa. Springer, New York

Woese CR, Vary JC, Halvorson HO (1968) A kinetic model for bacterial spore germination. Natl Acad Sci 59:869–875

Wright ADG, Williams AJ, Winder B, Christophersen C, Rodgers S, Smith K (2004) Molecular diversity of rumen methanogens from sheep in Western Australia. Appl Environ Microbiol 70:1263–1270

Xu B, Xu W, Yang F, Li J, Yang Y, Tang X, Yuelin M, Junpei Z, Zunxi H (2013) Metagenomic analysis of the pygmy loris fecal microbiome reveals unique functional capacity related to metabolism of aromatic compounds. PLoS ONE 8:e56565

15

Opportunities and Challenges for Carbon Trading from Livestock Sector

Smita Sirohi

Abstract

Livestock are important source of GHG emissions accounting for about 28 % of the global anthropogenic methane emissions. The participation of this sector in the carbon markets is, however, in nascent stage, largely confined to animal waste management projects, although the emissions from enteric fermentation are several times more than that from manure. This chapter discusses the potential of generating carbon credits by improving the feed fermentation efficiency through nutritional interventions such as dietary manipulation and feed additives and increasing the productivity of animals through breeding and other long-term management strategies. There are several socioeconomic, institutional, and technical challenges for the stakeholders in successful formulation and implementation of such mitigation options from the perspective of carbon trading. As the global carbon trading system in one form or the other will be a fixture in the world economy for decades, it is imperative that the uptake of programmatic approaches to project development is increased and standardized approaches to baseline, additionality assessment, and activity-based monitoring methods underpinned by regionally specific field research are developed.

Keywords

Carbon credits • Methane mitigation • Socioeconomic barriers

Livestock resources make multifarious contribution to the society in the form of food, clothing, soil nutrients, draft power, income, and employment and serve as liquid assets for their owners at the time of exigencies. The livestock sector accounts for 40 % of the agricultural gross domestic product, employs 1.3 billion people, and creates livelihood for 1 billion of the world's

S. Sirohi (✉)
Dairy Economics, Statistics and Management Division, ICAR-National Dairy Research Institute, Karnal 132001, Haryana, India
e-mail: smitasirohi@yahoo.com

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_15, © Springer India 2015

poor. Livestock production accounts for 30 % of the land surface of planet Earth, 70 % of all agricultural land, and 8 % of the global freshwater use (Steinfeld et al. 2006). Due to heavy reliance on land and water resources, livestock are seen as major players in global environmental problems. Also, in the context of climate change, although the sector would be adversely affected by the changing climate (Sirohi and Michaelowa 2007; Thornton et al. 2009) yet, it is itself a large contributor of greenhouse gases (GHGs) to the atmosphere. As per the recent estimates, the annual total non-CO_2 GHG emissions from agriculture in 2010 are 5.2–5.8 $GtCO_2eq$/year (Tubiello et al. 2013), that is, about 10–12 % of global anthropogenic emissions. Nearly 53–59 % of agricultural emissions are from livestock, 2.1 $GtCO_2eq$/year from enteric emissions and 0.99 $GtCO_2eq$/year from manure, either applied as organic fertilizer on cropland or manure deposited on pasture (IPCC 2014). During the past decade, Asia not only has the highest contribution to the global enteric emissions but has also registered a high growth rate of 2.0 % per annum in the same during the decade.

Fuelled by the anticipated growth of over 1 % per annum during 2005/7-2030 (Alexandratos and Bruinsma 2012) in global consumption of meat (1.6 %) and dairy products (1.3 %), as livestock production increases commensurately, the GHG emissions from livestock sector would continue to rise substantially, unless extensive mitigation options are put in place. The strategies for reducing CH_4 emissions from enteric fermentation can be broadly focused in two main areas: (1) improving the feed fermentation efficiency through nutritional interventions such as dietary manipulation and feed additives (Sirohi et al. 2007; Beauchemin et al. 2008; Eckard et al. 2010) and (2) increasing the productivity of animals through breeding and other long-term management strategies (Attwood et al. 2011; Hegarty et al. 2007). The methane reduction achievable from the first set of options is on "per animal" basis. The Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (AR4) centered on the mitigation potential of such options. In the recent Fifth Assessment Report (AR5), attention has also been paid to second set of options, wherein emission intensity is reduced by improving the efficiency of production (i.e., less GHG emissions per unit of animal product). The technical mitigation potential of both set of options is considered to be moderate, that is, achieving about 5–15 % reduction of enteric emissions (IPCC 2014).

The other source of GHG emissions from livestock, viz., animal waste management, accounts for only 32 % of the total emissions from livestock. However, the technical mitigation potential from this source is high (>15 %) by installing anaerobic digesters, biofilters, etc. (Chadwick et al. 2011; Petersen and Sommer 2011). The technical potentials represent the full biophysical potential of a mitigation option, taking account of the constraints and factors such as land availability and suitability but without accounting for economic constraints (Smith 2012). The technical viability of mitigation option is a necessary but not sufficient condition for its successful implementation; the economic incentives are vital for application of the technology. Carbon trading which is an outcome of "cap-and-trade" approach of the international policy on global climate protection provides economic incentives for achieving reductions in the emissions of GHGs.

This chapter presents the existing status of livestock sector in the carbon business, discusses the sectoral scope of carbon trading, and delineates the key issues and barriers in enhancing the participation of this sector in carbon markets. An overview of the genesis and mechanism of carbon trading system precedes the discussion on carbon trading and livestock sector.

15.1 Carbon Trading: Brief Overview

15.1.1 Genesis

The vital issue of climate change came to limelight about two decades ago when the IPCC published its First Assessment Report in 1990, confirming that climate change is for real and sought for an international treaty to address the problem. The emergence of concerns over potential threat of climate change can, however, be traced back to the first “World Climate Conference” organized by the World Meteorological Organization (WMO) in 1979 which called for global cooperation to explore the possible future course of global climate and appealed to nations of the world to prevent potential man-made changes in climate that might be adverse to the well-being of humanity. In fact, it was the WMO and United Nations Environment Programme (UNEP) that established IPCC in 1988 as a scientific body for providing objective information about the causes and consequences of climate change.

In response to the IPCC AR1, the UN General Assembly formally launched negotiations on a framework convention on climate change in 1991 and established an intergovernmental negotiating committee to develop the treaty. The negotiations to this end were completed by May 1992, in the form of United Nations Framework Convention on Climate Change (UNFCCC). The UNFCCC was opened for signature in June 1992 during the UN Conference on Environment and Development, also known as the Rio Earth Summit, and came into force on 21 March 1994. There are now 195 member countries of the convention. The convention divides countries into two groups: Annex I parties, the industrialized countries who have historically contributed the most to climate change, and non-Annex I parties, which include primarily the developing countries. The principles of equity and “common but differentiated responsibilities” contained in the convention required Annex I parties to take the lead in returning their greenhouse gas emissions to 1990 level by the year 2000.

The convention established the Conference of the Parties (COP) as its supreme body with the responsibility to oversee the progress toward the aim of the convention. At the first session of the COP in Berlin in 1995, the countries realized that emission reduction provisions in the convention were inadequate and there was a need to strengthen the global response to climate change. Hence, negotiations to this effect culminated in the form of the Kyoto Protocol during the third session of the COP held in Kyoto (Japan) in December 1997. The protocol is a legally binding set of obligations for 38 industrialized countries including 11 countries in Central and Eastern Europe to reduce their emissions of GHGs to an average of approximately 5.2 % below their 1990 levels over the commitment period 2008–2012. In the 8th Session of the COP in 2012 at Doha, a second commitment period from 2013 to 2020 was launched with some modifications.

The Kyoto Protocol (KP) set the stage for global carbon trading as an economic approach to reduce global concentration of GHGs. The concept of emission trading had its roots in the successful sulfur dioxide trading system instituted to stop acid rain under the US Clean Air Act of 1990. In 1990, the US Environmental Protection Agency set a limit on SO_2 emissions from obvious point sources and allowed those who emit less than their quota to trade excess allowances. As a result, regional acid deposition was dramatically reduced. Following a similar approach, provisions were made in KP to achieve the quantified emission reduction targets set for the complying countries (Annex I countries) not through domestic emission reduction alone, instead through the use of less costly emission reduction potential elsewhere by way of carbon trading.

15.1.2 Trading Standards and Systems

Carbon credits – the standard of trading in the carbon markets – are certificates awarded to countries that are successful in reducing emissions of GHGs. One carbon credit is equal to one metric ton of carbon dioxide emission. The five GHGs other than CO_2 (methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride) are converted into tons of CO_2 equivalent (CO_2e) using their global warming potential (GWP) factor.

Two types of carbon trading systems are currently in vogue: compliance based and voluntary mechanism**.** The compliance-based systems are driven by countries and companies subject to emission constraints under the Kyoto Protocol, European Union (EU) regulations, and other developed-country climate policies. On the other hand, the transactions in the voluntary carbon markets, as the name suggests, are not required by regulation. Carbon credits can be voluntarily purchased in one of two ways – through a private exchange or on the decentralized "over-the-counter" (OTC) market, where buyers and sellers engage directly through a broker or online retail "storefront." As the voluntary carbon trading system is not part of any mandatory cap-and-trade system, almost all carbon credits purchased voluntarily are sourced specifically for the OTC market. Credits are generically referred to as verified (or voluntary) emission reductions (VERs) – or simply as carbon offsets.

15.2 Livestock Sector and Carbon Business

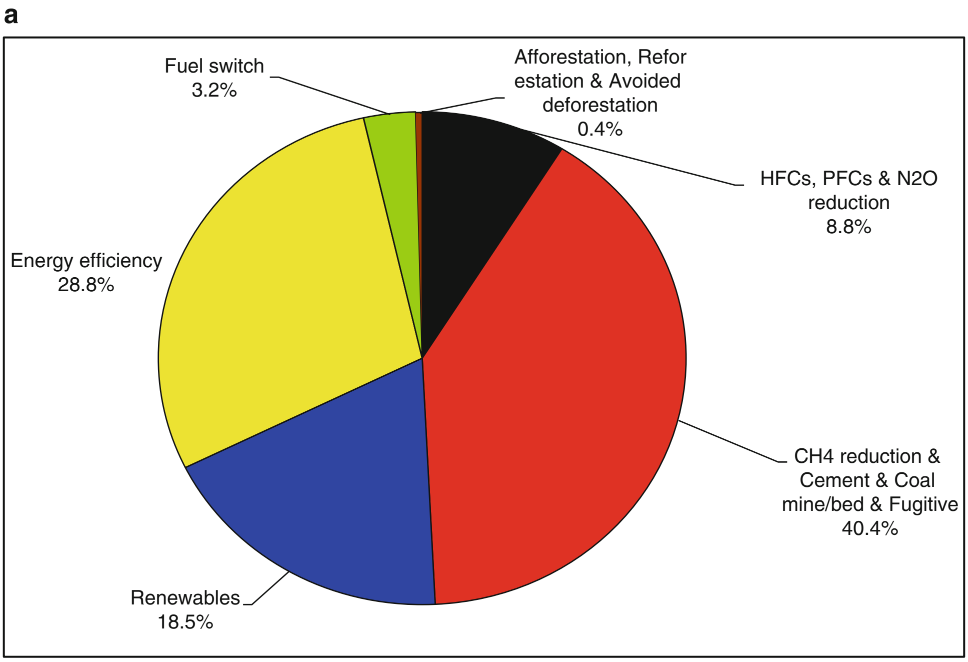
The size of the global carbon markets that was worth US$11 billion in 2005 rose sharply to US$176 billion in 2011 (Kossoy and Guigon 2012), but as negotiations for a post-2012 legally binding protocol did not yield definite results, the value of transactions in the compliance-based markets fell by about 36 % in 2012 (Bloomberg 2013). Outside the framework of the Kyoto Protocol, the reach of carbon pricing is steadily increasing. The world's two largest emitters, viz., the USA and China, are now home to carbon pricing instruments. Carbon pricing systems are in operation in subnational jurisdictions of the two countries. A total of eight new carbon markets (California Cap-and-Trade Program, Québec Cap-and-Trade System, Kazakhstan Emissions Trading Scheme, and five Chinese pilot emission trading schemes, viz., Shenzhen, Shanghai, Beijing, Guangdong, and Tianjin) opened their doors in 2013 alone. With these new joiners, the world's emission trading schemes (excluding the three flexible mechanisms under KP) are worth about US$30 billion (World Bank 2014). The size of voluntary markets is much smaller than the compliance market. Up to 2013, the voluntary buyers have directly funded 844 $MtCO_2e$ in emission reductions worth $4 billion. In 2013, offset suppliers transacted 76 $MtCO_2e$ of carbon offsets – down from 102.8 $MtCO_2e$ in 2012 – as structural changes in California's carbon market impacted millions of previously "voluntary" tons. Market value in the corresponding period fell from $523 million to $379 million (Stanley and Gonzalez 2014).

Given the vast size of the GHG emissions from the agriculture sector, the carbon markets can be a powerful policy instrument to leverage private capital for green growth, including activities under climate-smart agriculture (CSA). Notwithstanding that CSA has a twin benefit of mitigation and adaptation, it can help reduce emissions by carbon sequestration, decreasing enteric fermentation, etc., and can help agriculture adapt to the impacts of climate change and increase productivity; the overall agricultural carbon markets are still in nascent stage. Most of the compliance-based systems do not cover the agriculture sector within their fold.

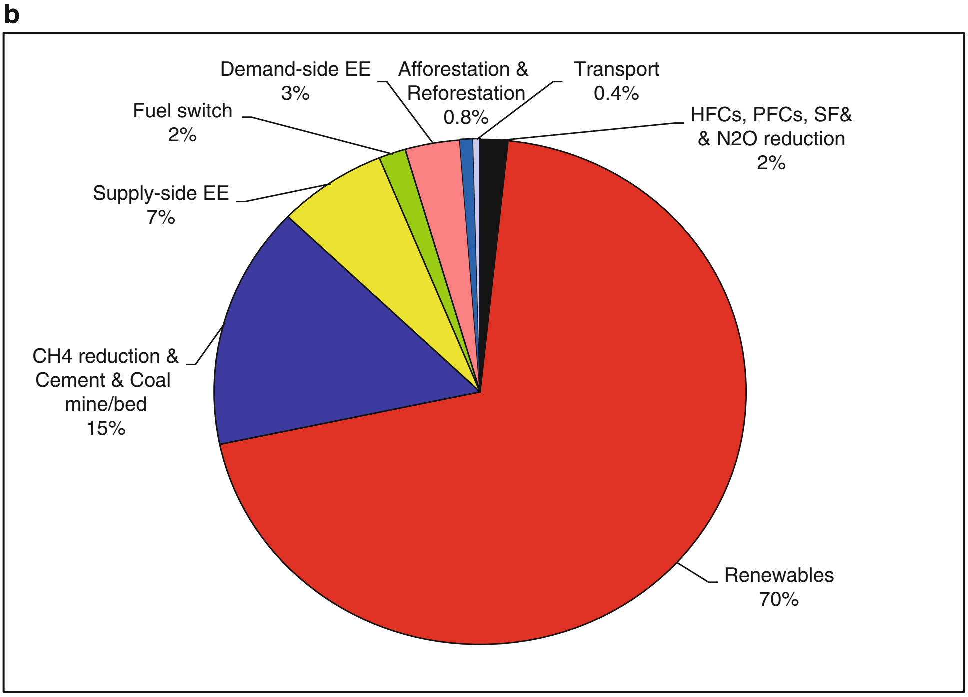
The European Union Emission Trading System (EU ETS) is the leader accounting for about 84 % of the global carbon market transactions. The carbon credits in this trading system accrue from the industrial and other nonagricultural activities. The sectoral composition of carbon credits issued under the compliance-based systems of KP, joint implementation (JI), and clean development mechanism (CDM) is heavily skewed in favor of renewable energy methane and cement and coal bed/mine methane reduction and energy efficiency projects (Fig. 15.1).

The JI and CDM pipeline (as on 1 August 2013) show a total of 599 and 7,128 registered projects, respectively. The projects relevant to the agriculture, forestry, and other land use (AFOLU) are quite few in number and are largely confined to methane avoidance from animal waste management (Table 15.1). The carbon crediting potential of the methane avoidance projects under CDM up to the year 2020 is only 114 $MtCO_2e$, i.e., 1 % of the total expected carbon credits. The three major host countries of these projects are Mexico, China, and Brazil.

In the voluntary markets also, the share of the offsets developed from livestock methane is very



Distribution of JI Projects

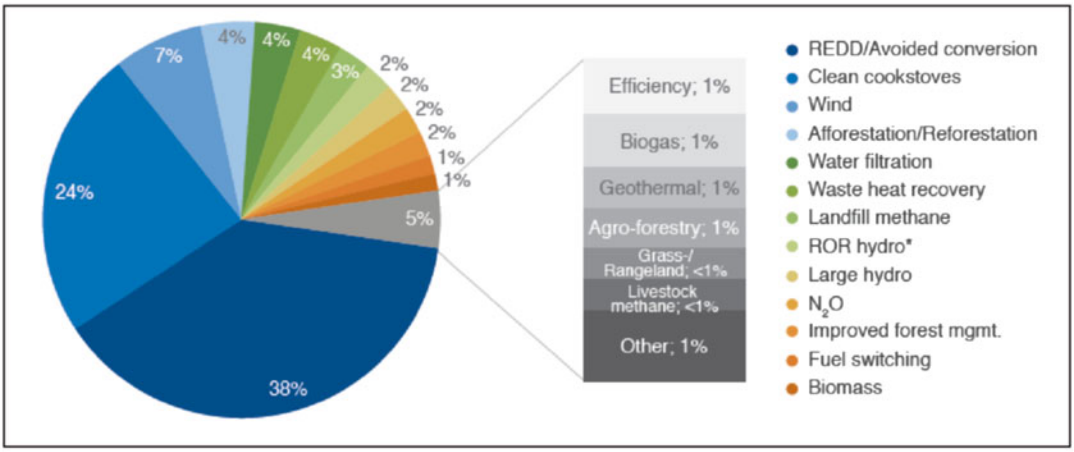


Distribution of CDM Projects

Fig. 15.1 Sectoral composition of projects in compliance-based carbon markets (as on 1 Aug., 2013)

Table 15.1 Status of AFOLU projects (as on 1.8.13)

		Number of CDM projects		Number of JI projects	
Type	Subtype	Registered	Validation stage	Registered	Determination stage
Agriculture	Energy efficiency	1		2	
	Zero tillage			7	3
	Rice crops		1		
Methane avoidance	Domestic manure	41	3		
	Manure	240	36	4	1
Afforestation/ reforestation	Afforestation/ reforestation	43	23	2	
	Mangroves	1	2		
	Agroforestry	2			
Avoided deforestation	Improved forest management			1	



Source: Stanley and Gonzalez, 2014

Fig. 15.2 Market share by project type, OTC 2013

marginal (Fig. 15.2). Before 2011, the Chicago Climate Exchange (CCX) operated as a voluntary cap-and-trade scheme, joined mostly by US-based entities who volunteered to track and reduce their GHG emissions. In 2005, the dairies in Washington and Minnesota received the first carbon credit payments from anaerobic digestion projects through the CCX.

After the closure of CCX in 2010, the existing landscape of livestock anaerobic digestion projects in the USA illustrates various types of models of carbon market finance (Box 15.1). The carbon markets for animal waste management system outside the framework of KP are in vogue in Mexico also. The Climate Action Reserve has released version 2.0 of the Mexico Livestock Project Protocol, which provides guidance to calculate, report, and verify GHG emission reductions associated with installing a manure biogas control system for livestock operations, such as dairy cattle and swine farms, in Mexico.

The GHG mitigation projects for carbon finance are so far confined to management of animal wastes, although the contribution of enteric emissions is several times more than emissions from manure. Business and research groups have

Box 15.1: Animal Waste Management for GHG Avoidance: Carbon Market Developments in the USA

Utility-Based Opportunities

Vermont State has at least 15 operational dairy-based digesters that produce renewable electricity and participate in one or more utility-based incentive programs, such as Vermont's Sustainably Priced Energy Enterprise Development (SPEED), Cow Power Program, etc. By one estimate, customers participating through the Cow Power program have provided to dairy digester operators more than $3.5 million in value for the environmental attributes created in the projects. Other examples of this type of utility-based standard offer or incentive pricing for farm power can be found in North Carolina and Wisconsin.

Climate Action Reserve

California market allows offsets in livestock methane. Registration with the Climate Action Reserve (CAR), North America's largest carbon offset registry, is the first step to participation in the California market. Of the 60 digester projects listed with CAR, 36 have registered more than 800,000 verified carbon credits. CAR released version 3.0 of the Livestock Project Protocol, providing updated guidelines for livestock operations to participate in the carbon market. The Livestock Project Protocol ensures the integrity and long-term environmental benefit of installing manure biogas control systems at livestock operations, including dairy cattle and swine farms.

Source: Jensen (2013)

made some early efforts to address enteric fermentation emissions, but these efforts have not yet materialized in the form of carbon credits. The first potential CDM project on reduction of enteric methane emissions through strategic supplementation of cattle in Uganda submitted in 2008 by RuMeth International Ltd., USA, in collaboration with TransAlta Corporation, Canada, and NutriMix Inc., Uganda, was not accepted by the CDM Executive Board on account of shortcomings in methodology. In 2013, the methodology and project were submitted afresh by the project proponents and the methodology AMS-III.BK stands approved (UNFCCC 2014). This would pave the way for trading carbon credits from enteric methane mitigation.

Some efforts in this direction were being made by New Zealand and Australia. New Zealand established the emission trading scheme (ETS) in 2008, under which it was envisaged to cap emissions from agriculture in that country – including enteric fermentation emissions. Under compliance obligations, owners of livestock operations out of compliance with their cap would have to buy permits from those in compliance in order to emit, or they would have to pay a fine. However, mandatory target for biological emissions in agriculture is delayed indefinitely (MoE, NZ 2014). The proposed Carbon Farming Initiative in Australia also offers some potential opportunities for cattle industry. It offers a financial incentive to undertake new on-farm greenhouse gas abatement activities where they would not otherwise be undertaken.

15.3 Potential Opportunities of Carbon Trade

The important prerequisite for setting up GHG mitigation projects to earn carbon credits is the existence of considerable emission reduction potential at low cost. This section synthesizes the attempts made by various researchers to delineate the potential for carbon trading from livestock projects.

In most of the developed countries (except Australia and New Zealand), the significance of animal waste management in GHG emissions is quite high, with the emissions from manure management accounting for more than 25 % of the total emissions from livestock (Table 15.2).

Table 15.2 GHG emissions from livestock in selected countries: 2009 (in Gg CO_2 equivalent)

Countries	Enteric fermentation: CH_4	Manure management: CH_4	Manure management: N_2O
Austria	3,265	320	923
Belgium	3,548	1,620	774
Denmark	2,881	1,229	428
France	29,629	13,947	6,030
Germany	20,951	6,028	2,230
Netherlands	6,496	2,887	997
United Kingdom	15,263	2,817	1,995
EU (27)	149,102	50,557	31,028
Australia	54,736	1,752	1,564
New Zealand	22,506	728	56
Canada	19,325	2,682	3,878
USA	139,758	49,469	17,860

Source: UNFCCC (2013)

The previous section brought out that the project activities in this direction are already underway. Not only the technical mitigation potential of available technology is high, it is readily available and has universal acceptability (IPCC 2014); thus, there is vast potential for earning carbon credits from animal waste management.

In India, where dung of cattle and buffaloes is extensively used as fuel and is largely managed in dry systems, emissions from manure are much lower (5,088 $GgCO_2e$) in relation to enteric emissions (211,429 $GgCO_2e$) (NATCOM 2012). The theoretical potential of the GHG emission projects in India can be gauged from the fact that achieving just a 15 % annual reduction in manure and 10 % in enteric methane emissions would generate 0.76 and 21 million carbon credits, respectively. Given the vast size of the country, and the immense number of stakeholders that would have to be involved, a single project cannot cover the entire ruminant population to achieve these reductions. Nevertheless, even small-scale mitigation projects in the sector – covering a group of districts – have the potential to generate reasonable amounts of carbon credits. The map (Fig. 15.3) indicates that in a number of districts, particularly from the eastern and western parts of the country, with even a conservative coverage of 15 % of the bovine population (as per 2007 Livestock Census) for 10 % enteric methane mitigation, there is a possibility of generating more than 7,500 carbon credits annually from each district. In the northern parts of the country also, in most of the districts, there is likelihood of rendering over 3,000 carbon credits annually. It is amply evident from the map that broadly, besides the northern Himalayas and northeastern and south coastal region, implementing a CDM project even in a small group of 5–6 districts can give a substantial amount of carbon credits to the investors, similar to the certified emission reduction (CER) volumes currently generated by the majority of small-scale renewable energy CDM projects promoted by Indian project developers.

Field experiments in India involving dietary manipulation through concentrate feeding, supplementation of green fodder, monensin feed additives, and urea-molasses mineral block have shown encouraging results, due to improved microbial growth efficiency and digestibility, with reduction potential ranging from about 6 to 32 % (Sirohi and Michaelowa 2008). Besides good technical potential, the cost of methane abatement is also low in India (Sirohi et al. 2007). An ex ante analysis integrating market economics in the assessment of strategic supplementation with urea-molasses products also brought out that even with one-fourth market penetration, the GHG mitigation generates positive economic surplus which would be much higher than business-as-usual scenario (Sirohi and Upadhyay 2009).

In the mixed crop-livestock production systems of sub-Saharan Africa and Asia, the evaluation of

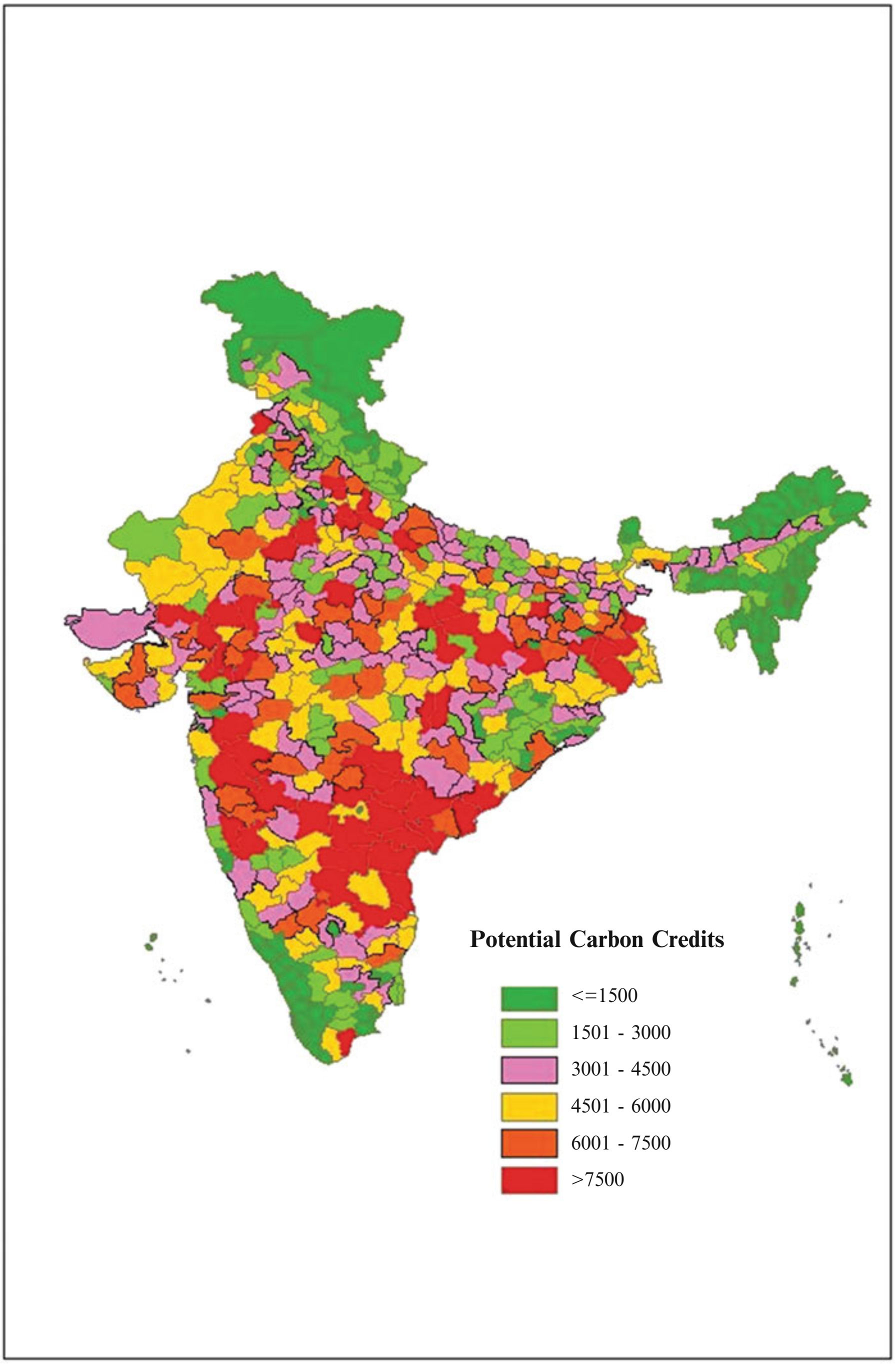


Fig. 15.3 Potential annual carbon credits from enteric methane mitigation in India

ruminant diet intensification on the GHG emissions from livestock also substantiated existence of good emission reduction potential (Thornton and Herrero 2010). A 10 % improvement in digestibility of stovers can mitigate 14.2 $MtCO_2e$ (23 % adoption rate), while with increasing grain supplementation from 0.5 to 2 kg/head/day, methane reduction of 5.1 $MtCO_2e$ (23 % adoption rate) is achievable. The full potential (100 % adoption rate) of these technologies has been assessed to be 61.6 and 22.1 $MtCO_2e$, respectively.

The recent studies suggest that besides nutritional interventions, the emission intensity of livestock can also be improved through pasture management, improved land use, and breed selection. In the rangeland-based livestock production system of tropical Central and South America, depending on the varied adoption rates, the GHG mitigation potential from pasture improvement was assessed as 29.8–44.5 $MtCO_2e$, primarily from C sequestration via restoration of degraded pastures and land-use change (Thornton and Herrero 2010). Consequent upon resulting improvement in animal productivity and hence requirement of less number of animals to meet the demand, this mitigation option can also lead to CH_4 mitigation per unit of animal product. Considering the historical adoption rates of four mitigation options, Thornton and Herrero (2010) worked out their reduction potential to be approximately 4 % of global agricultural GHG mitigation amounting to $1.3 billion per year in value terms.

The Chinese Academy of Agricultural Science (CAAS) and the Food and Agriculture Organization (FAO) also seek to harness the positive link between C sequestration, grassland, and grazing cattle to improve emission intensity and thereby generate additional income from carbon trading (Forster 2014). They are working to restore degraded grasslands in Northern China through improved grazing practice and forage production. This would substantially improve animal nutrition and livestock output and would also counter climate change through C sequestration and reduction of CH_4 intensity.

Among the genetic approaches of methane reduction, the selection of animals based on the residual feed intake (RFI) seems to be promising. Using data from the Australian research projects on RFI, Alford et al. (2006) undertook to model the methane abatement resulting from the anticipated adoption of RFI in breeding programs within the Australian beef industry over a 25-year period. For a representative 100-cow commercial herd in southern Australia, in which bulls of superior RFI were purchased in year 1, the cumulative total of enteric methane abatement during the 25-year simulation period was 24.5 t. The estimated 24.5 t of methane saved over 25 years by the representative southern Australian herd is equivalent to an annual average saving of 20.6 tCO_2e which have the potential to be transacted under a carbon trading scheme. Arthur et al. (2010), applying various adoption rates and adoption time lags of RFI, computed the cumulative reduction over 25 years in Australian emissions as 568,100 t of methane.

Interestingly, in the Alberta province of Canada, a GHG reduction protocol based on selection for RFI has been developed and it is in the final stages of the approval process (Climate Change Central 2010). After approval, the protocol will be used in the carbon offset program of the province.

15.4 Key Issues and Challenges

Conceptually, the idea behind promoting carbon markets is that these markets put a price on carbon which helps stimulate abatement and technology transfer and drive investment in low-carbon technologies and services. This price signal assists in the identification of low-cost abatement opportunities (e.g., energy efficiency measures), reducing the overall global cost of mitigation. Appropriately designed carbon markets have the potential to drive private sector investment at scale within the agricultural sector, underwriting the training of farmers in new practices; the provision of inputs such as seeds, fertilizer, feed additives, etc.; and the establishment of measurement, reporting, and verification (MRV) systems to track carbon and agricultural benefits that accrue (Gledhill et al. 2011).

Despite of the potential to reduce sectoral GHG emissions, there are number of barriers that limit the entry of livestock sector in the carbon markets. These include:

15.4.1 Social Factors

In the developing countries, the sensitivity of livestock producers to the climate change concerns is limited due to several factors such as low-level education, inadequate institutional mechanisms to sensitize them, etc. Additionally, due to low income levels, livestock is a subsidiary component in their livelihood priorities, and hence, with the limited resources at their disposal, the willingness to adopt the mitigation options for livestock may not be forthcoming.

Also, cultural values and social acceptance can determine the feasibility of the mitigation option. For instance, the strategies involving significant reductions in animal numbers while increasing their productivity are likely to have sociocultural tradeoffs for the pastoralist societies in Africa and Asia, where wealth is measured at least partially in terms of livestock numbers. Options that propose reducing peoples' assets may not only affect households culturally, but they may also have unintended consequences on households' ability to manage risk as the value of livestock to livelihoods in marginal environments goes far beyond the direct impacts of their productive capacity (Thornton and Herrero 2010).

15.4.2 Economic Factors

The economic viability of a mitigation project for carbon trading depends on the volume of credits generated to cover at least the transactions and monitoring costs. In the smallholder livestock production system, the small size of the livestock holding not only imposes technical difficulties in implementation, monitoring, and verification but also increases the transaction cost. Thus, the project coverage has to be very wide to make it viable.

Inherent price volatility of the mitigation options itself and that of carbon prices lead to economic risk in mitigation projects. For instance, enteric fermentation mitigation options dependent on diet manipulation are subject to volatility in feed markets. A diet that is affordable 1 year may not be so in the following year. This will make long-term mitigation dynamic in nature as farmers will have to periodically adjust the composition of animal diets in accordance with the costs and availability of certain feeds. It would thus impact the costs of mitigation and the level of emissions abated at any given period.

The uptake of breeding specifically for a low-methane trait is likely to be closely related to the explicit or implicit carbon cost used in any economic analysis (Shackell 2012). This means that, at least in part, industry uptake of low-carbon production systems may be dictated by decisions around how carbon costs at a national level are transferred to the commercial farmer. Cottle and Conington (2012) calculated that in extensive UK sheep systems, a carbon price of £1,396 per tCO2e for indirect selection and £296 per tCO2e for direct selection is required to achieve a 20 % reduction in GHG production over a 30-year period. Farmers will therefore consider the tradeoff between improving traits which contribute to farm profit and those that reduce GHG when making their breeding objective and selection decisions.

15.4.3 Institutional Factors

At present, there is no international agreement that supports a wide implementation of mitigation projects in agriculture sector. This is one of the major barriers for realizing the mitigation potential from the sector globally. Transparent and accountable governance and swift institutional establishment are very important for a sustainable implementation of livestock mitigation measures. This includes the need to have clarity about carbon ownership, especially when the business is not vertically integrated. For instance, the beef cattle industry in Australia involves several intermediaries. An animal typically changes ownership a number of times from conception to slaughter. Thus, if the genetic selection mitigation option is implemented, it needs to be worked out who will own the carbon credits – the animal breeder who originally produced the parent, or the cow-calf manager who produced the progeny or the feedlot operator who fed the cattle but may not own them (Arthur et al. 2010).

15.4.4 Technological Factors

Some mitigation options are currently available (e.g., diet manipulation, feed additives), while several others (vaccination, defaunation, etc.) are in development stage. Studies examining abatement through enteric fermentation mitigation must assume baseline diets and management practices from which reductions are taking place. In reality, farms have many different diets they feed animals that vary with season, price, and availability. Thus, it becomes difficult for farmers to accurately estimate emission reductions from new management practices because their baselines may be dramatically different than those assumed in studies.

The response of mitigation strategies available option may also vary across regions due to location-specific factors such as animal and feed characteristics. Inadequate field testing of the technologies can cause substantial difference in ex ante assessment of carbon credit generation and actual credits generated after the application of these technologies, thus leading to project failures.

Challenges relating to monitoring, reporting, and verification of the progress of the mitigation measures are also responsible for their limited field application. Emissions from enteric fermentation are diffuse and this makes them difficult to measure. Emissions can be measured in vitro or in vivo, but in farmers' field especially in smallholder conditions, the actual measurements are very difficult. Livestock holdings are widely scattered in smallholder production system, with the herd size usually ranging from two to five adult animals. Therefore, to access the small-scale farms for implementation of the mitigation option and their subsequent monitoring for estimation of the carbon credits generated under a project is a difficult task.

15.5 Conclusions

The first phase of the compliance-based carbon trading under the Kyoto Protocol has expired in 2012, although the generation of carbon credits from the existing projects is permissible till 2020. However, there is general consensus that global carbon trading system in one form or the other will be a fixture in the world economy for decades. For instance, a new market instrument in the form of nationally appropriate mitigation actions (NAMA) is in the pipeline. NAMA refers to a set of mitigation policies and/or actions a developing country undertakes aiming at reducing its GHG emissions and reports to UNFCCC on a voluntary basis.

Given the size of the GHG emissions from livestock sector, there exists a vast potential to earn carbon credits through a range of mitigation options. However, there are number of challenges that need to be surmounted for greater entry of the sector in the carbon markets. These include the technical complexity and lack of availability of carbon methodologies, and high transaction costs relating to MRV of livestock carbon. The mitigation options cannot only be a source of additional income through carbon markets but also there are productivity benefits to the livestock rearers. Therefore, to link the small farmers to the carbon markets, it is imperative that the uptake of programmatic approaches to project development is increased and standardized approaches to baseline, additionality assessment, and activity-based monitoring methods underpinned by regionally specific field research are developed. The researchers need to develop tools and methodologies to better estimate on-farm GHG and emission reductions and simulate emission reduction options based on changes in management practices.

References

Alexandratos N, Bruinsma J (2012) World agriculture towards 2030/2050: the 2012 revision, ESA working paper No. 12–03. FAO, Rome

Alford AR, Hegarty RS, Parnell PF, Cacho OJ, Herd RM, Griffith GR (2006) The impact of breeding to reduce residual feed intake on enteric methane emissions from the Australian beef industry. Aust J Exp Agric 46:813–820

Arthur PF, Herd RM, Basarab JA (2010) The role of cattle genetically efficient in feed utilisation in an Australian carbon trading environment. AFBM J 7(2):5–13. http://www.csu.edu.au/faculty/science/saws/afbmnetwork/

Attwood GT, Altermann E, Kelly WJ, Leahy SC, Zhang L, Morrison M (2011) Exploring rumen methanogen genomes to identify targets for methane mitigation strategies. Anim Feed Sci Technol 166–167:65–75

Beauchemin KA, Kreuzer M, O'Mara F, McAllister TA (2008) Nutritional management for enteric methane abatement: a review. Aust J Exp Agric 48:21–27

Bloomberg (2013) Carbon market worth plunged by over a third in 2012. http://www.euractiv.com/climate-environment/carbon-market-worth-plunged-thir-news-516881

Chadwick D, Sommer S, Thorman R, Fangueiro D, Cardenas L, Amon B, Misselbrook T (2011) Manure management: implications for greenhouse gas emissions. Anim Feed Sci Technol 166–67:514–531

Climate Change Central (2010) Carbon Offset Solutions: Draft Alberta protocols. http://carbonoffsetsolutions.climatechangecentral.com/offset-protocols/draft-alberta-protocols. Verified on 2010-11-02

Cottle DJ, Conington J (2012) Breeding for reduced methane emissions in extensive UK sheep systems. J Agric Sci 150:570–583

Eckard RJ, Grainger C, de Klein CAM (2010) Options for the abatement of methane and nitrous oxide from ruminant production: a review. Livest Sci 130:47–56

Forster R (2014) China seeks to breed more cattle on back of carbon trading income from improved grassland. Livestock and Meat Industry Notes. www.rforster.com/index.php/articles/china-east-asia/china

Gledhill R, Herweijer C, Hamza-Goodacre D, Grant J, Webb C, Steege J (2011) Agricultural carbon markets: opportunities and challenges for Sub-Saharan Africa. PWC and the Rockefeller Foundation

Hegarty RS, Goopy JP, Herd RM, McCorkell B (2007) Cattle selected for lower residual feed intake have reduced daily methane production. J Anim Sci 85:1479–1486

IPCC (2014) Summary for policymakers. In: Edenhofer O, Pichs-Madruga R, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeier P, Kriemann B, Savolainen J, Schlömer S, von Stechow C, Zwickel T, Minx JC (eds) Climate change 2014, mitigation of climate change. Contribution of working group III to the fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge/New York

Jensen J (2013) Money from something: carbon market developments for agriculture animal manure management. Extension America's research based learning network, November 07, 2013. http://www.extension.org/pages/67612/money-from-something:-carbon-market-developments-for-agriculture

Kossoy A, Guigon P (2012) The state and trends of the carbon market 2012. Carbon Finance, The World Bank, Washington, DC

Moe NZ (2014) Legislative changes to the New Zealand emissions trading scheme (NZ ETS). Ministry for the Environment, New Zealand. http://www.climatechange.govt.nz/emissions-trading-scheme/ets-amendments/index.html

NATCOM (2012) India's second national communication to UNFCCC. Ministryof Environment and Forests, Govt. of India, New Delhi

Petersen SO, Sommer SG (2011) Ammonia and nitrous oxide interactions: roles of manure organic matter management. Anim Feed Sci Technol 166–67:503–513

Shackell GH (2012) Animal selection, genetics and genomics for low carbon livestock production. In: Proceeding of the 15th AAAP Animal Science Congress 7 Symposium 7: carbon footprint and low carbon livestock production. https://www.academia.edu/4000303/Symposium_7_Carbon_footprint_and_low_carbon_livestock_production

Sirohi S, Michaelowa A (2007) Sufferer and cause: Indian livestock and climate change. Clim Change 85:285–298

Sirohi S, Michaelowa A (2008) Implementing CDM for Indian dairy sector: prospects and issues. Clim Policy 8(1):62–74

Sirohi S, Upadhyay RC (2009) Economics of mitigation of GHG emission from livestock. In: Aggarwal PK (ed) Global climate change and Indian agriculture: case studies from the ICAR network project. ICAR, New Delhi, pp 140–145

Sirohi S, Michaelowa A, Sirohi SK (2007) Mitigation options for enteric methane emissions from dairy animals: an evaluation for potential CDM projects in India. Mitig Adapt Strateg Glob Change 12:259–274

Smith B (2012) Transnational carbon-trading standards: improving the transparency and coordination of post-Kyoto carbon trading markets. Pace Environ Law Rev 30(1):325

Stanley P, Gonzalez G (2014) Sharing the stage: state of the voluntary carbon markets 2014, executive summary. Forest Trends' Ecosystem Marketplace, Washington, DC

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow: environmental issues and options, FAO agriculture technical paper. Food and Agriculture Organization of the United Nations, Rome

Thornton PK, Herrero M (2010) Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. Proc Natl Acad Sci USA 107(46):19667–19672. www.pnas.org/cgi/doi/10.1073/pnas.0912890107

Thornton PK, Van de Steeg J, Notenbaert AM, Herrero M (2009) The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agric Syst 101:113–127

Tubiello FN, Salvatore M, Rossi S, Ferrara A, Fitton N, Smith P (2013) The FAOSTAT database of greenhouse gas emissions from agriculture. Environ Res Lett 8:1–11. doi:10.1088/1748-9326/8/1/015009, ISSN: 1748–9326

UNFCCC (2013) GHG Data from UNFCCC. http://unfccc.int/ghg_data/ghg_data_unfccc

UNFCCC (2014) New baseline and monitoring methodology recommendation form (Version 02.0) SSC-NM094. Strategic supplementation of a small holder dairy sector to increase productivity and reduce methane emissions. http://cdm.unfccc.int/

World Bank (2014) State and trends of carbon pricing 2014. World Bank, Washington, DC

Part IV

Methane Mitigation Strategies in Livestock

Manipulation of Rumen Microbial Ecosystem for Reducing Enteric Methane Emission in Livestock

16

D.N. Kamra, Neeta Agarwal, and L.C. Chaudhary

Abstract

Rumen has a complex consortium of microorganisms comprising of bacteria, protozoa, fungi, archaea and bacteriophages, which synergistically act upon the lignocellulosic feeds consisting of cereal straws and stovers, green forages and hays, oil cakes, etc., and produce a mixture of short-chain volatile fatty acids and microbial proteins which the animals can use as a source of nutrients. During this bioconversion process, hydrogen is generated in large quantities which combine with carbon dioxide to generate methane by the activity of methanogenic archaea. Depending upon the composition of diet, the animals might lose 5–12 % of gross energy intake in the form of methane, which leads to poor feed conversion efficiency. To avoid this loss of energy in the form of methane, several methods are technically available (e.g. methane analogues, inorganic terminal electron acceptors, ionophore antibiotics, organic unsaturated fatty acids, microbial intervention like use of probiotics and selective removal of ciliate protozoa and plant secondary metabolites), but each one of them has its own merits and demerits. In many cases, the results are based upon only in in vitro experiments. In this chapter, a few of the feed supplements which have a potential to inhibit methanogenesis and have been tested in in vivo experiments will be discussed.

Keywords

Defaunation • Enteric methane • Halogenated compounds • Ionophores • Methanogenic archaea • Methane mitigation

---

D.N. Kamra (✉) • N. Agarwal • L.C. Chaudhary
Animal Nutrition Division, ICAR-Indian Veterinary
Research Institute, Izatnagar, Bareilly 243 122,
Uttar Pradesh, India
e-mail: dnkamra@rediffmail.com

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_16, © Springer India 2015

16.1 Introduction

The rumen harbours a complex, highly diversified microbial population comprising of bacteria, protozoa, fungi, archaea and bacteriophages. The studies carried out by using group-specific 16S rRNA-targeted oligonucleotide probes indicate that the population range from 0.5 to 3 %, 60–90 % and 3–30 % of archaea (methanogens), prokarya (bacteria, bacteriophages) and eukarya (ciliate and flagellate protozoa and fungi), respectively, in the gastrointestinal tract of most of the ruminants (Lin et al. 1997). The overall microbial activity of the rumen is due to the mutualistic, synergistic, antagonistic and symbiotic interactions among all the microbial groups. The rumen microbes have ectosymbiotic relationship with the host which provides a suitable environment for the microbes to grow and in turn microbes provide them nutrients in the utilizable form (volatile fatty acids and microbial proteins, peptides and amino acids). It is only because of the rumen microbes that the animals can use nonprotein nitrogenous feeds to fulfil their protein requirement.

Different microbial groups live in harmony and maintain equilibrium for optimum fermentation of feed. The mode of action of each of these groups on lignocellulosic feed is different and that is why there is no competition among the microbes for the substrate. Lignocellulosic feed is degraded by the primary cellulose-degrading bacteria, namely, *Fibrobacter succinogenes*, *Ruminococcus flavefaciens* and *R. albus*, which attach closely with the feed particles. The cellulose-degrading enzymes are present in the form of cellulosome; hence adhesion of these microbes with the cellulose particle is essentially required. The enzymes exhibit the highest activity because these fibre-degrading enzymes are in direct contact with the substrate. On the other hand, rumen protozoa (spirotrichs) engulf the fibre and degradation of cellulose is intracellular, whereas holotrichs thrive upon soluble sugars, starch, etc. The anaerobic fungi grow deep into the plant tissue through hyphae and thus weaken the strength of the plant tissue and break them into smaller pieces, providing more surface area for primary cellulolytic bacteria to act upon. There is extracellular secretion of fibre-degrading enzymes from the tips of fungal hyphae, which hydrolyse the lignocellulosic feed. The fungi have good proteolytic activity, therefore can degrade plant tissue completely, whereas cellulolytic bacteria are protease negative. Rumen fungi are a rich source of esterases; therefore, cellulose and hemicelluloses are unshielded from lignin by breaking ester bonds between the two. The monosaccharides thus produced are fermented to produce volatile fatty acids, CO_2, H_2 and methanogens utilize CO_2 and H_2 to form methane.

16.2 Rumen Methanogenesis

During fermentation of sugars produced by degradation of polysaccharides, reduced equivalents are also generated, and the disposal of these reduced equivalents is a critical step in anaerobic fermentation (Fig.16.1). Hydrogen is produced from the reduced cofactors by the action of hydrogenases. Rumen protozoa (Paul et al. 1990) and fungi (Yarlett et al. 1986) have hydrogenase enzymes located within the hydrogenosomes. The reduced cofactors (nicotinamide adenine dinucleotide, NADH; nicotinamide adenine dinucleotide phosphate, NADPH; and flavin adenine dinucleotide, FADH) are oxidized to NAD+, NADP+ and FAD+ by the donation of electrons to hydrogen ions (H+) to form H_2 (Hino and

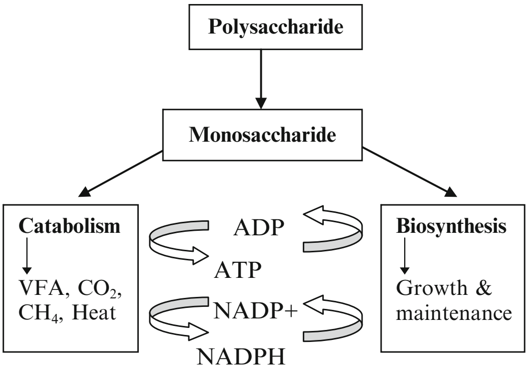


Fig. 16.1 Metabolism of polysaccharides by the rumen microbes

Asanuma 2003; Kittelmann and Janssen 2011). These cofactors are required for energy generation (as ATP) for microbial growth. The principal means of regenerating NAD+ from NADH is by the enzyme NADH-ferredoxin oxidoreductase, coupled to a hydrogenase. The activity of NADH-ferredoxin oxidoreductase is primarily controlled by the concentration of dissolved hydrogen, being suppressed by a high pH. Production of lactate and ethanol is not the preferred metabolic pathway in the rumen. Methanogenesis is the favourite channel for the disposal of H_2 because CO_2 has close affinity with H_2. Methanogens utilize CO_2 and H_2 to form methane. There are a number of enzymes and cofactors involved in combining CO_2 and H_2 to form CH_4. In an adult cattle or buffalo, 500–600 l of molecular hydrogen is produced every day, but it never accumulates in the gaseous phase of rumen because it is continuously utilized by methanogenic archaea. Hydrogen l/day can be interpreted by the amount of methane produced by the animal. A typical sheep emits about 25 l/day methane, so the amount of hydrogen produced by the animal is 100 l/day as 4 moles of hydrogen are required per mole of methane produced.

16.2.1 Rumen Methanogens

In the rumen, the archaea population is 10^6–10^8 cells/ml, representing 2–3 % of microbial biomass. Archaea is a group of microbes which include methanogens in the rumen. Previously methanogens were classified as bacteria, but based on their unique cell wall and 16S rRNA structure, these are assigned a separate group, archaea. Methanogens are obligate microbes requiring an Eh lower than −330 mV, CO_2 as the major carbon source, H_2 as the primary energy source and amino acids as a nitrogen source. Rumen methanogens can also metabolize formate, acetate, methylamines and methanol to produce CH_4. All methanogens have coenzyme F_{420}, which is a cofactor necessary for enzymes such as hydrogenase and formate dehydrogenase (Ashbey et al. 2001). Another unique characteristic of all methanogens is the presence of coenzyme M responsible for methane production (Rouviere and Wolfe 1988).

In the rumen, methanogenic archaea include species from *Methanobacteriales*, *Methanococcales*, *Methanomicrobiales* and *Methanosarcinales* (Skillman et al. 2006; Wright et al. 2007). *Methanobacteriales* which include *Methanobrevibacter* spp., *Methanobacterium* spp. and *Methanosphaera* spp. constitute 30–99 % of archaeal community, and *Methanomicrobiales* are the second most prevalent group in rumen archaeal community. Other than these known species of methanogens, there is a large fraction of uncultured methanogens also. According to Nicholson et al. (2007), uncultured methanogens along with *Methanobrevibacter* spp. constitute the major portion of rumen methanogen population. But this community structure is not always constant; it varies with the type of diet taken by the animal.

16.2.2 Interaction of Methanogens with Other Microbes in the Rumen

Interaction of methanogens starts since their establishment in the rumen. In fact methanogens can establish themselves in the rumen only when both facultative and strict anaerobic bacteria are established. Genome analysis of methanogens has revealed the presence of some specific surface proteins like glycosyltransferases, epimerases and transporters which enable them to survive and interact with other microbes in the gastrointestinal tract at an early stage (Fricke et al. 2006; Samuel et al. 2007). As discussed above, methanogens need hydrogen as energy source; therefore, the presence of cellulolytic microbes is essential to provide hydrogen and formate for the growth of methanogens. Conrad et al. (1985) demonstrated intimate associations between hydrogen-utilizing microbes such as methanogens and hydrogen-producing microbes. The authors stated that transfer of dissolved hydrogen might limit the growth of methanogens; hence an intimate relationship is required.

Similarly, Newbold et al. (1995) and Hegarty (1999) explained that to facilitate syntrophic relationship, a physical association exists between methanogens and protozoa in the rumen. Even after close physical relationship between H_2-producing and H_2-utilizing microbes, interspecies transfer of extracellular H_2 in the bulk fluid is very complicated, and in the rumen, 90 % of hydrogen atoms are present in water. The association between these two microbial groups has been proved by the use of 16S rRNA probes directed against different families of methanogens, but this study also indicated that majority of methanogens were free living in the liquid portion of rumen content (Sharp et al. 1998). The authors reported such association between the protozoa of genera *Entodinium*, *Polyplastron*, *Epidinium* and *Ophryoscolex* and methanogens mainly from *Methanobacteriales* and *Methanomicrobiale*s in bovine rumen. Interspecies hydrogen transfer between anaerobic fungi *Neocallimastix frontalis* and methanogens with similar relationship has also been reported (Mountfort et al. 1982; Joblin et al. 2002). Bauchop and Mountfort (1981) reported accumulation of hydrogen and formate (35.3 ± 2.5 and 83.1 ± 2.8 mol/100 mol cellulose unit) in monoculture of *Neocallimastix frontalis* in the absence of *Methanobrevibacter ruminantium*, whereas hydrogen and formate were disposed of in the form of methane in the presence of methanogens (<0.05 and 1.0 ± 0.07 mol/100 mol cellulose units). Therefore, the methanogen community structure very much depends on the type of protozoa present in the rumen.

16.3 Methane Emission by Indian Livestock

There have been several estimates from different laboratories in India about methane emitted by the livestock, using different techniques. Depending upon the technique and basic data used by the authors, the figures of estimates also vary greatly. Swamy and Bhattacharya (2006) compared methane emission by Indian livestock as per equations developed at CLRI (Central Leather Research Institute, Chennai, India), IPCC default values for methane emission factors calculated region wise, NPL estimates and ALGAS project estimates as 9.0, 13.2, 11.2 and 7.9 Tg/year, respectively (Table 16.1).

According to the latest calculations based on the data of the Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Govt. of India, the country is responsible for the production of methane to the tune of 14.55 Tg/year (13.27 Tg from enteric fermentation and 1.28 Tg from livestock waste management), out of which cattle (6.73 Tg/year) and buffalo (6.56 Tg/year) collectively are responsible for 91.3 % of total methane emitted by the livestock in India, while the rest 8.7 % is emitted by goats,

Table 16.1 Estimates of methane emission by Indian livestock

Methane emission, Tg/year	Base year	Method used	Reference
9.1 (enteric fermentation)	2003	Tier 2	Singh et al. (2012)
9.0 (enteric fermentation)	1997	CLRI estimates	Swamy and Bhattacharya (2006)
13.2 (enteric fermentation)	1997	IPCC default values (Tier 1)	
11.2 (enteric fermentation)	1997	NPL	
7.9 (enteric fermentation)	1997	ALGAS project	
13.3 (enteric fermentation) + 1.3 (manure management)	2012	Tear 1	Kamra (2014)
11.17 (enteric fermentation) + 1.19 (manure management)	2003	Tier 2	Patra (2012)
11.89 (enteric fermentation) + 1.25 (manure management)	2007	Tier 2	Patra (2012)

Table 16.2 Methane production by Indian livestock (enteric fermentation and manure management) as per IPCC default emission factors[a]

Animal	No. X 1000	Enteric methane production		Methane production from manure		Total methane emission	Methane emission (% of total)
		Kg/head/year	Tg/year	Kg/head/year	Tg/year	Tg/year	
Crossbred cattle	43,266	46	1.990	4.00	0.173	2.163	14.87
Indigenous cattle	164,935	25	4.123	2.66	0.439	4.562	31.36
Buffalo	109,316	55	6.012	5.00	0.547	6.559	45.09
Yak	71	55	0.004	5.00	0.001	0.005	0.03
Mithun	264	55	0.015	5.00	0.001	0.016	0.11
Sheep	72,676	05	0.363	0.21	0.015	0.378	2.60
Goat	141,155	05	0.706	0.22	0.031	0.737	5.06
Horse/pony	611	18	0.011	2.18	0.001	0.012	0.08
Mule	168	10	0.002	2.18	0.001	0.003	0.04
Donkey	458	10	0.005	1.19	0.001	0.006	0.04
Camel	517	46	0.024	2.56	0.001	0.025	0.17
Pig	11,905	01	0.012	6.00	0.071	0.083	0.57
Total	545,342		13.267		1.282	14.549	100.02

[a] The above calculations are based on data of the Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, Govt. of India

sheep, yak, mithun, horse, donkey, mules, pig, etc. (Table 16.2). The methane emission per kg of livestock production is very high due to various reasons and conditions of livestock production system prevalent in India. In India, as the animals are fed on poor quality low-density feeds, the animals have to consume larger quantity of feed to suffice its requirement, and the quantity of feed fermented in the rumen is directly proportional to methane emitted by the animals. Therefore, animals fed poor quality feed emit more methane per kilogramme of livestock product as compared to those animals fed good quality feed.

16.4 Inhibition of Methanogenesis

Global warming is primarily due to the accumulation of greenhouse gases near the surface of the Earth, the troposphere. The major greenhouse gases include water vapours, carbon dioxide, methane, nitrous oxide, chlorofluorocarbons and hydrofluorocarbons due to agricultural and industrial activities of human beings. In a layman's language, global warming can be defined as an average increase in near surface temperature of the Earth, primarily due to increased concentration of greenhouse gases in the troposphere. These levels are expected to increase several folds during the next century. The Intergovernmental Panel on Climate Change (IPCC 2011) redefined climate change as "a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties that persists for an extended period, typically decades or longer".

Reduction in methane emission is possible by several techniques by stimulating alternate hydrogen sinks available in the rumen. The important methane inhibitors are ionophores, organic acids, halogenated methane analogues, unsaturated oils, tannins, saponins, alkaloids, essential oils, plants containing secondary metabolites, probiotics, vaccines against methanogens, etc. But all these strategies have their own merits and demerits when used as methane inhibitors. Among various techniques, the use of plants containing secondary metabolites as feed additives is the most important technique because of their natural occurrence and routine use in Ayurvedic medicine. The exhaustive work has been done using plants rich in secondary metabolites as methane inhibitor.

16.4.1 Plants Containing Secondary Metabolites

16.4.1.1 Screening of Plants

As discussed above, in addition to some of the methanogens living free in the liquid portion of rumen content, there are certain methanogenic archaea which remain attached with the ciliate protozoa and are responsible for a significant production of methane in the rumen. In an elaborate screening experiment in the authors' laboratory, a large number of plants containing secondary metabolites have been tested for their ability to inhibit methanogenesis and ciliate protozoa in in vitro gas production test. The results are summarized in Table 16.3. The inhibition of methanogenesis and ciliate protozoa varied from 25 % to more than 90 % (Patra et al. 2006a, b; Kamra et al. 2008; Agarwal et al. 2008; Kumar et al. 2011).

Another major project on screening of plants containing secondary metabolites has been completed in the "RUMEN-UP" in Europe in which 450 plants were screened for their ability to inhibit methanogenesis in in vitro experiments. Out of 450 plants examined in this project, 35 plants inhibited methane by more than 15 % and only six plants (*Carduus pycnocephalus* L., *Populus tremula* L., *Prunus avium* L., *Quercus robur* L., *Rheum nobile* and *Salix caprea* L.) inhibited methane by more than 25 % (Bodas et al. 2008). These plants did not have any adverse effect on any of the fermentation parameters tested, indicating that the secondary metabolites present in these plants were selective inhibitors of methanogenic archaea and did not affect any other rumen microbe at the level used in this experiment.

Coconut and fish oil (0, 3.1 and 6.2 ml/L) inhibited in vitro methane production in a dose-

Table 16.3 Plants inhibiting (more than 25 %) methanogenesis and protozoa population in vitro

Plant	Common name	Methane inhibition, %	Protozoa inhibition, %
Acacia concinna[a]	Shikakai, pods	–	>50
Terminalia belerica[a]	Bahera, pulp	25–50	25–50
Terminalia chebula[a]	Harad, pulp	>50	>50
Emblica officinalis[a]	Amla, pulp	25–50	25–50
Azadirachta indica[a]	Neem, seed cake	25–50	>50
Quercus incana[b]	Oak, leaves	25–50	–
Populus deltoides[b]	Poplar, leaves	>50	0.00
Foeniculum vulgare[c]	Fennel, seeds	>50	>50
Syzygium aromaticum[c]	Clove, flower bud	>50	25–50
Allium sativum[c]	Garlic, bulb	>50	–
Psidium guajava[b]	Guava, leaves	>50	>50
Cannabis indica[b]	Bhang, leaves	25–50	25–50
Trachyspermum ammi[b]	Ajwain, seeds	25–50	25–50
Mangifera indica[b]	Mango, leaves	25–50	–
Mentha piperita[d]	Peppermint oil	>50	>50
Eucalyptus globulus[e]	Eucalyptus oil	>50	–
Sapindus mukorossi[d]	Berries	>50	>50
Acacia concinna[a]	Shikakai, pods	–	>50
Mangifera indica[f]	Leaves	>25	>50

[a] Patra et al. (2006a)
[b] Kamra et al. (2008)
[c] Patra et al. (2006b)
[d] Agarwal et al. (2006, 2008)
[e] Kumar et al. (2009)
[f] Kumar et al. (2011)

dependent manner. Fish oil was more detrimental to methanogens than coconut oil, but the opposite was true for protozoa, *R. flavefaciens* and *F. succinogenes*. The combination of both the oils might have an additive effect on methane inhibition, with no effect on microbial diversity (Patra and Yu 2013a). Essential oils when included in the incubation medium, e.g. clove oil at the rate of 1 g/L; origanum oil, 0.5 g/L; and peppermint oil, 1 g/L, inhibited ammonia production, indirectly by lowering the degradation of protein and had adverse effect on ciliate protozoa, *Megasphaera elsdenii*, *Clostridium aminophilum* and *C. sticklandii*, but *Quillaja* saponins (6 g/L) decreased protozoa and ammonia production and stimulated the growth *of Selenomonas ruminantium*, *Ruminobacter amylophilus*, *Prevotella ruminicola* and *P. bryantii* (Patra and Yu 2013b). Pawar et al. (2014) screened seven oils, garlic (*A. sativum*), clove (*S. aromaticum*), lemongrass (*Cymbopogon citratus*), wild turmeric (*Curcuma aromatica*), turmeric (*Curcuma longa*) and cinnamon (*Cinnamomum zeylanicum*) at graded levels and found that all the oils were detrimental for feed digestibility when the level was increased from 167 µl/L. Among the nine oils, garlic oil showed a maximum of 38.5 % methane inhibition without affecting feed digestibility.

Some of the selected plants containing secondary metabolites like saponins, tannins, essential oils, terpenoid/alkaloid, etc., and having a potential to inhibit rumen methanogenesis and modifying rumen fermentation favourably are summarized in Table 16.4. The information on the group of active principles responsible for biological activity to modify rumen fermentation has been compiled, but it is not certain that the effect on rumen fermentation of the individual component listed in this table is essentially the same.

16.4.1.2 In Vivo Methane Inhibition in Ruminants

The work on the use of plants rich in secondary metabolites as feed additive to mitigate methane production has been done mostly in in vitro system. There are very few feeding trials using these herbal feed additives. In the authors' laboratory, the plants selected on the basis of in vitro studies were evaluated as feed additives to inhibit methane emission in sheep. The animals were fed control diet (without additive), seed pulp of *T. chebula* (harad), bulb of *A. sativum* (garlic) and the mixture (Mix) of harad and garlic (1:1) at the rate 1 % of DM intake. The digestibility of dry matter and organic matter was significantly higher in *T. chebula*- and *A. sativum*-fed groups, whereas NDF, ADF and cellulose digestibility was significantly higher in all the three treated groups as compared to control (Patra et al. 2011). Methane emission (L/kg digested DM) as estimated by open circuit respiration chamber and methane energy loss as a per cent of digestible energy intake tended to be lower ($P = 0.09$ and $P = 0.08$) in *T. chebula* and Mix groups as compared to control, indicating that *T. chebula* and *A. sativum* had antimethanogenic activity and therefore could be used as feed additive to modify rumen microbial ecosystem for mitigation of methane emission by sheep.

In another in vivo trial with crossbred cattle calves, a mixture of three plant parts (*T. chebula* + *S. mukorossi* + *F. vulgare*, mixed in 1:1:1 ratio) was fed to the animals at the rate of 2 % of DM intake on alternate days for 148 days. There was no effect of feed additives on feed intake, nutrient digestibility and growth performance. The methane emission (l/day kg DDM) was 11 % lower in additive fed group as compared to control. The mixture appears to have a potential to be used as feed additive to inhibit methane emission. Feeding of whole-plant *Yucca schidigera* powder or whole-plant *Quillaja saponaria* powder at 10 g/kg DM which are rich source of saponin, to dairy cows did not show any reduction in methane emission (Holtshausen et al. 2009). The authors stated that these plants showed inhibition in in vitro methane production but at higher concentration, and therefore, low doses might be the reason for a negative response. But these secondary metabolites cannot be used at very high doses. There was 57 % reduction in methane emission (g/kg DMI) in goats fed ad libitum condensed tannin-containing *Lespedeza cuneata* (Puchala et al. 2005). Similarly, feeding of *Acacia mearnsii* (a tannin-containing plant) at the rate of

Table 16.4 Plants containing secondary metabolites and their active principles with potential to modify rumen fermentation characteristics

Botanical name	Common name, plant part	Active principles	Effect on rumen fermentation	Reference
Saponin-containing plants				
Acacia concinna	Shikakai seed pulp	Saponins, tannins	Methane inhibition with methanol extract, antiprotozoal activity	Patra et al. (2006b)
Sapindus mukorossi/S. saponaria	Soapnut seed pulp	Saponins (mukoroside)	Inhibition of methanogenesis, improve propionate production	Kamra et al. (2000), Hess et al. (2004), and Agarwal et al. (2006)
Tannin-containing plants				
Emblica officinalis	Amla seed pulp	Tannins, chebulinic acid (astringent substance), gallic acid and resin	Inhibits methanogenesis and ciliate protozoa	Sinha (1996) and Patra et al. (2006b)
Moringa oleifera	Sahjan leaves and seeds	Saponins, phenols and tannins	No effect on methanogenesis	Chaudhury (1995) and Kamra et al. (2006)
Psidium guajava	Guava leaves and fruit	β-selinene, β-caryophyllene, caryophyllene oxide, squalene, selin-11-en-4α-ol, guaijavarin, isoquercetin, hyperin, quercitrin and quercetin-3-O-gentobioside, β-sitosterol, uvaol, oleanolic acid and ursolic acid	Inhibition of methanogenesis and ciliate protozoa	Lozoya et al. (1994), Jaiarj et al. (1999), Begum et al. (2004), and Chatterjee (2005)
Quercus incana	Oak leaves	Catechin, hyperin, quajaverin, astragalin, tiliroside, tellimoside, isorhamnetin, kaempferol, triterpenoids, triterpene saponin, gallic acids	Inhibition of methanogenesis	Kamra et al. (2006)
Terminalia belerica	Bahera seed pulp	Gallic acid, ellagic acid and chebulagic acid, β-sitosterol, ethyl gallate, belleric acid and bellericanin	Inhibition of methanogenesis and ciliate protozoa	Sinha (1996), Elizabeth (2005), and Patra et al. (2006a)
Terminalia chebula	Harad seed pulp	Tannins, chebulinic acid (astringent substance), gallic acid and resin	Inhibition of methanogenesis and ciliate protozoa	Sinha (1996), Suguna et al. (2002), and Patra et al. (2006a)
Essential oil-containing plants				
Allium sativum	Garlic bulb	Volatile oil – allicin, diallyl disulphide and diallyl trisulphide	Inhibits methanogenesis, no effect on ciliate protozoa	Sharma et al. (1977), Rastogi and Mehrotra (1993), Patra et al. (2006c), and Busquet et al. 2006
Coriandrum sativum	Coriander leaves and seeds	Essential oils – linalool and geraniol, butylphthalides, pinene neocnidilide, ligustilide and terpinene, flavonoids, coumarins, phthalides and phenolic acids	No effect on methanogenesis and ciliate protozoa	Simon et al. (1984) and Kamra et al. (2006)

Eucalyptus globulus	Eucalyptus oil and leaves	α-pinene, β-pinene, α-phellandrene, 1,8-cineole, limonene, terpinen-4-ol, piperitone and globulol	Inhibition of methanogenesis	Morton (1981), Brooker et al. (1981), Kamra et al. (2006), and Kumar et al. (2009)
Foeniculum vulgare	Fennel seed	Essential oil – α-pinene, β-pinene, fenchone, trans-anethole, camphene, methyl chavicol, 1,8-cineole and anisic aldehyde	Inhibition of methanogenesis and ciliate protozoa	Simon et al. (1984) and Patra et al. 2006c
Mentha piperita/ Mentha haplocalyx	Peppermint oil	Menthol, menthone, 1,8-cineole, methyl acetate, menthofuran, isomenthone, α-pinene, trans-sabinene hydrate	Inhibition of methanogenesis and ciliate protozoa	Craker and Giblette (2002) and Agarwal et al. (2006)
Ocimum sanctum	Tulsi leaves	Essential oils (euganol, methyl euganol, caryophyllene, terpenes, sequiterpenes), camphor	Enhances rumen methanogenesis	Rastogi and Mehrotra (1993), Sivarajan and Balachandran (1996), and Kamra et al. (2006)
Populus deltoides	Poplar leaves	Essential oil, tannins, flavonoids and resin	Inhibition of methanogenesis and ciliate protozoa	Kamra et al. (2006)
Syzygium aromaticum	Clove flower buds/oil	Volatile oil – eugenol, pinene, acetyleugenol, methyl salicylate and vanillin, caryophyllene oxide, caryophylla-3(12), 6-dien-4-ol, caryophylla-3(12), gum and oleanolic acid, ellagitannin-eugeniin	Inhibition of methanogenesis, adverse effect on digestibility at high concentration	Altun et al. (2006) and Patra et al. (2006c)
Zingiber officinale	Ginger	Essential oil – zingerone, zingiberene, farnesene, curcumene, linalool, gingerol, shogaol, sesquiphellandrene, zingerone sesquiphellandrene	No effect on methane inhibition	Nanir and Kadu (1987), Kapoor (1997), and Kamra et al. (2006)
Terpenoid-/alkaloid-containing plants				
Azadirachta indica	Neem seed pulp, leaves	Bitter principles – nimbin, nimbidin, azadirachtin	Methane inhibition, protozoa inhibition, stimulates rumen fibre-degrading enzyme activities	Chaudhury (1995) and Patra et al. (2006b)
Citrus sinensis	Orange peels	Terpenoids	No effect on methanogenesis	Stange et al. (1993)
Curcuma longa	Turmeric	Terpenoids	NR	Apisariyakul et al. (1995)

41 g per kg DM resulted in 13 % reduction in methanogenesis in sheep (Carulla et al. 2005).

Since the last two decades, researchers are working exhaustively on plant secondary metabolites as a means of controlling methane production from the livestock, and with the result, a number of plants have been identified which have potential to be used as feed additive to mitigate methane production in the rumen. But this identification has been done on the basis of in vitro studies. However, in vitro studies cannot be used as an index for feeding trials because various extracts cannot be fed at very high doses as they might be toxic for the animals. Therefore, there is an urgent need to conduct more of feeding trials with the selected plants on large animals covering all the aspects of health and production. The diet of the animal should also be taken into consideration while selecting feed additive for the feeding of animals.

16.4.2 Microbial Intervention

16.4.2.1 Microbial Feed Additives

The use of microbial feed additives to mitigate methane emission has been tried but not with much success. A few microbes which have been used as feed additives are *Saccharomyces cerevisiae*, *Propionibacterium* and acetogens. The use of *S. cerevisiae* as feed additive has shown variable results in terms of methane inhibition. The variation was 0–58 % inhibition in methane production using different strains of *S. cerevisiae* in RUSITECH (Newbold and Rode 2006). The mode of action of *S. cerevisiae* is not well understood, but the simplest way to explain this is that it is well established that by feeding *S. cerevisiae* as feed additive, the production performance of the animals improves; it is this improvement which results in reduction of methane production per unit of product.

Production of propionate in the rumen is inversely proportionate to methane production in the rumen. If the propionate is high, methane is low because propionate production is a hydrogen-consuming metabolic reaction. Therefore, *Propionibacterium* which utilizes lactic acid and produces propionate can also be used as feed additive to check methane emission in the rumen.

Acetogens are the group of bacteria present in the rumen which utilize hydrogen for reduction of carbon dioxide to acetate at the cost of methanogenesis. If all the reducing power generated during rumen fermentation is diverted towards reductive acetogenesis, 5–10 % of the gross energy intake by the animals can be saved and brought back into the energy cycle of the animals, which otherwise would have been lost in methane generation and released by the animals into the atmosphere. So, acetogens are beneficial in two ways, one by providing more acetate which is a good source of energy and second by inhibiting methanogenesis. But in the rumen, it cannot compete with methanogens because the affinity of acetogens to hydrogen is lower than that of methanogens. There is colonization of acetogenic bacteria in 20-h-old lamb, but as methanogens appeared in 30-h-old lamb, the acetogen population decreased proportionately indicating a competition for hydrogen between these two groups (Morvan et al. 1994). One of the major reasons for failure of acetogens to compete with methanogens might be due to poor affinity of acetogens with molecular hydrogen as it requires higher molecular hydrogen threshold level (1.26 vs. 0.067 mmol/l) as compared to that required by methanogens. Acetogens are effective when the methanogen population is inhibited by any means. Lopez et al. (1999) showed significant increase in acetate production by the isolates of acetogenic bacteria (*Acetitomaculum ruminis*, *Eubacterium limosum* strains ATCC 10825 and ATCC 8486, *Ruminococcus productus* ATCC 35244 and two acetogenic bacteria, Ser 5 and Ser 8, isolated from 20-h-old lambs) when methanogenesis was inhibited by BES and there was an accumulation of hydrogen. They concluded that even a large population of acetogens cannot compete with methanogens for hydrogen.

16.4.2.2 Defaunation

As discussed above, there is interspecies hydrogen transfer between protozoa and methanogens; hence they are in syntrophic relationship. Keeping in view this relationship, the effect of defaunation (removal of protozoa from the rumen) was tested to mitigate methane production in rumen. There are different ways to remove protozoa from the rumen with individual merits and demerits of each of the techniques. Keeping the animals in isolation immediately after birth (within 48–72 h of colostrum feeding) keeps the animals in defaunated stage. This method is one of the most reliable technique and is safe, but needs extra care and infrastructure for keeping the faunated and defaunated animals in separate sheds. In another technique, the rumen is emptied by suction and the rumen contents are either heated up to 50 °C or kept frozen for 15 min. Protozoa are eliminated; bacteria and fungi are either not affected or slightly affected reversibly. The rumen is washed with 2 % formaldehyde solution and refilled with treated rumen contents to obtain defaunated animals. The third technique is by diet manipulation. The animals are shifted to low-protein diet for 2 days and then starved for 2 days; thereafter, grain is offered at the rate of 1.5 kg/100 kg BW resulting in a pH fall below 5.0 which kills protozoa. The next day, the animals are offered roughage-based diet and the animals get defaunated. The chemicals like copper sulphate, hydrochloric acid, aerosol OT (dioctyl sodium sulphosuccinate), nonylphenol ethoxylate (teric GN9, trade name), alkanate 3SL3, dioctyl sodium sulphosuccinate (Gebeyehu and Mekasha 2013) and calcium peroxide with prolong starvation are used for defaunation.

Chaudhary et al. (2000) and Kamra et al. (2000) induced partial defaunation in buffaloes by feeding bentonite and soapnut. A lot of work has been done on the use of herbs, especially saponin-containing plants, and essential oils as antiprotozoal agents associated with antimethanogenesis. Ethanol extracts of *Sapindus mukorossi* (a seed rich in saponins) when included in the incubation medium showed a 52 % reduction in protozoa population, and this was associated with 96 % inhibition in CH_4 production by rumen microbes of buffaloes (Agarwal et al. 2009). There is a close association of methanogens with protozoa, and methane production in ruminants is attributed to this relationship, but Kamra et al. (2008) compiled the data of series of in vitro experiments using various plant extracts to inhibit methanogenesis and its correlation with protozoa population and showed that methane inhibition is not always associated with inhibition in protozoa population. Similarly, feeding of coconut oil at the rate of 50 g/kg DM to sheep resulted in 94 % reduction in protozoa population. Though total tract fibre digestibility was reduced, there was no effect on methane production (Machmuller et al. 2003).

16.4.3 Chemical Interventions

16.4.3.1 Organic Acids

The rumen microbes break down feed and produce VFA (acetate, propionate, butyrate and isoacids), CO_2 and hydrogen. By increasing the molar proportion of propionate in the rumen, the hydrogen production is reduced which results in less methane production. Several organic acids (fumarate and malate) have been used as precursors of propionate, and if in the rumen, the concentrations of these acids increase, the propionate production would also increase, and this will result in lower methane production. The most extensively studied organic acids to reduce methane production are malate and fumarate (Wood et al. 2009; Lin et al. 2013). Martin and Streeter (1995) reported that malate increases propionate production and decreases methane production under in vitro conditions. Martin et al. (1999) also reported that the supplementation of malate in animal diet improves feed conversion efficiency in cattle. There are reports where fumarate has not shown any effect on methane production under in vivo conditions (Beauchemin and McGinn 2006). Yang et al. (2012) studied the effects of fumarate on methane production, ruminal fermentation and microbial population in goats under different forage concentrate ratios and reported that the fumarate reduced methane production by 11.9 %, irrespective of the diet. The production of TVFA, acetate and propionate was greater in the rumen of goats supplemented with fumarate, whereas methanogens were lower. Asanuma et al. (1999) reported depressed methane production with fumarate under in vitro conditions and concluded that it could be an economical feed additive. Acrylate, a precursor of propionate, also reduced methane production in RUSITECH, but it was less effective than fumarate (Ouda et al. 1999). However, Carro et al. (1999) found that malate actually increased methane production in a rumen-simulating fermentor, although this was largely explained by stimulation in fibre digestion, and methane produced per unit of feed fermented was actually reduced. There was no stimulation in propionate concentration in the cattle rumen as well as estimated methane production with the supplementation of malate (Martin et al. 1999; Montano et al. 1999). The effect of organic acid supplementation on methane production is inconsistent, and the high cost of organic acids is another hurdle in using these acids as antimethanogenic agents.

16.4.3.2 Halogenated Methane Analogues

Halogenated methane analogues like chloroform, iodoform, carbon tetrachloride and methyl chloride are some of the compounds which inhibit methanogenesis by blocking the terminal enzyme of methane synthesis, i.e. methyl CoM reductase. Bromochloromethane (BCM) is another compound of this group which is a potent antimethanogenic agent (Sarvanan et al. 2000). Bromoethanesulphonic acid is a structural analogue of HS-CoM, a cofactor essentially required for methanogenesis; hence it directly affects methanogenesis and growth of methanogens. It is highly specific, and in mixed rumen, microbial culture inhibits methanogens as observed by using real-time PCR (Agarwal et al. 2008). McCrabb et al. (1997) reported that the supplementation of BCM at the rate of 5 g per day in ruminants' diet reduces methane production up to 15 h posttreatment. The improvement in the feed conversion efficiency has been reported due to addition of BCM (McCrabb 2000). A compound containing BCM and cyclodextrin was found very effective against enteric methane production in ruminants (May et al. 1995). The mode of supplementation of BCM has significant effect on methane inhibition. Complete inhibition in methane production was reported in cattle when supplemented at hourly interval and when fed twice daily to cattle over an 8-week period; it reduced methane to the tune of about 50 % (McCrabb et al. 1997). The chemical (BCM) is highly volatile; therefore, it was stabilized by tannins, and the feeding trials were conducted on the diet supplemented with BCM and tannin. BCM was highly effective and caused 89 % reduction in methane production in sheep (Sarvanan 2000). Feeding of BCM with alkali-treated mahua seed cake also showed methane reduction in sheep (Bhar and Haque 2004). Another compound 2-bromoethanesulphonic acid (BES) has been tried by researchers to reduce methanogenesis in the rumen, and the results have been very encouraging on methane inhibition under in vitro conditions (Choi et al. 2004; Agarwal et al. 2008). The major drawback in using halogenated compounds as methane inhibitors is that the rumen microbes get adapted and the inhibitory effect on methane might be short lived (van Nevel and Demeyer 1996). The halogenated compounds are highly unstable and are also toxic to host as well as human beings.

16.4.3.3 Ionophores

Ionophores like monensin, lasalocid, tetronasin, lysocellin, salinomycin, etc., are commercially available, and they inhibit hydrogen-producing bacteria. The ionophores are lipophilic ion carriers. They pass through the porous peptidoglycan layer of Gram-positive bacteria and remain in lipid membrane which causes death of microorganism by affecting energy production of the cells (Tedeschi et al. 2003). There are several formate- and hydrogen-producing bacteria which are Gram negative and sensitive to ionophores and hamper the formation of substrates for methanogens. Monensin inhibits methanogens and also enhances propionate production.

Inclusion of Rumensin in the rice straw-based diet of cattle resulted in a significant depression in methane production and acetate production in the rumen accompanied by a significant increase in propionate levels without affecting the production of total volatile fatty acids in the rumen liquor (Singh and Mohini 1999). This resulted in reduced dry matter intake and a lower ammonia nitrogen level in the rumen liquor. There was no effect on bacterial and protozoal biomass in the rumen liquor on feeding of 50 or 100 mg Rumensin per day in the diet of animals.

The ionophore antibiotics might improve on an average 8 % in feed conversion efficiency of the animals that is mainly due to reduction in methanogenesis in the rumen and ultimately improved animal productivity (Chalupa 1988). The uses of chemicals/antibiotics as additive in livestock are being discouraged because of the adaptation of microbes to a particular chemical and the presence of residues in the animal products. Therefore, the use of chemicals/antibiotics to reduce methanogenesis in livestock is not a popular intervention to be used.

16.4.3.4 Inorganic Compounds

Supplementation of diet with inorganic salts like nitrate and sulphur is another strategy of inhibiting enteric methane emission. Sulphate- and nitrate-reducing bacteria are natural inhabitants of the rumen which serve as an alternate hydrogen sink to methane, but the reduced products, H_2S and nitrite, at higher concentrations are toxic to the animals. Therefore, the use of these feed additives is of limited importance, and therefore, one must take utmost care in using these chemicals as antimethanogenic agents in ruminants (Sakthivel et al. 2012). The number of sulphate- and nitrate-/nitrite-reducing bacteria is present in small numbers as these substrates are present in small quantities in the rumen. Slowly increasing the concentration of sulphate and nitrate in the ration might help in increasing the number of bacteria responsible for their reduction to H_2S, nitrite and ammonia. As these reactions are hydrogen consuming, there is a depression in methane production due to lower availability of hydrogen in the rumen.

Sar et al. (2004a) reported a decrease in methanogenesis in sheep given nitrate (1.3 g $NaNO_3/W^{0.75}$) along with galacto-oligosaccharide (GOS) at the rate of 10 g/day plus 100 ml of *Candida kefyr* (1×10^7 cfu/ml). Simultaneous administration of nitrate with GOS decreased nitrite accumulation in the rumen, plasma and nitrite-induced methaemoglobin and caused lower methane production. However, the rate of ruminal methane production in sheep administered nitrate along with GOS or nisin was not affected when compared to nitrate-treated sheep (Sar et al. 2004b). Lin et al. (2011) reported that the protozoa- and bacteria-rich fractions have an important role in nitrate reduction. The nitrate was not having any effect on VFA concentration, but there was a shift in molar proportion of VFA with higher acetate, lower propionate and lower butyrate along with less methane production.

Sar et al. (2005) suggested that *E. coli* W3110 plus nitrate and *E. coli* nir-Ptac plus nitrate both have potential to be used as feed additive to mitigate methane production (6–12 %) in sheep. Van Zijderveld et al. (2010) assessed the effect of dietary addition of nitrate (2.6 % of DM) and sulphate (2.6 % of DM) on methane emission in lambs. The animals were gradually given nitrate and sulphate in corn silage-based diet for 28 days and methane production was found to be decreased. They also found that the decrease in methane production was at maximum immediately after nitrate feeding, but the effect was uniform for the entire day in sulphate feeding. Methane production was reduced by 16 % in cows fed maize silage and replacing 1.5 % urea with 2.2 % nitrate gradually (25 % per week). The methane-reducing effect was over a 4-month period (Van Zijderveld et al. 2010). Sophea et al. (2010) concluded that the nitrate could be safely used as supplementary nitrogen source to improve DM intake and animal performance along with reduced methane emission. Similar results were also reported by Sophea and Preston (2011) when growing goat fed 0, 2, 4 and 6 % KNO_3 by replacing isonitrogenous amounts of urea in a diet of fresh mimosa silage, rice straw and water spinach.

The effect of dietary nitrate on methane production was studied in sheep which were acclimatized to oat hay diet supplemented with either 4 or 0 % KNO_3, but made isonitrogenous by the addition of urea (Nolan et al. 2010). Methane was reduced by 23 % in KNO_3-supplemented group. Hulshof et al. (2010) reported that the daily methane production per animal was reduced by 32 % when steers were fed nitrate (2.2 % of DM) without affecting DMI. Supplementation of calcium nitrate led to a reduction in the methane/carbon dioxide ratio in the goats compared with control animals supplemented with urea. Adding 0.8 % sulphur as sodium sulphate to the diet also reduced the methane/carbon dioxide ratio, with the two supplements having additive effects (Silivong et al. 2011). The addition of fumarate enhanced the rate of nitrate and nitrite reduction. The addition of fumarate lightens the inhibitory effects of nitrate on VFA production and cellulose digestion. The addition of nitrate and fumarate together resulted in decreased methane production without affecting rumen fermentation and feed digestion (Iwamoto et al. 1999). The use of nitrate seems to be one of the good strategies to be adapted by the livestock owners to reduce methanogenesis in the rumen. The animal must be adapted to nitrate feeding by gradually increasing the level in the diet to avoid nitrate/nitrite toxicity in ruminants.

16.5 Consequences of Partial or Complete Methane Inhibition

In a cattle weighing around 600 kg, approximately 1,000 l of hydrogen is generated, but on examination of the rumen gases, only traces of hydrogen are observed and the rest of hydrogen is converted immediately to methane, the most energy dense and highly reduced carbon compound which cannot be oxidized in the rumen due to absence of oxygen and is expelled out into the surrounding atmosphere. Therefore, if methanogenesis is inhibited (by any of the techniques listed above), one has to take care of molecular hydrogen generated during fermentation of feed. This hydrogen must be used by an alternate hydrogen sink available in the system itself for maximum efficiency of feed utilization. If this hydrogen is expelled out of the rumen as other gases, the benefit of methane inhibition will be lost. When alternate terminal electron acceptors are used as feed additive (like nitrate/nitrite, sulphate, etc.), there is an enhanced formation of ammonia and hydrogen sulphide which in excess might be toxic for other reactions going on in the rumen. This can be taken care of if sufficient basic structures are available in the ecosystem for synthesis of amino acids and sulphur-containing amino acids so that these toxic compounds are converted to safe protein precursors. There will not be any adverse effect of methane inhibition if hydrogen is not allowed to accumulate in the gas phase of the rumen, as hydrogen might inhibit further oxidation of glucose and other energy sources.

16.6 Conclusions

The literature surveyed in this chapter and the experience of laboratory for the last more than a decade in this area of research indicates that there do exist some of the techniques which have a potential to inhibit methanogenesis in the rumen and enhance feed conversion efficiency of feed. The in vivo trials conducted with plant secondary metabolites and terminal electron acceptors like nitrate and sulphate can be suitable feed supplements for controlling methane emission by the animals. Only long-term feeding trials are needed to test whether these feed supplements have any adaptation leading to reversion of methane inhibition and whether these feed supplements have any adverse effect on the quality and acceptability of the livestock products of animals fed these feed supplements.

References

Agarwal N, Kamra DN, Chaudhary LC (2006) Effect of *Sapindus mukorossi* extract on *in vitro* methanogenesis and fermentation characteristics in buffalo rumen liquor. J Appl Anim Res 30:1–4

Agarwal N, Kamra DN, Chatterjee PN, Kumar R, Chaudhary LC (2008) Changes in microbial profile, methanogenesis and fermentation of green forages with buffalo rumen liquor as influenced by 2-bromoethanesulphonic acid. Asian-Australas J Anim Sci 21:818–823

Agarwal N, Shekhar C, Kumar R, Chaudhary LC, Kamra DN (2009) Effect of peppermint (*Mentha piperita*) oil on fermentation of feed and methanogenesis in *in vitro* gas production test. Anim Feed Sci Technol 148:321–327

Altun T, Hunt AÖ, Usta F (2006) Effects of clove oil and eugenol on anaesthesia and some hematological parameters of European eel *Anguilla anguilla*, L., 1758. J Appl Anim Res 30:171–176

Apisariyakul A, Vanittanakom N, Buddhasukh D (1995) Antifungal activity of turmeric oil extracted from *Curcuma longa* (Zingiberaceae). J Ethnopharmacol 49:163–169

Asanuma N, Iwamoto M, Hino T (1999) Effect of the addition of fumarate on methane production by ruminal microorganisms in vitro. J Dairy Sci 82:780–787

Ashbey KD, Casey TA, Rasmussen MA, Petrich JW (2001) Steady-state and time-resolved spectroscopy of F_{420} extracted from methanogen cells and its utility as a marker for fecal contamination. J Agric Food Chem 49:1123–1127

Bauchop T, Mountfort DO (1981) Cellulose fermentation by rumen anaerobic fungus in both the absence and presence of rumen methanogens. Appl Environ Microbiol 42:1103–1110

Beauchemin KA, McGinn SM (2006) Methane emissions from beef cattle: effects of fumaric acid, essential oil, and canola oil. J Anim Sci 84:1489–1496

Begum S, Hassan SI, Ali SN, Siddiqui BS (2004) Chemical constituents from the leaves of *Psidium guajava*. Nat Prod Res 18:135–140

Bhar R, Haque N (2004) Effect of mode of supplementation of bromochloromethane with alkali treated mahua seed cake on methane production in sheep fed on roughage based diet. In: Proceedings of the X animal nutrition conference, NDRI, Karnal, Nov 9–11

Bodas R, Lopez S, Fernandez M, Garcia-Gonzalez R, Rodriguez AB, Wallace RJ, Gonzalez JS (2008) *In vitro* screening of the potential of numerous plant species as antimethanogenic feed additives for ruminants. Anim Feed Sci Technol 145:245–258

Brooker SG, Cambie RC, Cooper RC (1981) New Zealand medicinal plants. Heinemann Publishers, Auckland

Busquet M, Calsamiglia S, Ferret A, Carro MD, Kamel C (2006) Effect of garlic oil and four of its compounds on rumen microbial fermentation. J Dairy Sci 88:4393–4404

Carro MD, Lopez S, Valdes C, Ovejero FJ (1999) Effect of D, L-malate on mixed ruminal microorganism fermentation using the rumen simulation technique (RUSITEC). Anim Feed Sci Technol 79:279–288

Carulla JE, Kreuzer M, Machmüller A, Hess HD (2005) Supplementation of *Acacia mearnsii* tannins decreases methanogenesis and urinary nitrogen in forage-fed sheep. Aust J Agric Res 56:961–970

Chalupa W (1988) Manipulation of rumen fermentation. In: Haresign W, Cole DJA (eds) Recent developments in ruminant nutrition 2. Butterworths, London, pp 1–18

Chatterjee PN (2005) Influence of diet and plant secondary compounds on methanogenesis and rumen fermentation pattern. PhD thesis, IVRI Deemed University, Izatnagar, India

Chaudhary LC, Kamra DN, Singh R, Agarwal N, Pathak NN (2000) Effect of feeding bentonite on rumen fermentation, enzyme activity and protozoal population in adult buffaloes (*Bubalus bubalis*). Buffalo J 16:73–79

Chaudhury RR (1995) Principles of pharmacology: basic concepts and clinical applications. In: Munson PL, Mueller RA, Breese GR (eds) Chapman & Hall International, New York, pp 1530–1533

Choi NJ, Lee SY, Sung HG, Lee SC, Ha JK (2004) Effect of halogenated compounds, organic acids, unsaturated fatty acids on in vitro methane production. Asian-Australas J Anim Sci 17:1255–1259

Conrad R, Phelps TJ, Zeikus JG (1985) Gas metabolism evidence in support of the juxtaposition of hydrogen-producing and methanogenic bacteria in sewage sludge and lake sediments. Appl Environ Microbiol 50:595–601

Craker LE, Giblette J (2002) Chinese medicinal herbs: opportunities for domestic production. In: Janick J, Whipkey A (eds) Trends in new crops and new uses. ASHS Press, Alexandria

Elizabeth KM (2005) Antimicrobial activity of *Terminalia bellerica*. Indian J Clin Biochem 20:150–153

Fricke WF, Seedorf H, Henne A, Kruer M, Liesegang H, Hedderich R, Gottschalk G, Thauer RK (2006) The genome sequence of Methanosphaera stadtmanae reveals why this human intestinal archaeon is restricted to methanol and H_2 for methane formation and ATP synthesis. J Bacteriol 188:642–658

Gebeyehu A, Mekasha Y (2013) Defaunation: effects on feed intake, digestion, rumen metabolism and weight gain. Wudpecker J Agric Res 2:134–141

Hegarty RS (1999) Reducing rumen methane emissions through elimination of rumen protozoa. Aust J Agric Res 50:1321–1328

Hess HD, Beuret RA, Lotscher M, Hindrichsen IK, Machmüller A, Carulla JE, Lascano CE, Kreuzer M (2004) Ruminal fermentation, methanogenesis and nitrogen utilization of sheep receiving tropical grass hay-concentrate diets offered with *Sapindus saponaria* fruits and *Cratylia argentea* foliage. Anim Sci 79:177–189

Hino T, Asanuma N (2003) Suppression of ruminal methanogenesis by decreasing the substrates available to methanogenic bacteria. Nutr Abstr Rev Ser B 73:1R–8R

Holtshausen L, Chaves AV, Beauchemin KA, McGinn SM, McAllister TA, Odongo NE, Cheeke PR, Benchaar C (2009) Feeding saponin-containing *Yucca schidigera* and *Quillaja saponaria* to decrease enteric methane production in dairy cows. J Dairy Sci 92:2809–2821

Hulshof RBA, Berndt JJ, Demarchi A, Gerrits WJJ, Perdok HB (2010) Dietary nitrate supplementation reduces methane emission in beef cattle fed sugarcane-based diets. In: Proceedings of the 4th international conference *GGAA*, Banff, Canada, p 81

IPCC (2011) Intergovernmental Panel on Climate Change. UNEP, United Nations, Geneva

Iwamoto M, Asanuma N, Hino T (1999) Effects of nitrate combined with fumarate on methanogenesis, fermentation and cellulose digestion by mixed ruminal microbes in *in vitro*. Anim Sci J 70:471–478

Jaiarj P, Khoohaswan P, Wongkrajang Y, Peungvicha P, Suriyawong P, Saraya MLS, Ruangsomboon O (1999) Anticough and antimicrobial activities of *Psidium guajava* Linn. leaf extract. J Ethnopharmacol 67:203–212

Joblin KN, Matsui H, Naylor GE, Ushida K (2002) Degradation of fresh ryegrass by methanogenic co-cultures of ruminal fungi grown in the presence or absence of *Fibrobacter succinogenes*. Curr Microbiol 45:46–53

Kamra DN (2014) Enteric methane mitigation: present status and future prospects. In: Proceedings of the global animal nutrition conference (Glance) 2014. Climate resilient livestock feeding systems for global feed security, NIANP, Bangalore, pp 77–87

Kamra DN, Singh R, Agarwal N, Pathak NN (2000) Soapnut (Reetha) as natural defaunating agent – its effect on rumen fermentation and *in sacco* degradability of jowar hay in buffaloes. Buffalo J 16:99–104

Kamra DN, Agarwal N, Chaudhary LC (2006) Inhibition of ruminal methanogenesis by tropical plants containing secondary compounds. Int Congr Ser 1293:156–163

Kamra DN, Patra AK, Chatterjee PN, Kumar R, Agarwal N, Chaudhary LC (2008) Effect of plant extracts on methanogenesis and microbial profile of the rumen of buffalo: a brief overview. Aust J Exp Agric 48:175–178

Kapoor A (1997) Antifungal activities of fresh juice and aqueous extracts of turmeric and ginger (*Zingiber officinale*). J Phytol Res 10:59

Kittelmann S, Janssen PH (2011) Characterization of rumen ciliate community composition in domestic sheep, deer and cattle, feeding on varying diets, by means of PCR-DGGE and clone libraries. FEMS Microbiol Ecosyst 75:468–481

Kumar R, Kamra DN, Agarwal N, Chaudhary LC (2009) Effect of eucalyptus (*Eucalyptus globulus)* Oil on *in vitro* methanogenesis and fermentation of feed with buffalo rumen liquor. Anim Nutr Feed Technol 9:237–243

Kumar R, Kamra DN, Agarwal N, Chaudhary LC, Zadbuke SS (2011) Effect of tree leaves containing plant secondary metabolites on *in vitro* methanogenesis and fermentation of feed with buffalo rumen liquor. Anim Nutr Feed Technol 11:103–114

Lin CZ, Raskin L, Stahl DA (1997) Microbial community structure in gastrointestinal tracts of domestic animal: comparative analyses using rRNA targeted oligonucleotide probes. FEMS Microbiol Ecol 22:281–294

Lin M, Schaefer DM, Guo WS, Ren LP, Meng QX (2011) Comparisons of in vitro nitrate reduction, methanogenesis, and fermentation acid profile among rumen bacterial, protozoal and fungal fractions. Asian-Australas J Anim Sci 24:471–478

Lin B, Lu Y, Salem AZM, Wang JH, Liang Q, Liu JX (2013) Effects of essential oil combinations on sheep ruminal fermentation and digestibility of a diet with fumarate included. Anim Feed Sci Technol 184:24–32

Lopez S, Mcintosh FM, Wallace RJ, Newbold CJ (1999) Effect of adding acetogenic bacteria on methane production by mixed rumen microorganisms. Anim Feed Sci Technol 78:1–9

Lozoya X, Meckes M, Abou-Zaid M, Tortoriello J, Nozzolillo C, Amason JT (1994) Quercetin glycosides in *Psidium guajava* L. leaves and determination of spasmolytic principle. Arch Med Res 25:11–15

Machmuller A, Solvia CR, Kreuzer M (2003) Effect of coconut oil and defaunation treatment on methanogenesis in sheep. Reprod Nutr Dev 43:41–55

Martin SA, Streeter MN (1995) Effect of malate on in vitro mixed ruminal microorganism fermentation. J Anim Sci 73:2141–2145

Martin SA, Streeter MN, Nisbet DJ, Hill GM, Willamns SE (1999) Effects of DL-malate on ruminal metabolism and performance of cattle fed a high-concentrate diet. J Anim Sci 77:1008–1015

May C, Payne AL, Stewart PL, Edgar JA (1995) A delivery system for agents. International Patent Application No. PCT/AU95/00733

McCrabb GJ (2000) The relationship between methane inhibition, feed digestibility and animal production in ruminants. In: Methane mitigation international conference 2, 2000, Novasibirsk, Russia. Proceedings of the Novasibirsk, pp 125–131

McCrabb GJ, Berger KT, Magner T, May C, Hunter RA (1997) Inhibiting methane production in Brahman cattle by dietary supplementation with a novel compound and the effects on growth. Aust J Agric Res 48:323–329

Montano MF, Chai W, Zinn-Ware TE, Zinn RA (1999) Influence of malic acid supplementation on ruminal pH, lactic acid utilization, and digestive function in steers fed high-concentrate finishing diets. J Anim Sci 77:780–784

Morton JF (1981) Atlas of medicinal plants of middle America. Bahamas to Yucatan. C.C. Thomas, Springfield

Morvan B, Dore J, Rieu-Lesme F, Foucat L, Fonty G, Gouet P (1994) Establishment of hydrogen-utilizing bacteria in the rumen of the newborn lamb. FEMS Microbiol Lett 117:249–256

Mountfort DO, Asher RA, Bauchop T (1982) Fermentation of cellulose to methane and carbon dioxide by a rumen anaerobic fungus in a triculture with *Methanobrevibacter* sp. strain RA1 and *Methanosarcina barkeri*. Appl Environ Microbiol 44:128–134

Nanir SP, Kadu BB (1987) Effect of medicinal plant extracts on some fungi. Acta Bot Ind 15:170

Newbold CJ, Rode LM (2006) Dietary additives to control methanogenesis in the rumen. Int Congr Ser 1293:138–147

Newbold CJ, Lassalas B, Jouany JP (1995) The importance of methanogens associated with ciliate protozoa in ruminal methane production *in vitro*. Lett Appl Microbiol 21:230–234

Nicholson MJ, Evans PN, Joblin KN (2007) Analysis of methanogen diversity in the rumen using temporal temperature gradient gel electrophoresis: identification of uncultured methanogens. Microbiol Ecol 54:141–150

Nolan JV, Hegarty RS, Hegarty J, Godwin IR, Woodgate R (2010) Effects of dietary nitrate on rumen fermentation, methane production and digesta kinetics in sheep. Anim Prod Sci 50:801–806

Ouda JO, Newbold CJ, Lopez S, Nelson N, Moss AR, Wallace RJ, Omed H (1999) The effect of acrylate and fumarate on fermentation and methane production in the rumen simulating fermentor (Rusitec). Proc Brit Soc Anim Sci, p 36

Patra AK (2012) Estimation of methane and nitrous oxide emissions from Indian livestock. J Environ Monit 14:2673–2684

Patra AK, Yu Z (2013a) Effects of coconut and fish oils on ruminal methanogenesis, fermentation, and abundance and diversity of microbial populations *in vitro*. J Dairy Sci 96:1782–1792

Patra AK, Yu Z (2013b) Effects of vanillin, quillaja saponin, and essential oils on *in vitro* fermentation and protein-degrading microorganisms of the rumen. Appl Microbiol Biotechnol. doi:10.1007/s00253-013-4930-x

Patra AK, Kamra DN, Agarwal N (2006a) Effect of plant extracts on *in vitro* methanogenesis, enzyme activities and fermentation of feed in rumen liquor of buffalo. Anim Feed Sci Technol 128:276–291

Patra AK, Kamra DN, Agarwal N (2006b) Effect of plants containing secondary metabolites on *in vitro* methanogenesis, enzyme profile and fermentation of feed with rumen liquor of buffalo. Anim Nutr Feed Technol 6:203–213

Patra AK, Kamra DN, Agarwal N (2006c) Effect of spices on rumen fermentation, methanogenesis and protozoa counts in in vitro gas production test. Int Congr Ser 1293:176–179

Patra AK, Kamra DN, Bhar R, Kumar R, Agarwal N (2011) Effect of *Terminalia chebula* and *Allium sativum* on *in vivo* methane emission by sheep. J Anim Physiol Anim Nutr 95:187–191. doi:10.1111/j.1439-0396.2010.01039.x

Paul RG, Williams AG, Butler RD (1990) Hydrogenosomes in the rumen entodiniomorphid ciliate *Polyplastron multivesiculatum*. J Gen Microbiol 136:1981–1989

Pawar M, Kamra DN, Agarwal N, Chaudhary LC (2014) Effects of essential oils on *in vitro* methanogenesis and fermentation of feed with buffalo rumen liquor. Agric Res 3:67–74. doi:10.1007/s40003-014-0092-z

Puchala R, Min BR, Goetsch AL, Sahlu T (2005) The effect of a condensed tannin-containing forage on methane emission by goats. J Anim Sci 83:182–186

Rastogi RP, Mehrotra BN (1993) Compendium of Indian medicinal plants, vol 3, 1980–1984. Central Drug Research Institute, Lucknow and Publications and Information Directorate, New Delhi, p 831

Rouviere PE, Wolfe RS (1988) Novel biochemistry of methanogenesis. J Biol Chem 263:7913–7916

Sakthivel PC, Kamra DN, Agarwal N, Chaudhary LC (2012) Effect of sodium nitrate and nitrate reducing bacteria on *in vitro* methane production and fermentation with buffalo rumen liquor. Asian-Australas J Anim Sci 25:812–817

Samuel BS, Hansen EE, Manchester JK, Coutinho PM, Henrissat B, Fulton R, Latreille P, Kim K, Wilson RK, Gordon JI (2007) Genomic adaptations of Methanobrevibacter smithii to the human gut. Proc Natl Acad Sci U S A 104:10643–10648

Sar C, Santoso B, Gamo Y, Kobayash T, Shiozaki S, Kimura K, Mizukoshi H, Arai I, Takahashi J (2004a) Effects of combination of nitrate with β 1–4 galacto-oligosaccharides and yeast (*Candida kefyr*) on methane emission from sheep. Asian-Australas J Anim Sci 17:73–79

Sar C, Santoso B, Mwenya B, Gamo Y, Kobayashi T, Morikawa R, Kimura K, Mizukoshi H, Takahashi J (2004b) Manipulation of rumen methanogenesis by the combination of nitrate with β 1–4 galacto-oligosaccharides or nisin in sheep. Anim Feed Sci Technol 115:129–142

Sar C, Mwenya B, Pen B, Takaura K, Morikawa R, Tsujimoto A, Kuwaki K, Isogai N, Shinzato I, Asakura Y, Toride Y, Takahashi J (2005) Effect of ruminal administration of *Escherichia coli* wild type or a genetically modified with enhanced nitrite reductase activity on methane emission and nitrate toxicity in nitrate infused sheep. Br J Nutr 94:691–697

Sarvanan TS (2000) Effect of bromochloromethane on methanogenesis, nutrient utilization and growth rate of lambs. MVSc thesis, Indian Veterinary Research Institute, Izatnagar, India

Sarvanan TS, Haque N, Lal M, Kamra DN (2000) Third biennial conference of animal nutrition association, Hisar, India, p 124

Sharma VD, Sethi MS, Kumar A, Rarotra JR (1977) Antibacterial property of *Allium sativum* Linn.: *in vivo* and *in vitro* studies. Indian J Exp Biol 15:466–468

Sharp R, Ziemer CJ, Stern MD, Stahl DA (1998) Taxon specific associations between protozoal and methanogen populations in the rumen and in a model rumen system. FEMS Microbiol Ecol 26:71–78

Silivong P, Preston TR, Leng RA (2011) Effect of sulphur and calcium nitrate on methane production by goats fed a basal diet of molasses supplemented with mimosa (*Mimosa pigra*) foliage. Livest Res Rural Dev 23:Article #58. Retrieved from http://www.lrrd.org/lrrd23/3/sili23058.htm

Simon JE, Chadwick AF, Craker LE (1984) Herbs – an indexed bibliography, 1971–1980. Elsevier, Amsterdam

Singh GP, Mohini M (1999) Effect of different levels of monensin in diet on rumen fermentation, nutrient digestibility and methane production in cattle. Asian-Australas J Anim Sci 12:1214–1221

Singh S, Kushwaha BP, Nag SK, Bhattacharya S, Gupta PK, Mishra AK, Singh A (2012) Assessment of enteric methane emission of Indian livestock in different agro-ecological regions. Curr Sci 102:1017–1027

Sinha RK (1996) Ethnobotany – the renaissance of traditional herbal medicine. INA Shree Publishers, Jaipur, p 242

Sivarajan VV, Balachandran I (1996) Ayurvedic drugs and their plant sources. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, p 570

Skillman LC, Evans PN, Stromp C, Joblin KN (2006) 16S rDNA directed PCR primers and detection of methanogens in the bovine rumen. Lett Appl Microbiol 42:222–228

Sophea I, Preston TR (2011) Effect of different levels of supplementary potassium nitrate replacing urea on growth rates and methane production in goats fed rice straw, mimosa foliage and water spinach. Livest Res Rural Dev 23: Article #71. Retrieved from http://www.lrrd.org/lrrd23/4/soph23071.htm

Sophea I, Borin K, Leng RA, Preston TR (2010) Effect of different levels of supplementary potassium nitrate replacing urea on growth rates and methane production in goats fed sugar palm-soaked rice straw and mimosa foliage. MSc thesis, MEKARN-SLU. http://www.mekarn.org/MSC2008-10/theses/sophea.htm

Stange RR Jr, Midland SL, Eckert JW, Sims JJ (1993) An antifungal compound produced by grapefruit and Valencia orange after wounding of the peel. J Nat Prod 56:1627–1629

Suguna L, Singh S, Sivakumar P, Sampath P, Chandrakasan G (2002) Influence of *Terminalia chebula* on dermal wound healing in rats. Phytother Res 16:227–231

Swamy M, Bhattacharya S (2006) Budgeting anthropogenic greenhouse gas emission from Indian livestock using country specific emission coefficients. Curr Sci 91:1340–1353

Tedeschi LO, Fox DG, Tylutki TP (2003) Potential environmental benefits of ionophores in ruminant diets. J Environ Qual 32:1591–1602

Van Nevel C, Demeyer D (1996) Control of rumen methanogenesis. Environ Monit Assess 42:73–97

Van Zijderveld SM, Gerrits WJJ, Apajalahti JA, Newbold JR, Dijkstra J, Leng RA, Perdok HB (2010) Nitrate and sulfate: effective alternative hydrogen sinks for mitigation of ruminal methane production in sheep. J Dairy Sci 93:5856–5866

Wood TA, Wallace RJ, Rowe A, Price J, Yanez-Ruiz DR, Murray P, Newbold CJ (2009) Encapsulated fumaric acid as a feed ingredient to decrease ruminal methane emissions. Anim Feed Sci Technol 152:62–71

Wright A-DG, Auckland CH, Lynn DH (2007) Molecular diversity of methanogens in feedlot cattle from Ontario and Prince Edward Island, Canada. Appl Environ Microbiol 73:4206–4210

Yang CJ, Mao SY, Long LM, Zhu WY (2012) Effect of disodium fumarate on microbial abundance, ruminal fermentation and methane emission in goats under different forage: concentrate ratios. Animal 6:1788–1794

Yarlett N, Orpin CG, Munn EA, Yarlett NC, Greenwood CA (1986) Hydrogenosomes in the rumen fungus *Neocallimastix patriciarum*. Biochem J 236:729–739

17

Reducing Enteric Methane Emission Using Plant Secondary Metabolites

Raghavendra Bhatta

Abstract

Methane is produced from the anaerobic fermentation in ruminants as a pathway for the disposal of metabolic hydrogen produced during microbial metabolism. This methane is not only related to environmental problems but also is associated with energy losses to the tune of 8–12 % of ingested gross energy. In addition, methane is 23 times more potent as CO_2 in global warming, and its emissions from enteric fermentation and manure management cause 24 and 8 % of total methane emissions from anthropogenic activities, respectively. The increasing accumulation of CH_4 in the atmosphere has necessitated investigation on newer strategies of manipulating the rumen ecosystem to ameliorate methane emission. Various strategies have been developed to reduce ruminal methanogenesis by means of chemical and biotechnological means and by nutritional management. The use of concentrate to ameliorate methane emissions from livestock is practically difficult in many parts of the world including India due to the high price of cereals and their competition with human food. There are many naturally occurring compounds that appear to have anti-methanogenic properties, such as tannins, saponins, and essential oils. Researchers are actively engaged in evaluating the potential of these secondary plant constituents as natural means of modifying ruminal fermentation.

Keywords

Enteric methane • Plant secondary metabolites • Tannins • Saponins • Essential oils • Protozoa • Methane amelioration

---

R. Bhatta (✉)
ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Hosur Road, Bangalore, Karnataka 560 030, India
e-mail: ragha0209@yahoo.com

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_17, © Springer India 2015

17.1 Introduction

Ruminants produce methane from anaerobic fermentation in their gastrointestinal tracts as a pathway for the disposal of metabolic hydrogen produced during microbial metabolism. The methane produced from enteric fermentation of ruminants is not only related to environmental problems but also is associated with energy losses. Further, methane is 23 times as potent as CO_2 in global warming, and its emissions from enteric fermentation and manure management cause 24 and 8 % of total methane emissions from anthropogenic activities, respectively. Singhal et al. (2005) concluded that methane emission by indigenous cattle, buffalo, goat, crossbred cattle, and sheep is 48.5, 39, 4.7, 4.6, and 1.8 % of the total methane emitted by the livestock in India. Besides, emission of methane causes around 2–12 % loss of feed energy depending on the type of feed given to the animals (Johnson and Johnson 1995). The increasing accumulation of CH_4, one of the most important greenhouse gases in the atmosphere, has necessitated investigation on newer techniques of manipulating the rumen ecosystem to mitigate methane emission.

Numerous strategies have been developed to reduce ruminal methanogenesis by means of chemical (Itabashi et al. 2000) and biotechnological means (Attwood and McSweeney 2008) as well as by nutritional management, including through supplementation. The use of concentrate to mitigate methane emissions from livestock is difficult to implement in many areas of the world including India due to the high price of cereals on the market and its competition with human food. There are naturally occurring compounds in some forage that appear to have anti-methanogenic properties, specially tannins, saponins, and essential oils (Bhatta et al. 2012a, b). Researchers are actively engaged in evaluating the potential of secondary plant constituents as natural means of modifying ruminal fermentation (Bhatta et al. 2013a, b, c). The enormous biological diversity within tropical trees and shrubs provides a bank of materials that can be used in animal feeding to improve productive efficiency and also as future strategies for methane amelioration (Bhatta et al. 2000, 2001, 2005).

17.2 Plant Secondary Metabolites

The plant secondary metabolites (PSMs) are a vast variety of chemical compounds synthesized in plants besides primary metabolic products that are not involved in the primary biochemical processes of growth and reproduction. These bioactive compounds, which have antimicrobial activities, are meant for the protection of the host plant against invasion by the foreign particles including pathogenic microbes. Therefore, these compounds have been used as medicine in traditional system of medicine in India, China, Sri Lanka, Japan, and other Asian and African countries, for the preservation of foods and as spices in kitchen in many parts of the world since time immemorial. More than 200,000 defined structures of plant secondary compounds have been identified. The use of natural bioactive compounds like PSM, which are generally recognized as safe by the FDA instead of chemical compounds like antibiotics, methane analogues, ionophore as additives in livestock nutrition, etc., could be a novel approach to inhibit methane emission by the livestock (Tedesco et al. 2004). The effects of plant extracts are attributed to synergistic and/or antagonistic interactions of several secondary metabolites acting at single or multiple target sites (Cordell 2000).

Bioactive plant metabolites have been an important area of research to substitute chemical feed additives (Bhatta et al. 2006, 2008). Many phytochemicals such as saponins, tannins, essential oils, and many other unknown metabolites from a wide range of plant sources show potential for methane mitigation options (Kamra et al. 2008; Patra et al. 2008). These metabolites lessen methane production through a direct effect on methanogens and/or elimination of protozoa (Bhatta et al. 2009), reduction of organic matter (OM) digestion, and modification of fermentation in the rumen (Patra and Saxena 2010).

17.2.1 Tannins

The tannins are polyphenolic substances with variable molecular weights and complexity. These are chemically not well-defined substances but rather a group of substances with the ability to bind proteins in aqueous solution and are found as secondary metabolites. Their multiple phenolic hydroxyl groups lead to the formation of complexes primarily with proteins and to a lesser extent with metal ions, amino acids, and polysaccharides (Makkar 2003). Dietary tannins adversely affect fermentation by bacteriostatic and bactericidal activities and by inactivating ruminal enzymes. Based on their structure and chemical properties, tannins are divided into hydrolyzable tannins (HT: hydrolyzable tannins have a central carbohydrate core to which a number of phenolic carboxylic acids are bound by esters of gallic acid, gallotannin or ellagic acid, and ellagitannins) and condensed tannins (CT or proanthocyanidins, which have no carbohydrate core and are derived by condensation of flavonoid precursors, polymers of flavonoids) (Baker 1999). Tannins are considered to have both adverse and beneficial effects depending on their concentration and nature besides other factors such as animal species, physiological state of animal, and composition of diet (Makkar 2003).

Plant secondary metabolites might inhibit methane emission by the following modes as described by Kamra et al. (2012a):

- They might directly inhibit methanogens as these compounds have antimicrobial activities against different microbial groups.
- The plant secondary metabolites might have antiprotozoal activity, which might indirectly result in reduced number of methanogens. As the ciliate protozoa and methanogens have an ectosymbiotic relationship, the latter might lose their symbiotic partners and hydrogen supply due to killing of ciliates by the plant secondary metabolites and, therefore, might result in reduced production of methane.
- As the plant secondary metabolites have antimicrobial activity, which might reduce the numbers of bacteria and fungi and thus result into lower digestibility of feed and consequently cause a decrease in methanogenesis as the feed degradation and methane production are directly related to each other.

More than 450 plants containing secondary metabolites were screened for their ability to inhibit methanogenesis in in vitro experiments in a major project in Europe “RUMEN UP.” Out of the plants examined, 35 plants inhibited methane by more than 15 %, and only six plants (*Carduus pycnocephalus* L., *Populus tremula* L., *Prunus avium* L., *Quercus robur* L., *Rheum nobile* Hook. F. and Thoms., and *Salix caprea* L.) inhibited methane by more than 25 % (Bodas et al. 2008). These plants did not have any adverse effect on any of the fermentation parameters tested, indicating that the secondary metabolites present in these plants were selective inhibitors of methanogenic archaea and did not affect any other rumen microbe at the level used in this experiment.

The extracts (in water, ethanol, and methanol) of 41 plants (including 5 seed pulps, 20 leaves, 13 spices, and 3 fruit peels) containing plant secondary metabolites and three oils were screened in in vitro gas production test for their antimethanogenic and antiprotozoal activity by Kamra et al. (2006). The extracts of seed pulp of *Terminalia chebula*; leaves of *Populus deltoides* and *Psidium guajava*; spices like *Foeniculum vulgare*, *Syzygium aromaticum*, and *Allium sativum*; and oils like *Mentha piperita* and *Eucalyptus globulus*, when included in the incubation medium, exhibited more than 50 % inhibition in in vitro methanogenesis, whereas extracts of *Quercus incana* and *Trachyspermum ammi* inhibited methanogenesis by 25–50 %. Among these plants, the extracts of *T. chebula*, *S. aromaticum*, *P. guajava*, and *T. ammi* and the oils tested reduced protozoa population density by more than 50 %. But in some cases, the reduction in methanogenesis was accompanied with inhibition in in vitro digestibility of feed (Kamra et al. 2006, 2008; Patra et al. 2006; Agarwal et al. 2009; Kumar et al. 2009). Further, 23 combinations of these selected plant parts were evaluated to achieve maximum inhibition in methane production with no adverse effect on feed digestibility.

Bhatta et al. (2009) observed that inclusion of a *quebracho* tannin sample containing 7.62 % HT and 3.67 % CT inhibited methane at 50 g/kg of substrate. Waghorn et al. (2002) reported that in vitro incubation of *Lotus pedunculatus* (containing tannin) had lower methane production compared with *L. pedunculatus* treated with PEG. In the same study, sheep fed *L. pedunculatus* produced 17 % less methane compared with sheep fed *L. pedunculatus* plus PEG. Very few reports are available regarding the biological activities of tannin fractions on ruminal methane production. Extracts of HT, such as gallotannic acid, showed 50 % inhibition of methane production with lower inhibition associated with monomers compared with polymers (Field and Lettinga 1987). Kumar et al. (2007) analyzed the effect of extracts of tanniferous leaves on in vitro methanogenesis and observed methane inhibition to the tune of 35.7, 24.3, and 23.2 % with the use of methanol extract of mango and jamun leaves and ethanol extract of mango leaves, respectively. Methanol extract of *T. chebula* decreased methane production in vitro by 95 % when incubated at the level of 0.25 ml/30 ml incubation medium, and complete inhibition was observed at double this level (Patra et al. 2006). Hydrolyzable tannins such as gallotannic acid inhibited 50 % methane production from sludge at a concentration of 0.7 g/l (Field and Lettinga 1987).

Effect of tannin extracts on methane production both in vitro and in vivo condition depends upon their source and dose. For example, addition of *Acacia mearnsii* tannin extracts reduced methane production by 10 % in sheep (Carulla et al. 2005) and up to 30 % in cattle (Grainger et al. 2009). Inclusion of methanol extract of pericarp of *Terminalia chebula* reduced in vitro methane production up to 90 % (Patra et al. 2006) and in sheep fed 10 g/kg of DM intake (Patra et al. 2010). This was attributed to the presence of hydrolyzable tannins in these fruits. Min et al. (2005) reported in an in vitro condition that quebracho tannin (75 % CT) included at concentrations of 1–2 g/l decreased methane production by 12.3–32.6 %. Rumen inoculum collected from cattle grazing wheat grass fed with quebracho tannins at 10–20 g/kg DM intake decreased methane production by 25–51 % in vitro (Min et al. 2006). However, this anti-methanogenic effect was not seen in cattle grazing wheat grass in vegetative stage (Min et al. 2006). Recently, Bhatta et al. (2009) reported that quebracho tannins inhibited the methane production linearly (13–45 %) with increasing doses (5–25 % of substrates). However, Beauchemin et al. (2007) did not find any effect on methanogenesis when a quebracho tannin extract (10–20 g/kg DM intake) was fed to beef cattle, which may be due to low dosages of tannins. It has been suggested that the action of CT on methanogenesis may be attributed to the direct inhibitory effects on methanogens depending upon the chemical structure of CT and also indirectly by decreasing fiber degradation (Patra and Saxena 2010). Bhatta et al. (2009) established that the effect of tannin on methane is directly due to reduced number of methanogen and indirectly due to reduced number of protozoa. For the first time, it was unequivocally proved that sources containing both CT and HT were more effective as methane suppressants than those containing only HT (Bhatta et al. 2009). Large number of tree leaves, medicinal and aromatic plants/shrubs, were screened by Bhatta et al. (2013a, b, c), and some of them have shown very promising results as methane suppressants (Tables 17.1 and 17.2) to be used in ruminant diets.

The above results based on the effect of PEG on in vitro incubation established that plants containing secondary metabolites such as *A. integrifolis*, *J. curcas*, *S. grandiflora*, *Rauvolfia serpentina*, *Indigofera tinctoria*, and *Withania somnifera* have great potential to suppress methanogenesis. Further, it was also established that methanogenesis was not essentially related to the density of protozoa population in vitro. The tannins contained in these plants could be of interest in the development of new additives in ruminant nutrition. The optimum dose to get maximum methane suppression without any adverse effect on digestibility needs to be determined.

Sheep fed *Lotus pedunculatus* (80 g CT/kg DM) yielded less methane than when fed on perennial ryegrass or grazing on lucerne pasture (3.9, 6.2, and 5.7 % GEI, respectively). Similar

Table 17.1 Gas production (ml/200 mg DM), methane production with and without PEG, and methane reduction/ml of total gas reduction (ratio) among tree leaves

	Gas production (ml/200 mg DM)		Tannin bioassay	Methane (ml)		Methane reduction/ml of total gas reduction
Tree leaves	−PEG	+PEG	(percent increase in gas[a])	−PEG	+PEG	
Autocarpus integrifolis	32.2	32.8	1.86	3.67	6.51	4.73
Azadirachta indica	18.1	32.3	78.5	3.16	6.13	0.21
Ficus benghalensis	2.38	15.6	555	0.43	3.86	0.26
Ficus mysorensis	19.2	22.8	18.8	3.08	4.45	0.38
Ficus racemosa	29.2	29.8	2.05	5.90	5.86	0
Ficus religiosa	30.8	31.4	1.95	5.47	7.62	3.58
Glyricidia maculata	29.9	30.2	1.00	7.73	7.77	0.13
Jatropha curcas	21.2	22.2	4.72	3.83	7.26	3.43
Leucaena leucocephala	31.2	35.2	12.8	8.61	8.12	0
Moringa oleifera	37.0	39.6	7.03	9.15	10.17	0.39
Morus alba	25.2	28.2	11.9	5.19	4.72	0
Simarouba glauca	28.7	32.7	13.9	3.55	3.93	0.09
Sesbania grandiflora	36.8	39.8	8.15	4.45	10.51	2.02

Samples were incubated at 1:2 ratio with PEG-6000 (w/w basis)

For calculation of methane (%) and methane increase with PEG addition (%)

[a] On PEG-6000 addition percent increase represents increase with PEG addition compared to without PEG

responses were also reported by Woodward et al. (2001), when dairy cows were fed silages of *L. pedunculatus* or perennial ryegrass. In addition, other in vitro studies have also found depression of methane production with other CT-containing plant species, such as *Mangifera indica* and sainfoin (*Onobrychis viciifolia*) (McMahon et al. 1999). In another study, in which diets differing in protein source (soybean meal, pea, or rapeseed meal) were supplemented with very high proportion of tannin-rich extracts from chestnut and mimosa (HT) or quebracho (CT), chestnut tannin was very effective in reducing methane production. Woodward et al. (2001) reported that methane emission relative to digestible DMI was decreased by 24–29 % when CT-containing forage *L. pedunculatus* was fed compared with ryegrass or lucerne in sheep. It is believed that tannins adversely affect feed intake by the animals; however, the effect is dose dependent as plant species with high CT content reduce the feed intake drastically, while medium and low consumption has no effect on feed intake. Feeding of high tannin (CT) forage *Lespedeza striata* to goats at increasing levels (0, 33, 67, and 100 % inclusion) decreased methane quadratically (26.2, 17.6, 13.8, and 10.91 l/d) along with decreased methanogen and protozoa population with stable population of other microbes (Animut et al. 2008). Hess et al. (2006) showed that the low-tannin legume *Cratylia argentea* addition had better methane inhibition than that of the tannin-rich legume *Calliandra calothyrsus* supplementation with minimal suppression of the feed intake. *Lotus pedunculatus* having condensed tannin, when fed to lamb, showed 16 % reduction in methane production (Waghorn et al. 2002).

In sheep fed with *T. chebula* and *A. sativum* alone or in combination (1:1) at the rate of 1 % of DMI, the methane emission (l/kg digested DM) and methane energy loss as a percent of digestible energy intake tended to be lower in *T. chebula* and mix groups as compared to control (Patra et al. 2011; Kumar et al. 2011; Verma et al. 2012; Kamra et al. 2012a, b). In a mixture of four plants (mix 12) when fed at the rate of 1 percent of DMI daily, 2 % of DMI on alternate day, and 3 % of DMI on every third day to the buffaloes, there was an inhibition in methane emission by 31.8 %, 19.5 %, and 5.56 %, respectively. There was no adverse effect on nutrient utilization, rumen

Table 17.2 Gas production (ml/200 mg DM), methane production with and without PEG, and methane reduction/ml of total gas reduction (ratio) among medicinal and aromatic plants

Name of the plant	Gas production (ml/200 mg DM)		TBA (percent increase in gas[a])	Methane (ml)		Methane reduction per ml of total gas reduction
	−PEG	+PEG		−PEG	+PEG	
Adhatoda zeylanica	29.3	29.7	1.37	6.21	6.92	1.78
Alpinia galanga	0.9	4.2	367	0.31	1.00	0.21
Andrographis paniculata	28.8	29.5	2.43	5.74	6.37	0.90
Artemisia annua	41.4	42.2	1.93	6.86	7.90	1.30
Artemisia absinthium	27.4	27.4	0.00	5.57	6.51	0.00
Cichorium intybus	31.4	36.4	15.9	8.05	5.05	0.00
Cinnamomum verum	16.2	18.2	12.3	2.87	4.31	0.72
Cymbopogon flexuosus	30.1	30.8	2.33	7.65	7.87	0.31
Cymbopogon martini	30.4	30.5	0.33	3.26	3.71	4.50
Cymbopogon winterianus	21.5	22.2	3.26	3.27	2.77	0.00
Foeniculum vulgare	27.4	28.1	2.55	4.52	5.03	0.73
Hemigraphis colorata	35.0	37	5.71	5.88	4.88	0.00
Indigofera tinctoria	31.2	31.3	0.32	3.42	5.10	16.80
Lavandula stoechas	29.8	30.2	1.34	3.96	4.14	0.45
Lawsonia inermis	40.1	42.1	4.99	3.36	6.40	1.52
Leucas aspera	36.5	38.4	5.21	5.41	5.64	0.12
Lippia citriodora	30.4	30.5	0.33	6.31	6.89	5.80
Medicago sativa	38.0	38.5	1.32	5.38	7.73	4.70
Melissa officinalis	13.5	14.9	10.4	3.06	3.59	0.38
Mentha citrata	25.5	25.8	1.18	1.50	2.96	4.87
Matricaria chamomilla	26.2	27.8	6.11	3.58	3.94	0.23
Murraya koenigii	28.9	30.2	4.50	2.18	2.88	0.54
Myristica fragrans	25.8	30.8	19.4	4.22	6.08	0.37
Oenothera lamarckiana	16.4	27.4	67.1	7.03	7.03	0.00
Origanum vulgare	20.5	21.2	3.41	2.07	2.68	0.87
Pandanus amaryllifolius	36.8	37.2	1.09	7.96	8.67	1.77
Pelargonium graveolens	12.5	25.1	101	2.12	5.31	0.25
Pimenta officinalis	6.9	20.2	193	4.09	1.85	0.00
Pogostemon cablin	21.8	22.1	1.38	4.32	4.66	1.13
Rauvolfia serpentina	33.8	34	0.59	7.25	33.6	131.75
Rauvolfia tetraphylla	25.8	26.8	3.88	5.16	5.36	0.20
Rosmarinus officinalis	10.2	12.2	19.6	1.66	2.88	0.61
Ruta graveolens	32.8	33	0.61	7.84	7.92	0.40
Salvia officinalis	26.1	27.1	3.83	6.31	6.06	0.00
Strobilanthes flaccidifolius	22.1	22.5	1.81	5.22	3.70	0.00
Taraxacum officinale	40.7	42.7	4.91	6.73	6.10	0.00
Thymus vulgaris	38.4	39.4	2.60	8.36	8.42	0.06
Withania somnifera	21.1	21.4	1.42	4.52	7.59	10.23

All the samples were leaf samples

Samples were incubated at 1:2 ratio with PEG-6000 (w/w basis)

TBA- tannin bioassay

[a] On PEG-6000 addition

Table 17.3 Effect of tannins, saponins, and essential oils on methane inhibition

Name of the phytochemicals	Animal	Dose of the phytochemical used	Methane inhibition (%) (compared with control)	References
Tannins				
Mimosa tannins	Goat	2.8 g/kg DM	9.0 %	Bhatta et al. (2013a, b, c)
Mimosa tannins	Goat	5.6 g/kg DM	11.0 %	Bhatta et al. (2013a, b, c)
Terminalia chebula seed pulp	Sheep	10 g/kg DM intake	No effect	Patra et al. (2010)
A. mearnsii tannins	Cattle	8.6 and 14.6 g/kg of DM intake	17 and 30 %	Grainger et al. (2009)
A. mearnsii tannins	Cattle	8.6 and 14.6 g/kg of DM intake	11.5 and 28 %	Grainger et al. (2009)
Acacia mearnsii extract (CT 72.5 %)	Sheep	41 g/Kg	9.9 %	Carulla et al. (2005)
Castanea sativa wood extract (contains HT 20 %)	Sheep	5 and 10.1 g/kg DM equivalent to 1 and 2 g/kg	−21.5 at 10.1 g/kg to 32.6 % at 5 g/kg	Sliwinski et al. (2002)
Saponins				
Tea saponins	Lamb	4.1 g/kg diet	27.2 %	Mao et al. (2010)
Y. schidigera extract (6 % saponins)	Dairy cows	10 g/kg of DM	No effect	Holtshausen et al. (2009)
Q. saponaria plant (3 % saponin)	Cattle	10 g/kg of DM	No effect	Holtshausen et al. (2009)
Saponins	Sheep	170 mg/day or 0.13 g/kg diet	15.5 %	Wang et al. (2009)
Tea saponins	Sheep	5 g/kg diet	8.71 %	Yuan et al. (2007)
Quillaja saponaria extract (5–7 % saponins)	Sheep	13.5 g/kg diet	16.9 %	Pen et al. (2007)
Yucca schidigera extract (8–10 % saponins)	Sheep	13.8 g/kg diet	11.7 %	Pen et al. (2007)
Sarsaponin	Sheep	0.12 g/kg diet	7.1 %	Santoso et al. (2004)
Sapindus saponaria fruit	Sheep	5 g/kg $BW^{0.75}$	6.5 %	Hess et al. (2004)
Sarsaponin (1.25 % saponins)	Sheep	0.002 and 0.03 g/kg DM of sarsaponin	No effect	Sliwinski et al. (2002)
Lucerne saponin (27.8 % saponins)	Sheep	10–40 g/kg diet	No effect	Klita et al. (1996)
Essential oil				
Cinnamaldehyde	Sheep	0.02 g/Kg diet	–	Ohene-Adjei et al. (2008)
Juniper berry oil (*Juniperus communis*)	Sheep	0.02 g/Kg diet	–	Ohene-Adjei et al. (2008)

microbial and enzyme profile, and rumen fermentation. In growing buffalo calves, feeding of mix 12 at the rate of 1.0 % of DMI daily resulted in improved feed conversion efficiency (5.94 *vs*. 6.36) (Kamra et al. 2006). The effect of tannins, saponins, and essential oils on methane inhibition was shown in Table 17.3.

17.2.2 Saponins

Saponins are high molecular weight glycosides in which sugars are linked to a hydrophobic aglycone (sapogenin) which may be triperpene or a steroid in nature. They form stable foam in aqueous solutions similar to soaps. Saponins occur in leaves, tuber, bark, roots, seeds, and fruits; however, saponins of all these sources are not promising methane inhibitors (Goel et al. 2008).

There is increasing evidence to suggest that addition of saponins in the diets suppress methane production due to reduced protozoal numbers and/or methanogenic archaeal activity. Depression in methane production up to 96 %, 39.4 %, and 20 % compared with controls with ethanol, water, and methanol extracts of *Sapindus mukorossi* seed pulp, respectively, was reported by Agarwal et al. (2006). However, despite a depression in protozoal numbers, saponins extracted from pods of *Acacia concinna* extracts did not affect methane production (Patra et al. 2006). Saponins of *Sapindus saponaria* suppressed methane production by 20 % without affecting methanogen numbers in Rusitec (Hess et al. 2003) or in lamb (Hess et al. 2004). It was reported that the effect of *S. saponaria* on methane was less pronounced in faunated (14 %) than in defaunated (29 %) rumen fluid. This indicated that reduced methane production per se was not entirely due to associated depression in protozoal numbers (Hess et al. 2003). The inhibitory activities of saponins on methanogenesis are not only dependent on the levels of saponins but also on the composition of diet itself. For example, saponins of *Sapindus rarak* fruits at lower levels had no effect on methanogens numbers while significantly reduced methanogen RNA concentration at the highest (4 mg/ml) saponin concentration (Wina et al. 2005). Goel et al. (2008) observed that methane inhibition effect of saponins from *Sesbania sesban* and fenugreek was pronounced in concentrate-based diets as compared to that with roughage-based diets. Total archaeal population was reduced by saponins extracted from *S. sesban* leaves (78 %), fenugreek seeds (22 %), and Knautia leaves (21 %). Despite inhibition of archaea, methane production was not affected in their study (Goel et al. 2008), which was attributed to the changes in the rate of methanogenesis as a result of changing fermentation pattern and microbial diversity. Patra and Saxena (2009) noted that one of the problems of using saponins or saponin-containing plants is that antiprotozoal activity was found to be transient. Protozoa did not become resistant to these antiprotozoal compounds (Newbold et al. 1997). Therefore, it is possible that bacterial populations of the rumen degraded the saponins or saponin-containing plants (Newbold et al. 1997). These results are providing conclusive evidence that mixed rumen microbial populations were able to adapt to saponins over a period of time. This presents a challenge for practical application of this technology at the field level. In addition to suppressing methane outputs, the use of saponins may also confer nutritional benefits as they might increase microbial protein synthesis due to inhibition of protozoa, and the fiber-degrading bacteria and fungi in the rumen might increase, which is beneficial for utilization of feeds in low-quality-based diets (Patra and Saxena 2009).

17.2.2.1 Effects of Saponins on In Vitro Rumen Fermentation

A number of studies have reported that saponins or plants rich in saponins decreased methane production in the rumen. Saponin extracts from *Yucca schidigera* and *Quillaja saponaria* have been demonstrated to reduce methanogenesis both in vitro (Pen et al. 2006, 2007) and in vivo (Holtshausen et al. 2009). Goel et al. (2008) in a study with saponin-rich fenugreek and sesbania extract in water, 50 % methanol, and 95 % methanol did not observe any methane inhibition in vitro, despite decrease in protozoa count by nearly 50 % in both concentrate and roughage-based diet, whereas supplementation of fenugreek and sesbania as such to hay, concentrate, or mixed substrate showed a decrease in methane production by 5.1–11.9 %. Agarwal et al. (2006) reported a reduced methane production in vitro with water, ethanol, and methanol extracts of soap nut (*Sapindus mukorossi*) with the highest in ethanol extract (96 %). The results on the effects of saponins on methane production are not always consistent even if same plant or similar types of animals are used.

17.2.2.2 Effect of Saponins on In Vivo Methane Emission

There are very few reports with saponin as a feed additive or supplementation to animal diets. One of the problems of using saponins or saponin-containing plants is (Newbold et al. 1997) that antiprotozoal activity was found to be transient. Kamra (2012b) after a series of studies reported that ethanol extract of soap nut at the rate of 20 ml/animal induced 67 % depression in methane emission (26.99 vs. 8.91 l/kg DDM). *Sapindus mukorossi* is rich in saponins and can be used for manipulation of rumen fermentation in sheep. *Y. schidigera* plant extract has been found to improve growth, feed efficiency, and health in ruminants Mader and Brumm (1987). *Sesbania sesban* leaves, known for their high saponin content, have been found to have a potential to improve protein flow from rumen by suppressing protozoal action (Newbold et al. 1997). The time dependence of the detoxification process of the saponins was clearly demonstrated in ruminal fluid in vitro. However, some of the studies suggested that protozoa per se did not develop resistance to these antiprotozoal compounds (Newbold et al. 1997). Therefore, it is possible that bacterial population of the rumen degraded saponins or saponin-containing plants, which are rendered no more effective against protozoa.

17.2.3 Essential Oils

There are a number of reports on the amelioration of methane production by essential oils (EO) and organosulfur compounds. Methanol and ethanol extracts of *Foeniculum vulgare* and *Syzygium aromaticum* inhibited methane production in vitro (Patra et al. 2006, 2010), which was also accompanied by reduction of degradability of feeds by *S. aromaticum*, whereas the extracts of *A. sativum* and *F. vulgare* had no effects on degradability of feeds (Patra et al. 2010). In an experiment with sheep fed on wheat straw and concentrate (1:1), inclusion of *Allium sativum* at 10 g/kg of DM intake also reduced methane production per unit of OM digested and increased digestibility of fiber (Patra et al. 2010). Thymol (400 mg/l), a main component of EO derived from *Thymus* and *Origanum* plants, was a strong inhibitor of methane in vitro (Evans and Martin 2000). In batch cultures with garlic oil (organosulfur compounds) and four of its main components, i.e., diallyl sulfide, diallyl disulfide, allyl mercaptan, and allicin, Busquet et al. (2005) observed that garlic oil and diallyl disulfide (300 mg/l of ruminal fluid) reduced methane production by 74 % and 69 %, respectively, without altering digestibility of nutrients. Busquet et al. (2005) hypothesized that garlic oil and diallyl disulfides have inhibited methane production due to the direct inhibition of rumen methanogens.

Ohene-Adjei et al. (2008) reported that cinnamaldehyde, garlic, and juniper oil supplementation did not affect total number of methanogenic archaea quantified by archaeal 16S rRNA in barley-based diet. In a culture-based study, EO did not inhibit *Methanobrevibacter smithii* up to a concentration of 0.16 ml/l, although inhibition occurred at 1.0 ml/l (McIntosh et al. 2003). The phylogenetic analysis showed that cinnamaldehyde, garlic, and juniper oil supplementation reduced the proportion of clones associated within the *M. ruminantium*-related cluster, which was more pronounced for juniper berry oil supplementation. In contrast, clones affiliated to *Methanosphaera stadtmanae* and *M. smithii* and some uncultured groups increased in the supplemented treatments. Ohene-Adjei et al. (2008) reported that EO increased the phylogenetic distribution of methanogenic archaea that might have resulted from changes in associated protozoal species. Agarwal et al. (2009) reported that inclusion of 0.33 ml/l of peppermint oil increased methanogen numbers by twofold, although there was a decrease in methane production by 20 % without affecting volatile fatty acid production. In this study, the higher levels (1 and 2 ml/l) of peppermint oil decreased total methanogen population and methane production. The decrease in methanogenesis at low doses might be associated with the changes in the rate of methanogenesis by archaea due to the alteration of archaeal community or in the activity of CH_4-producing genes (Ohene-Adjei et al. 2008).

17.3 Conclusion

Although phytochemicals such as tannins, saponins, and essential oils look very promising in suppressing enteric methane emissions in ruminants, results are not consistent in various studies due to great variations in chemical composition of phytochemicals, doses, and feed composition. A lot of research work still needs to be done to study the structure–activity relationship for practical application of phytochemicals at industry level to exploit the beneficial effects.

References

Agarwal N, Kamra DN, Chaudhary LC, Patra AK (2006) Effect of *Sapindus mukorossi* extracts on *in vitro* methanogenesis and fermentation characteristics in buffalo rumen liquor. J Appl Anim Res 30:1–4

Agarwal N, Chandra S, Kumar R, Chaudhary LC, Kamra DN (2009) Effect of peppermint (*Mentha piperita*) oil on *in vitro* methanogenesis and fermentation of feed with buffalo rumen liquor. Anim Feed Sci Technol 148:321–327

Animut G, Puchala R, Goetsch AL, Patra AK, Sahlu T, Varel VH, Wells J (2008) Methane emission by goats consuming diets with different levels of condensed tannins from lespedeza. Anim Feed Sci Technol 144:212–227

Attwood G, McSweeney C (2008) Methanogen genomics to discover targets for methane mitigation technologies and options for alternative H2 utilization in the rumen. Aust J Exp Agric 48:28–37

Baker SK (1999) Rumen methanogens and inhibition of methanogenesis. Aust J Agric Res 50:1293–1298

Beauchemin KA, McGinn SM, Petit HV (2007) Methane abatement strategies for cattle: lipid supplementation of diets. Can J Anim Sci 87:431–440

Bhatta R, Krishnamoorthy U, Mohammed F (2000) Effect of feeding tamarind (*Tamarindus indica*) seed husk as a source of tannin on dry matter intake, digestibility of nutrients and production performance of crossbred dairy cows in mid lactation. Anim Feed Sci Technol 83:67–74

Bhatta R, Krishnamoorthy U, Mohammed F (2001) Effect of tamarind (*Tamarindus indica*) seed husk tannins on *in vitro* rumen fermentation. Anim Feed Sci Technol 90:143–152

Bhatta R, Vaithiyanathan S, Shinde AK, Jakhmola RC (2005) Effect of feeding complete feed block containing *Prosopis cineraria* leaves and polyethylene glycol (PEG)-6000 on nutrient intake, its utilization, rumen fermentation pattern and rumen enzyme profile in kids. J Sci Food Agric 85:1788–1794

Bhatta R, Tajima K, Uyeno Y, Enishi O, Kurihara M (2006) Effect of plant extracts as natural source of tannins on methane production *in vitro*. In: International workshop on Monsoon Asia Agricultural Greenhouse Gas Emissions, March 7–9, Tsukuba, Japan, p 67

Bhatta R, Enishi O, Takusari N, Higuchi K, Nonaka I, Kurihara M (2008) Diet effects on methane production by goats and a comparison between measurement methodologies. J Agric Sci (Camb) 146:705–715

Bhatta R, Uyeno Y, Tajima K, Takenaka A, Yabumoto Y, Nonaka I, Enishi O, Kurihara M (2009) Difference in the nature of tannins on *in vitro* ruminal methane and volatile fatty acid production, and methanogenic archaea and protozoal populations. J Dairy Sci 92:5512–5522

Bhatta R, Saravanan M, Baruah L, Sampath KT (2012a) Nutrient content, in vitro ruminal fermentation characteristics and methane reduction potential of tropical tannin-containing leaves. J Sci Food Agric 92:2929–2935

Bhatta R, Saravanan M, Baruah L, Sampath KT (2012b) Phenolic composition, fermentation profile, protozoa population and methane production from sheanut (*Butyrospermum parkii*) byproducts in vitro. Asian-Australas J Anim Sci 25:1389–1394

Bhatta R, Saravanan M, Baruah L, Sampath KT, Prasad CS (2013a) In vitro fermentation profile and methane reduction in ruminal cultures containing secondary plant compounds. J Appl Microbiol 115:455–465

Bhatta R, Baruah L, Saravanan M, Suresh KP, Sampath KT (2013b) Effect of tannins from medicinal and aromatic plants on rumen fermentation, protozoa population and methanogenesis in vitro. J Anim Physiol Anim Nutr 97:446–456

Bhatta R, Enishi O, Yabumoto Y, Nonaka I, Takusari N, Higuchi K, Tajima K, Takenaka A, Kurihara M (2013c) Methane reduction and energy partitioning in goats fed two concentrations of tannin from Mimosa spp. J Agric Sci (Camb) 151:119–128

Bodas R, Lopez S, Fernandez M, Garcia-Gonzalez R, Rodriguez AB, Wallace RJ, Gonzalez JS (2008) In vitro screening of the potential of numerous plant species as antimethanogenic feed additives for ruminants. Anim Feed Sci Technol 145:245–258

Busquet M, Calsamiglia S, Ferret A, Carro MD, Kamel C (2005) Effect of garlic oil and four of its compounds on rumen microbial fermentation. J Dairy Sci 88:4393–4404

Carulla JE, Kreuzer M, Machmuller A, Hess HD (2005) Supplementation of Acacia mearnsii tannins decreases methanogenesis and urinary nitrogen in forage-fed sheep. Aust J Agric Res 56:961–970

Cordell GA (2000) Biodiversity and drug discovery- a symbiotic relationship. Phytochemistry 55:564–582

Evans JD, Martin SA (2000) Effects of thymol on ruminal micro-organisms. Curr Microbiol 41:336–340

Field JA, Lettinga G (1987) The methanogenic toxicity and anaerobic degradability of hydrolysable tannin. Water Res 21:367–374

Goel G, Makkar HPS, Becker K (2008) Changes in microbial community structure, methanogenesis and rumen fermentation in response to saponin-rich fractions from different plant materials. J Appl Microbiol 105:770–777

Grainger C, Clarke T, Auldist MJ, Beauchemin KA, McGinn SM, Waghorn GC, Eckard RJ (2009) Potential use of Acacia mearnsii condensed tannins to reduce methane emissions and nitrogen excretion from grazing dairy cows. Can J Anim Sci 89:241–251

Hess HD, Monsalve LM, Lascano CE, Carulla JE, Diaz TE, Kreuzer M (2003) Supplementation of a tropical grass diet with forage legumes and *Sapindus saponaria* fruits: effects on *in vitro* ruminal nitrogen turnover and methanogenesis. Aust J Agric Res 54:703–713

Hess HD, Beuret RA, Lotscher M, Hindrichsen IK, Machmüller A, Carulla JE, Lascano CE, Kreuzer M (2004) Ruminal fermentation, methanogenesis and nitrogen utilization of sheep receiving tropical grass hay-concentrate diets offered with *Sapindus saponaria* fruits and *Cratylia argentea* foliage. Anim Sci 79:177–189

Hess H, Tiemann T, Noto F, Carulla J, Kreuzer M (2006) Strategic use of tannins as means to limit methane emission from ruminant livestock. Int Congr Ser Elsevier 1293:164–167

Holtshausen L, Chaves AV, Beauchemin KA, McGinn SM, McAllister TA, Odongo NE, Cheeke PR, Benchaar C (2009) Feeding saponin-containing yucca schidigera and quillaja saponaria to decrease enteric methane production in dairy cows. J Dairy Sci 92:2809–2821

Itabashi H, Bayaru E, Kanda S, Nishida T, Ando S, Ishida M, Itch T, Isobe Y, Nagara K (2000) Effect of fumaric acid on methane production, rumen fermentation and digestibility in cattle. In: Proceedings of the 3rd joint symposium of Japan and Korea on Rumen metabolism and Physiology, 1–3 October, Japan

Johnson KA, Johnson DE (1995) Methane emissions from cattle. J Anim Sci 73:2483–2492

Kamra DN, Agarwal N, Chaudhary LC (2006) Inhibition of ruminal methanogenesis by tropical plants containing secondary compounds. Int Congr Ser 1293:156–163

Kamra DN, Patra AK, Chatterjee PN, Kumar R, Agarwal N, Chaudhary LC (2008) Effects of plant extract on methanogenesis and microbial profile of the rumen of buffalo: a brief overview. Aust J Exp Agric 48:175–178

Kamra DN, Agarwal N, Sakthivel PC, Chaudhary LC (2012a) Garlic as a rumen modifier for eco-friendly and economic livestock production. J Appl Anim Res 40:90–96

Kamra DN, Pawar M, Singh B (2012b) Effect of plant secondary metabolites on rumen methanogens and methane emission by ruminants. In: Patra A (ed) Dietary phytochemicals and microbes. Springer, Dordrecht/London, pp 351–370

Klita PT, Mathison GW, Fenton TW, Hardin RT (1996) Effects of alfalfa root saponins on digestive function in sheep. J Anim Sci 74:1144–1156

Kumar R, Kamra DN, Agarwal N, Chaudhary LC (2007) In vitro methanogenesis and fermentation of feeds containing oil seed cakes with rumen liquor of buffalo. Asian-Australas J Anim Sci 20:1196–1200

Kumar R, Kamra DN, Agarwal N, Chaudhary LC (2009) Effect of eucalyptus oil on *in vitro* methanogenesis and fermentation of feed with buffalo rumen liquor. Anim Nutr Feed Technol 9:237–243

Kumar R, Kamra DN, Agarwal N, Chaudhary LC (2011) Effect of feeding plant part mixture and peppermint oil on rumen fermentation, microbial profile and nutrient digestibility in fistulated buffaloes. Indian J Anim Sci 81:488–492

Mader TL, Brumm MC (1987) Effect of feeding Sarsaponin in cattle and swine diets. J Anim Sci 65:9–15

Makkar HPS (2003) Quantification of tannins in tree and shrub foliage. A laboratory manual. FAO/IAEA Publication, Rome, Italy

Mao HL, Wang JK, Zhou YY, Liu JX (2010) Effects of addition of tea saponins and soybean oil on methane production, fermentation and microbial population in the rumen of growing lambs. Livest Sci 129:56–62

McIntosh FM, Williams P, Losa R, Wallace RJ, Beever DA, Newbold CJ (2003) Effects of essential oils on ruminal microorganisms and their protein metabolism. Appl Environ Microbiol 69:5011–5014

McMahon LR, Majak W, McAllister TA, Hall JW, Jones GA, Popp JD, Cheng KJ (1999) Effect of sainfoin on *in vitro* digestion of fresh alfalfa and bloat in steers. Can J Anim Sci 79:203–212

Min BR, Pinchak WE, Fulford JD, Puchala R (2005) Wheat pasture bloat dynamics, *in vitro* ruminal gas production, and potential bloat mitigation with condensed tannins. J Anim Sci 83:1322–1331

Min BR, Pinchak WE, Anderson RC, Fulford JD, Puchala R (2006) Effects of condensed tannins supplementation level on weight gain and *in vitro* and *in vivo* bloat precursors in steers grazing winter wheat. J Anim Sci 84:2546–2554

Newbold CJ, Hassan SME, Wang J, Ortega ME, Wallace RJ (1997) Influence of foliage from African multipurpose tree on activity of rumen protozoa and bacteria. Br J Nutr 78:237–249

Ohene-Adjei S, Chaves AV, McAllister TA, Benchaar C, Teather RM, Forster RJ (2008) Evidence of increased diversity of methanogenic archaea with plant extract supplementation. Microb Ecol 56:234–242

Patra AK, Saxena J (2009) The effect and mode of action of saponins on microbial populations and fermentation in the rumen and ruminant production. Nutr Res Rev 22:204–219

Patra AK, Saxena J (2010) A new perspective on the use of plant secondary metabolites to inhibit methanogenesis in the rumen. Phytochemistry 71:1198–1222

Patra AK, Kamra D, Agarwal N (2006) Effects of plants containing secondary metabolites on *in vitro* methanogenesis, enzyme profile and fermentation of feed with rumen liquor of buffalo. Anim Nutr Feed Technol 6:203–213

Patra AK, Kamra DN, Agarwal N (2008) Effect of leaf extracts on fermentation of feds and methanogenesis with rumen liquor of buffalo. Indian J Anim Sci 78:91–96

Patra AK, Kamra DN, Bhar R, Kumar R, Chaturvedi VB, Agarwal N (2010) Effect of Terminalia chebula and Allium sativum on nutrient utilization and methane production in sheep. J Anim Physiol Anim Nutr 95:187–191

Patra AK, Kamra DN, Bhar R, Kumar R, Agarwal N (2011) Effect of *Terminalia chebula* and *Allium sativum* on *in vivo* methane emission by sheep. J Anim Physiol Anim Nutr 95:187–191

Pen B, Sar C, Mwenya B, Kuwaki K, Morikawa R, Takahashi J (2006) Effects of *Yucca schidigera* and *Quillaja saponaria* extracts on *in vitro* ruminal fermentation and methane emission. Anim Feed Sci Technol 129:175–186

Pen B, Takaura K, Yamaguchi S, Asa R, Takahashi J (2007) Effects of *Yucca schidigera* and *Quillaja saponaria* with or without β-1,4 galacto-oligosaccharides on ruminal fermentation, methane production and nitrogen utilization in sheep. Anim Feed Sci Technol 138:75–88

Santoso B, Mwenya B, Sar C, Gamo Y, Kobayashi T, Morikawa R et al (2004) Effects of supplementing galacto-oligosaccharides, Yucca schidigera and nisin on rumen methanogenesis, nitrogen and energy metabolism in sheep. Livest Prod Sci 91: 209–217

Singhal KK, Mohini M, Jha AK, Gupta PK (2005) Methane emission estimates from enteric fermentation in Indian livestock: dry matter intake approach. Curr Sci 88:119–127

Sliwinski BJ, Solvia CR, Machmuller A, Kreuzer M (2002) Efficacy of plant extracts rich in secondary constituents to modify rumen fermentation. Anim Feed Sci Technol 101:101–114

Tedesco D, Tava A, Galletti S, Tameni M, Varisco G, Costa A, Steidler S (2004) Effects of silymarin a natural hepatoprotector, in periparturient dairy cows. J Dairy Sci 87:2239–2247

Verma V, Chaudhary LC, Agarwal N, Bhar R, Kamra DN (2012) Effect of feeding mixture of garlic bulb and peppermint oil on methane emission, rumen fermentation and microbial profile in buffaloes. Anim Nutr Feed Technol 12:157–164

Waghorn GC, Tavendale MH, Woodfield DR (2002) Methanogenesis from forages fed to sheep. Proc N Z Grassl Assoc 64:167–171

Wang CJ, Wang SP, Zhou H (2009) Influences of flavomycin, ropadiar, and saponin on nutrient digestibility, rumen fermentation, and methane emission from sheep. Anim Feed Sci Technol 148:157–166

Wina E, Muetzel S, Hoffmann E, Makkar HPS, Becker K (2005) Saponins containing methanol extract of *Sapindus rarak* affect microbial fermentation, microbial activity and microbial community structure *in vitro*. Anim Feed Sci Technol 121:159–174

Woodward SL, Waghorn GC, Ulyatt MJ, Lassey KR (2001) Early indication that feeding lotus will reduce methane emission from ruminants. Proc N Z Soc Anim Prod 61:23–26

Yuan ZP, Zhang CM, Zhou L, Zou CX, Guo YQ, Li WT et al (2007) Inhibition of methanogenesis by tea saponin and tea saponin plus disodium fumarate in sheep. J Anim Feed Sci 16(Suppl 2):560–565

Ration Balancing: A Practical Approach for Reducing Methanogenesis in Tropical Feeding Systems

18

M.R. Garg and P.L. Sherasia

Abstract

Imbalanced feeding is widely prevalent in the smallholder dairy systems of tropical countries. Dairy animals fed on imbalanced rations not only produce less milk at a higher cost but also produce more methane per unit of milk production. As imbalanced feeding adversely impacts livestock productivity, health and the environment, it is a need of the hour to implement a practical and cost-effective approach for improving productivity and reducing methanogenesis in tropical ruminants. Changing plane of nutrition through balanced feeding has improved feed conversion efficiency, milk production and microbial protein synthesis and reduced methane emissions in cows and buffaloes, under field conditions. Balanced feeding might have resulted in a shift in volatile fatty acid pattern towards more propionate and less acetate, resulting in lower methane production. Thus, ration balancing could be a practical approach for reducing methanogenesis in tropical feeding systems.

Keywords

Balanced feeding • Methane emissions • Productivity • Tropical countries

18.1 Introduction

Livestock production is undertaken in a multitude of ways across the planet, providing a large variety of goods and services, in a wide spectrum of agro-ecological and socio-economic conditions. The livestock sector is fundamental to the economies of many tropical countries, especially in terms of employment, incomes and food security. Livestock products contribute significantly to the diets of both the rural and fast-growing urban populations. The livestock sector also contributes a significant share to the global anthropogenic greenhouse gas (GHG) emissions. It represents about 14.5 % of global anthropogenic GHG emissions, and methane (CH_4) contributes about 44 % among GHGs emitted from the sector (Gerber et al. 2013). The sustainability of the livestock sector is a major concern, mainly

---

M.R. Garg (✉) • P.L. Sherasia
National Dairy Development Board, Anand 388001, Gujarat, India
e-mail: mrgarg@nddb.coop

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_18, © Springer India 2015

because of the ever-increasing population and the limited availability of feed resources in tropical countries.

Feeding is the foundation of livestock systems and accounts for more than 70 % of the total cost of milk production. It directly or indirectly affects the entire livestock sector, including animal productivity, health and welfare and the environment. Feeding as per the nutrient requirement of animals, using locally available feed resources, is an imperative for improving the genetic potential of low-yielding dairy animals in tropical countries. Devendra and Leng (2011) have stated that the locally available feed resources act as the key driving force for improving the productivity of animals in Asia. To maximise profitability from the dairy animals, one needs to ensure that the dairy animals receive required quantity of protein, energy, minerals and vitamins, preferably from locally available feed resources. Improving production and nutrient use efficiencies through balanced nutrition approach is also one of the most promising ways to reduce methanogenesis in ruminants. It is documented that the most relevant methane mitigation strategy for smallholder mixed crop-livestock systems in tropical countries is to increase individual animal productivity as a consequence of providing nutritionally balanced feeds (Bayat and Shingfield 2012; Hristov et al. 2013).

Imbalanced feeding is widely prevalent in the smallholder dairy systems of tropical countries, like India. Imbalanced feeding not only produces less milk at a higher cost but also produces more methane per litre of milk production. Livestock fed imbalanced rations produce more methane, as most of the dietary organic matter (OM) is fermented to produce acetate and butyrate, resulting into more CH_4 production (Blummel 2000). On the contrary, Leng (1991) has reported that if the ration is balanced for all essential nutrients, OM is fermented to produce more microbial biomass and less of CH_4. Changing plane of nutrition through balanced feeding improves rumen fermentation pattern and thus reduces methanogenesis in ruminants.

The concept of ration balancing is already in place in most of the developed countries, where the feed resources are available in abundance with good sources of protein, energy and minerals, herd sizes are much bigger and the livestock owners are better versed with the scientific practices of feeding and management. In most of the tropical countries, herd sizes are smaller and dairy farmers follow traditional feeding practices, causing imbalance of nutrients in terms of protein, energy, minerals and vitamins. In view of this, the concept of ration balancing for smallholder dairy farmers in most of the tropical countries has been a challenge owing to their lack of knowledge and skills to prepare a balanced ration. Also the smallholder farmers are not in a position to hire specialists for preparing balanced rations. Keeping this in mind, the National Dairy Development Board (NDDB) of India has developed a user-friendly ration balancing software for working out a least-cost balanced ration at the farmers' doorstep. This software is the backbone of the Ration Balancing Programme (RBP). With the help of RBP, milk producers in the villages are advised to balance the ration of their animals, with the available feed resources and an area-specific mineral mixture. Various field studies conducted by the NDDB in different parts of India indicate that feeding nutritionally balanced rations (i.e. closely matching animal's requirements and dietary nutrient supply) has improved milk production up to 14 % and reduced methane emissions (g/kg milk yield) by 15–20 % in lactating cows and buffaloes (FAO 2012; Garg et al. 2013a). Large-scale implementation of RBP in tropical countries would also help in improving productivity and reducing methanogenesis, with the available feed resources in tropical feeding systems.

18.2 Tropical Feeding Systems

Tropical feeding systems – primarily consist of mixed crop-livestock – are widespread at all altitudes in the tropical world. Smallholder livestock keepers represent almost 20 % of the world population and steward most of the agricultural land in the tropics. Mixed production systems produce about 73 % of milk, 68 % of beef, 54 % of lamb and significant amounts of poultry and eggs in the developing world (Herrero et al. 2010). At the same time, these tropical systems play significant roles in providing integrated environmental solutions that benefit poor people. Observed and expected increase in future demand for livestock products in the region provides unique opportunities for improving livelihoods and, linked to that, improving guardianship of the environment.

Livestock in tropical countries are fed mainly on by-products of various food crops, oil seeds and locally available green and dry fodder. In some situations these by-products, especially oil seed cakes or meals, are not available in sufficient quantity to meet the entire demand of the livestock population. Limited land available for meeting the needs of an ever-growing human population in developing countries cannot be spared for growing additional green fodder and coarse grains for feeding livestock. Even the available feed resources are not utilised judiciously as the majority of the animals in these countries are fed imbalanced rations, resulting in milk yields below their genetic potential. If the increased demand for milk caused by an increase in population, urbanisation and buying capacity is to be met, the productivity of dairy animals must be improved coupled with greater efficiency of the use of locally available feed resources. The role of livestock in tropical countries is quite complex and extends beyond their traditional uses to supply milk and meat (Sansoucy 1995; Wanapat 2009). Livestock are certainly multipurpose and are valued for one or several (sometimes all) traits like capital, credit, traction, milk, meat, hides, fuel and fertiliser. Thus, for landless families, livestock are primarily a means of increasing the family income.

18.3 Status of Microbial Growth in the Rumen

An approach to estimating the net efficiency of microbial growth in the rumen depends upon knowledge of rumen biochemistry – mainly the factors that are involved in the production of volatile fatty acids (VFAs) in fermentative processes relative to microbial growth in the rumen (Werner 1979). Microbial protein synthesis relative to VFA production determines the protein to energy ratio in the nutrients absorbed. Maximisation of microbial growth on any carbohydrate source requires all necessary microbial nutrients to be present at optimum levels. This will lead to a maximisation of the protein-energy rates in the nutrients absorbed from the rumen (Leng 1982). One of the best methods for determining rumen efficiency is through estimation of microbial cells. Urinary excretion of purine derivatives has been successfully used to estimate microbial protein synthesis in the rumen and subsequently in the lower gut of ruminants (Smith and McAllen 1971). Excretion of purine derivatives relative to digestible feed intake is an index of the efficiency of rumen microbial ecosystem (Chen and Gomes 1992).

18.4 Enteric Fermentation

Fermentation of feeds in the rumen is the largest source of CH_4 from enteric fermentation and is primarily emitted from the animal by eructation (Fig. 18.1). The conversion of feed materials to CH_4 in the rumen involves the integrated activities of different microbial species, with the final step carried out by methanogenic bacteria (McAllister et al. 1996; Moss et al. 2000). Methane and CO_2 are natural by-products of microbial fermentation of carbohydrates and, to a lesser extent, amino acids in the rumen and the hindgut of animals. Methane is produced in strictly anaerobic conditions by highly specialised methanogenic prokaryotes, all of which are archaea. In ruminants, the vast majority of enteric CH_4 production occurs in the reticulorumen, while rectal emissions account only 2–3 % of the total CH_4 emissions in ruminants (Muñoz et al. 2012).

18.5 Methanogens

Methanogens represent a unique group of microorganisms, which are directly responsible for the formation of methane. They belong to the group

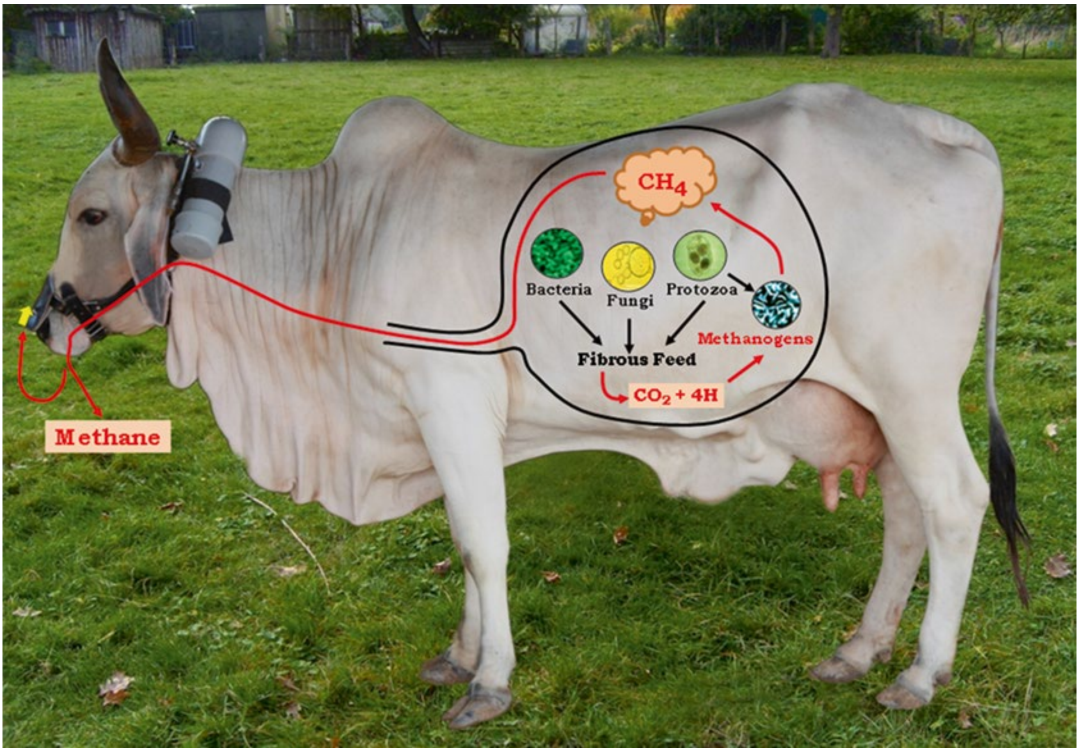


Fig. 18.1 Methane emission from enteric fermentation

of *Archaea* within the kingdom of *Euryarchaeota. Archaea* differ fundamentally from bacteria belonging to the group of *Eubacteria*, both in terms of their structural strains and metabolism. Methanogens possess three coenzymes which have not been found in other microorganisms.

These three coenzymes are *coenzyme 420*, involved in electron transfer in place of ferredoxin; *coenzyme M*, involved in methyl transfer; and *factor B*, a low-molecular-weight, oxygen-sensitive, heat-stable coenzyme involved in the enzymatic formation of CH_4 from methyl coenzyme M (Baker 1999; Jones et al. 1987). Methanogens also differ from almost all bacteria in cell envelope composition. There is no muramic acid in the cell wall of methanogens, and the cell membrane lipids are composed of isoprenoids ether-linked to glycerol or other carbohydrates (Baker 1999). Analyses of the nucleotide sequence of the 16S ribosomal RNA indicate that the methanogens have very early evolutionary divergence from all other forms of life studied so far. They have therefore been classified in a different domain named the *Archaea* (formerly archaebacteria) within the kingdom *Euryarchaeota* (Baker 1997, 1999). Methanogens are nutritionally fastidious anaerobes and grow only in environments with a redox potential below −300 mV and pH between 6 and 8.

Methanogens use the process of formation of methane to generate energy for their own growth. Substrates used in the process include hydrogen (H_2), carbon dioxide (CO_2), formate, acetate, methanol, methylamines, dimethyl sulphide and some alcohols (Jones 1991; McAllister et al. 1996). In the rumen, methanogens primarily use H_2, CO_2 and formate as substrates in methanogenesis. The interaction of methanogens with other bacteria through interspecies H_2 transfer in the fermentation process allows methanogens to gain energy for their own growth, while the accumulation of H_2 and other intermediates is prevented, which benefits the growth of H_2-producing bacteria allowing further degradation of fibrous feed material (Hegarty and Gerdes 1998). Methanogens are hydrophobic and therefore stick to feed particles as well as onto the surface of protozoa. Although methanogens are only directly involved in the very terminal stages of fermentation, they are very important because they are capable of effectively utilising electrons in the form of H_2 to reduce CO_2 to CH_4, thereby maintaining low H_2 pressure in the rumen. Recently, a new group of methylotrophic methanogens (the so-called rumen cluster C) that does not require hydrogen as an energy source has been described and appears to play a role in CH_4 formation in ruminants (Poulsen et al. 2012).

18.6 Methanogenesis

Primary digestive microorganisms (bacteria, protozoa and fungi) hydrolyse proteins, starch and plant cell wall polymers into amino acids and sugars. These simple products are then fermented to VFAs, H_2 and CO_2 by both primary and secondary digestive microorganisms. Energy (as ATP) released during the fermentation supports microbial growth, while most of the VFAs are absorbed from the rumen and used by the animal for energy or the synthesis of milk or body fat (acetate and butyrate) and glucose (propionate). The major producers of H_2 are the organisms which produce acetic acid in the fermentation pathway (Hegarty and Gerdes 1998; Van Soest 1982). Acetate and butyrate promote CH_4 production, while propionate formation is considered as a competitive pathway for H_2 use in the rumen. As stated by Van Soest (1994), the basic problem in anaerobic metabolism is the storage of oxygen (i.e. as CO_2) and disposal of H_2 equivalents (i.e. as CH_4). Methane, formed from CO_2 directly or through formate, is the most important '2H' sink (the ultimate acceptor of reducing equivalents from NADH + H^+, $FADH_2$ or reduced ferredoxin, commonly referred to as 2H because pairs of protons and electrons are donated and accepted in metabolic reactions) in the rumen.

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2C_2H_4O_2(\text{acetate}) + 2CO_2 + 8H$$

$$C_6H_{12}O_6 + 4H \rightarrow 2C_3H_6O_2(\text{propionate}) + 2H_2O$$

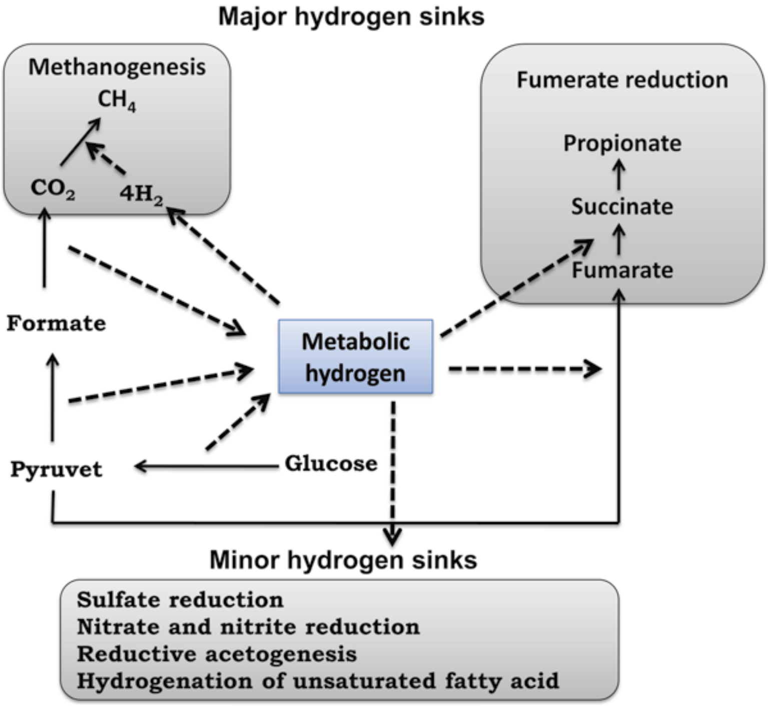
$$C_6H_{12}O_6 \rightarrow C_4H_8O_2(\text{butyate}) + 2CO_2 + 4H$$

It has been established that with an increased molar proportion of propionate, the molar proportions of acetate and/or butyrate are reduced. Methane production can also be calculated from the stoichiometry of the main VFAs formed during the fermentation, indicating that the molar percentage of VFAs influence the production of methane in the rumen (Moss et al. 2000). Janssen (2010) has estimated that the amount of CH_4 formed from fermentation of glucose in the rumen can vary from 0 (0.67 acetate + 1.33 propionate; no net H_2 production) to 1 (2 acetate + 4 H_2) mol CH_4/mol glucose. It has been concluded that CH_4 production in the rumen depends on the amount of H_2 formed and thus on the relative activities of various microbial species involved in fermentation pathways responsible for H_2 production (Janssen 2010). According to Janssen (2010), H_2 concentration in the rumen can influence which pathways are active, thus positioning H_2 as a central regulator of pathway selection in the rumen.

18.6.1 Hydrogen: A Central Regulator of Rumen Fermentation

Hydrogen is a central metabolite in rumen fermentation, and its partial pressure is an important determinant of rumen methanogenesis. The balance of hydrogen ion and dissolved hydrogen gas concentrations directly determines the redox potential of the rumen and therefore the possible extent of oxidation of feedstuffs. Hydrogen for CH_4 synthesis occurs in three key states in the rumen, these being hydrogen gas, reduced cofactors (such as NADH and NADPH) and free protons. Although H_2 is one of the major end products of fermentation by protozoa, fungi and pure monocultures of some bacteria, it does not accumulate in the rumen because it is immediately utilised by other bacteria, which are present in the mixed microbial ecosystem. In the rumen, formation of methane is the major way of H_2 sink through the reaction $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$. Since CH_4

Fig. 18.2 Major and minor H_2 sinks in the rumen (Source: Yasuo Kobayashi 2010)



has no nutritional value to the animal, its production represents a loss of dietary energy to the animal. In general, CH_4 production in cattle constitutes about 2–12 % of dietary gross energy intake (Johnson and Johnson 1995). Reduction in CH_4 production can result from a decreased extent of fermentation in the rumen or from a shift in the VFA pattern towards more propionate and less acetate. Major and minor H_2 sinks in the rumen are shown in Fig. 18.2.

18.7 Approaches for Reducing Methanogenesis

Various approaches, mainly focusing on feeding, breeding and rumen manipulation, have been studied for reducing methanogenesis (Fig. 18.3). All these approaches including feeds and feeding management like feed intake, feeding frequency, feed processing, inclusion of concentrates, forage quality, forage preservation and ration balancing; feed additives like ionophores, probiotics, enzymes, dietary lipids, inhibitors, propionate enhancers, secondary plant metabolites and bacteriocins; rumen manipulation like defaunation, vaccination and ruminally produced bacteriocins and archaeocins; and breeding like animal and plant breeding have been published (Beauchemin et al. 2007, 2009; Boadi et al. 2004; Cottle et al. 2011; de Klein and Eckard 2008; Eckard et al. 2010; Ellis et al. 2008; Goel and Makkar 2012; Kebreab et al. 2006; Martin et al. 2010; McAllister and Newbold 2008). Most of these approaches are inept for long-term use because of their limit. Further, many of these approaches require years of research before practical application and commercially viable products are available.

For the tropical feeding systems, the approaches for reducing methanogenesis should be cost-effective and should also address socio-economic issues of the society. Bayat and Shingfield (2012) have documented that the dietary manipulation to induce changes in rumen fermentation characteristics remains the most feasible approach to achieve reduction in methanogenesis. Hristov et al. (2013) have also documented that increasing animal productivity by providing nutritionally balanced feed is the most relevant approach for reducing methanogenesis

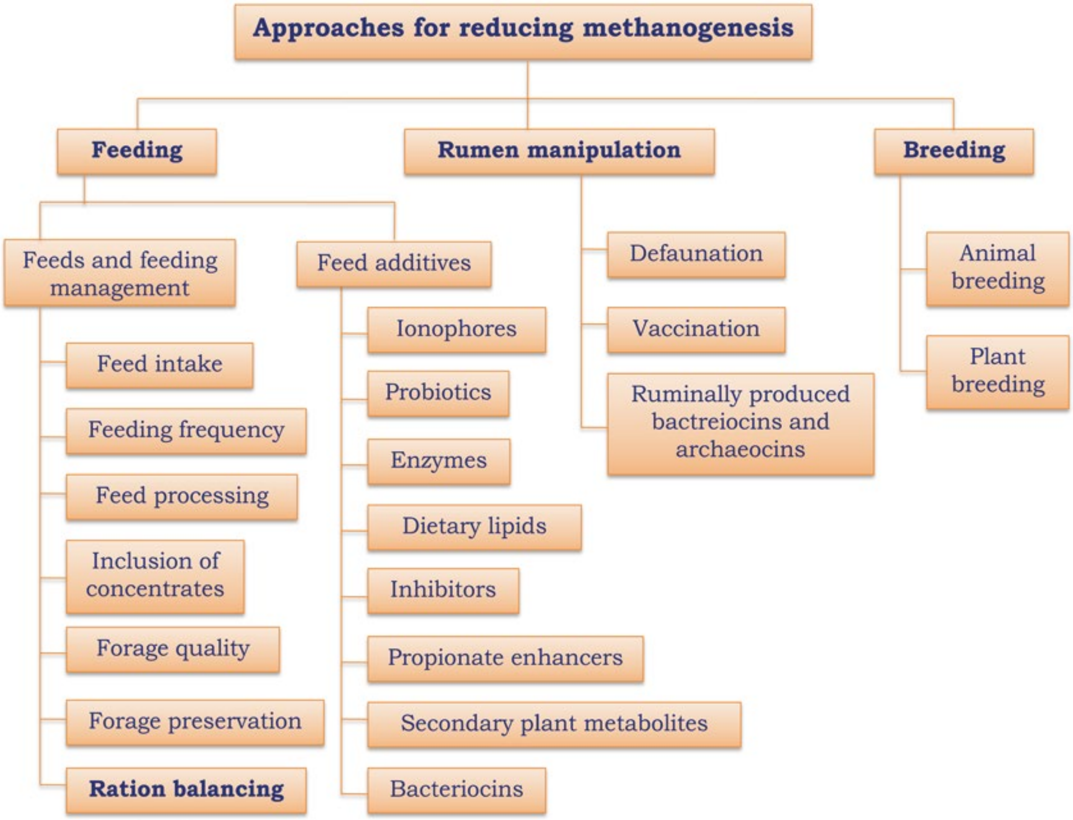


Fig. 18.3 Various approaches for reducing methanogenesis

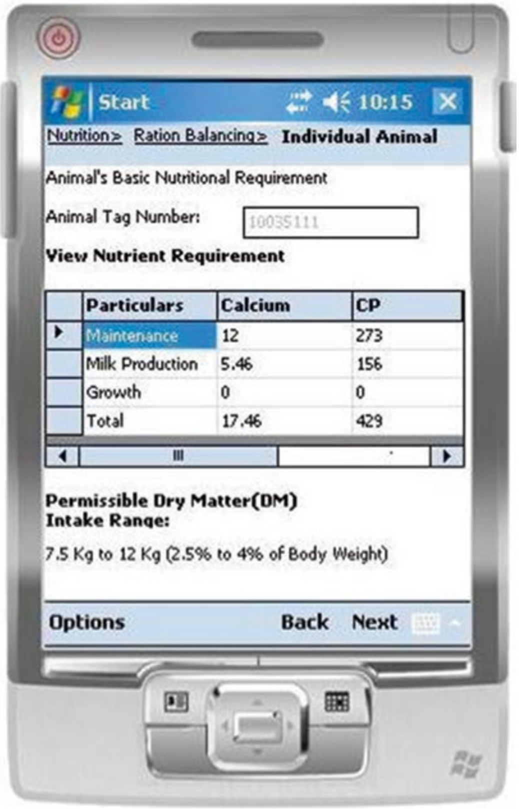
for smallholder mixed crop-livestock systems in tropical countries. In this situation, ration balancing using locally available feed resources and area-specific mineral mixtures helps in improving the productivity of dairy animals, by way of increasing feed conversion efficiency and microbial protein synthesis, and thereby reducing methanogenesis in ruminants.

18.8 Concept of Ration Balancing

A ration is the amount of feed that is fed to livestock during a 24 h period. When all nutrients present in a ration are as per the nutrient requirements of the animal, the ration is known as a balanced ration. A balanced ration should provide protein, energy, minerals and vitamins from dry fodders, green fodders, concentrates, mineral supplements, etc., in appropriate quantities to enable the animals to perform optimally and remain healthy. In order to balance a ration properly, one must know the chemical composition of available feedstuffs, nutrient availability and requirement of animals. The concept of ration balancing is already in place in most of the developed countries, where the feed resources are available in abundance, herd sizes are much bigger and the livestock owners are better versed with the scientific practices of feeding and management. However, in most of the tropical countries, herd sizes are smaller and dairy farmers follow traditional feeding practices, causing imbalance of nutrients in terms of protein, energy, minerals and vitamins. In view of this, the concept of ration balancing for smallholder dairy farmers in most of the tropical countries has been a challenge owing to their lack of knowledge and skills.

18.9 Development of Ration Balancing Programme

The NDDB of India has developed a user-friendly computer software called 'Ration Balancing Programme (RBP)' for advising milk producers at their doorstep to balance the rations of their dairy animals, with the available feed resources and area-specific mineral mixtures. In this programme, a window-based Internet-linked application has been designed to assess the prevailing nutritional status of an animal's diet versus its nutrient requirements. Both sets of information are used to determine a least-cost ration with the available feed resources and an area-specific mineral mixture. The RBP is comprised of a feed data library and various 'nutrition masters'. To create the feed data library, a wide range of feed ingredients such as green and dry forages, tree leaves, grains, oil cakes and agro-industrial by-products were collected from different agro-climatic regions of the country and analysed for chemical composition. Simultaneously, existing national and international feeding standards for nutrient requirement of growing, lactating and pregnant animals were used to create various 'nutrition masters' of nutrient requirements (Kearl 1982; NRC 2001). The software is compatible with desktops, laptops and net books and can be used on personal digital assistants for areas devoid of Internet connectivity (Fig. 18.4).



Nutrition> Ration Balancing> **Individual Animal**

Animal's Basic Nutritional Requirement

Animal Tag Number: 10035111

View Nutrient Requirement

Particulars	Calcium	CP
Maintenance	12	273
Milk Production	5.46	156
Growth	0	0
Total	17.46	429

Permissible Dry Matter(DM) Intake Range:

7.5 Kg to 12 Kg (2.5% to 4% of Body Weight)

Fig. 18.4 RBP software loaded in PDA

18.10 Steps for Formulating a Least-Cost Balanced Ration Using the Software

18.10.1 Registration of Animals

Animals identified for the ration balancing programme are first ear tagged with a unique 12-digit number. Details of the animals (e.g. species, breed, age, milking status, number of calving, last calving date and pregnancy status) are captured. Along with the animal's details, the owner's profiles (e.g. name, father's name, age, village, village institution, tehsil/block, district and state) are also noted. After completing all the information, the animal is registered on the server. Animal registration is a once-only activity.

18.10.2 Assessing Nutrient Status of Animals

After registration, the animal's daily feed intake, daily milk yield and milk fat per cent are recorded. In addition, the animal's body weight (BW) is also recorded, using Shaeffer's formula as BW (kg) = ([(heart girth in inches)^2 × length of the body in inches]/300) × 0.4536.

Based on the milk yield, milk fat per cent, BW and pregnancy status, the animal's nutrient requirements are computed by the software.

Considering the prevailing feeding practices (feed intake), consumption of nutrients (e.g. energy, protein, calcium and phosphorus) is assessed. This information helps in understanding the deficiencies/excesses of various nutrients in the ration and the cost of feeding per kg of milk production.

18.10.3 Formulating a Least-Cost Balanced Ration

Based on the chemical composition of available feed resources (a prerequisite to this is the preparation of inventories of feed resources that are used in a region) and in accordance with the nutrient requirement of the animals, the software computes a least-cost ration within the given constraints. These constraints could include non-availability or limited availability of green fodder and/or compound cattle feed, affordability of milk producers to purchase specific feed ingredients from the market, roughage to concentrate ratio, stage of lactation, type of feed offered, etc. A least-cost ration, with suggested feed ingredients in proportions as indicated by the software, is designed to reduce the costs of feeding and/or increase milk production.

18.11 Implementation of Ration Balancing Programme

The RBP has been implemented using individual animal profiles, and data generated was based on individual animals. The Dairy Board of India has implemented a multistate RBP on more than one lakh dairy animals in different parts of the country through various end implementing agencies (EIAs). The EIAs could be dairy cooperative societies, service-providing organisations, state animal husbandry departments, producer companies and nongovernment organisations. NDDB imparts training to the identified technical officers and trainers of implementing agencies on the latest concepts of animal nutrition and the RBP software. Technical officers and trainers identify potential villages and village-based local resource persons who are well versed with dairy husbandry practices, to implement the programme at the farmer's doorstep (Fig. 18.5).

Fig. 18.5 An officer explaining the concept of ration balancing to milk producers

18.12 Effect of Ration Balancing

Large-scale implementation of RBP in tropical feeding systems of India increased net daily income by way of increasing daily milk yield and/or milk fat level, while decreased the cost of feeding. In addition, enteric methane emissions and manure nitrogen (N) excretion were decreased, while feed conversion efficiency and microbial N synthesis were improved. Balanced feeding also helped in improving immunity and reducing incidences of parasitism in field animals. The effect of ration balancing on various parameters has been presented in Fig. 18.6.

Fig. 18.6 Effect of ration balancing on various parameters

18.12.1 Improving Efficiency

The ultimate goal of dairy production system is to convert available feed resources into healthy and high-quality milk at the highest economic return, while ensuring proper animal health and well-being and using practices that are respectful of the environment and acceptable to the consumer. One of the most important parameters to ensure economic returns of dairy animals is feed conversion efficiency/feed efficiency/ feed use efficiency, a reflection of the efficiency with which nutrients from the diet are converted into milk. Opportunities to improve feed conversion efficiency (FCE) are large in tropical countries, where average productivity of dairy animals is very low and mostly fed imbalanced rations. Therefore, ration balancing provides a practical approach for improving FCE of low-producing animals, with available feed resources in the region.

18.12.1.1 Feed Conversion Efficiency

Feed conversion efficiency can be expressed as kg of fat-corrected milk per kg of dry matter (DM) intake. In tropical countries, where the level of production of milking animals is not that much high and the returns from milk production are marginal, this is primarily due to higher consumption of DM per kg of milk production. Good FCE is not only of economic importance but also a reflection of nutrient management practices followed by the farmers. Improving FCE for milk production with available feed resources at the disposal of farmers is of paramount importance in a tropical region. Improving FCE inevitably results in more feed nutrients being converted into animal products, with an associated reduction in nutrients lost to the environment. Average achieved FCE of converting feed nutrients into milk is considerably lower in ruminants than what is possible with the genetic potential of many animals (Beever and Drackley 2013; Makkar and Beever 2013). However, increased animal performance as a result of improved genetics, nutrition and management has resulted in improved FCE over time, albeit at a lower rate in ruminants than in monogastrics.

Improving FCE is well established as one of the best ways to reduce methane production in an individual animal (IPCC 1990). Feed ingredients provide the substrates for microbial fermentation, and differences in feed quality alter the amount of energy extracted by the microbes and the pattern of VFAs and CH_4 production. These alterations can impact energy and protein availability to the animal and, ultimately, the efficiency at which the feed nutrients are used for productive functions, including growth and milk synthesis (NRC 2001). Further, Colman et al. (2011) have established that there is a negative curvilinear relationship between FCE and CH_4 production. As FCE increases, more nutrients are directed into milk production with fewer nutrients excretion in the manure. There is considerable potential to improve production potential and to reduce nutrient losses from the dairy animals, through dietary manipulation. Improved efficiency of nutrient utilisation would allow increased productivity and reduced nutrient excretion in manure.

In our study, ration balancing has improved FCE from 0.61 to 0.74, 0.79 to 0.90 and 0.80 to 0.91 in local cows ($n = 569$), crossbred cows ($n = 6{,}521$) and buffaloes ($n = 4{,}534$), respectively. Therefore, through ration balancing, it is possible to increase the FCE for milk production in cows and buffaloes to produce more milk per kg DM. This is useful to increase the profitability of milk producers and contributes to efficient use of scarce feed resources in tropical countries while achieving targeted milk production. Achieving higher milk production from the same amount of feeds would also decrease water and carbon footprints of animal products because the water footprint of feed production is very high (Mekonnen and Hoekstra 2012), and fossil fuel energy is utilised in the production of feed biomass (Flachowsky and Kamphues 2012). Shahjalal et al. (2000) and Castillo et al. (2001) have also reported increased FCE for milk production by balancing the ration of milking animals.

18.12.1.2 Milk Production Efficiency

Undoubtedly, there is a significant potential for increased milk production to achieve the genetic potential of the animals in tropical countries. Milk production potential from ruminants is linked to genetic merit, balanced nutrition and good management practices. If a cow with high genetic merit for milk production is fed rations that are unable to meet her nutritional requirement, she will not produce milk as per her potentials. Feeding nutritionally balanced rations plays a vital role in realisation of the genetic potential of an animal for milk production.

The implementation of RBP under field conditions has improved daily milk yield from 0.2 to 1.2 kg and fat level in milk from 1.0 to 9.0 g/kg in cows and buffaloes. There has been a decrease in ration cost by 5–11 % after feeding a balanced ration. An average increase in the net daily income of farmers has been reported by 6–60 % per animal due to the increase in milk yield and milk fat level, as well as a decrease in the cost of feeding (Garg et al. 2013a). Solid-not-fat percentage also increased in milk when animals were fed a balanced ration. Through the ration balancing advisory services, it has been possible to increase milk production efficiency and reduce the cost of milk production. The improvement in milk yield and milk fat level in cows and buffaloes after feeding a nutritionally balanced ration could be due to increased rumen microbial protein synthesis due to more optimal rumen functions because of the more balanced nutrient supply.

Improvement in milk yield due to supplementation of deficient nutrients, particularly minerals in lactating ruminants, has been reported by many authors in tropical countries (Dutta et al. 2010; Haldar and Rai 2003; Khochare et al. 2010). The size of response in milk production as a result of ration balancing advisory activities mainly depends on the type of animal, breed, stage of lactation and farmer compliance. Breeds with higher genetic potential are expected to respond better, in terms of increases in daily milk yield, to ration balancing. Similarly, responses in milk production are dependent on the stage of lactation – animals in early lactation responding better than those in mid and late lactations. Other contributory issues are genetic potential and management, including cleaning of animals (important in tropical climate), adequate provision of fresh drinking water, parasitic load, presence of mastitis, etc.

18.13 Effect of Ration Balancing on Methane Emissions

To quantify the impact of ration balancing on milk production and methane emissions under field conditions, NDDB has undertaken methane emission measurement studies in different agro-climatic regions of the country, using the sulphur hexafluoride (SF_6) tracer technique. For the measurement of CH_4 emissions from a large number of cows and buffaloes under natural conditions of feeding and management, the SF_6 tracer technique proves to be a more reliable technique, as compared to other techniques. The SF_6 tracer technique is widely applied, economic and the only viable technique with minimum disturbance of animals under field conditions (Johnson et al. 1994). Methane emission measurements were carried out in 162 early lactating cows and buffaloes, before and after feeding a balanced ration, and the CH_4 emission reduction on feeding a balanced ration was measured per kg of milk production. Studies indicate that balanced feeding has reduced CH_4 emissions (g/kg MY) by 15–20 % in lactating cows and buffaloes. An average increase in daily milk yield has been observed from 0.4 to 0.7 kg and milk fat percent from 0 to 0.5 in different regions of the country (Table 18.1). The result of these studies indicates that the balanced feeding has the potential for improving milk production efficiency and reducing methanogenesis with an increase in net daily income of milk producers (Garg et al. 2012a, b,

Table 18.1 Effect of ration balancing (RB) on milk yield and methane emissions

Species		Milk yield (kg/day)	Fat (%)	Methane emission (g/kg MY)	Reduction (%)
Western region					
Cows (*n* = 30)	Before RB	11.9^a	4.1	19.3^a	15.5
	After RB	12.4^b	4.3	16.3^b	
Buffaloes (*n* = 22)	Before RB	8.5	6.5^a	27.3^a	17.9
	After RB	8.9	6.8^b	22.4^b	
Northern region					
Cows (*n* = 20)	Before RB	6.5^a	4.2	32.8^c	19.8
	After RB	7.2^b	4.3	26.3^d	
Buffaloes (*n* = 34)	Before RB	6.5^a	6.5^a	36.9^a	17.6
	After RB	7.0^b	7.0^b	30.4^b	
Southern region					
Cows (*n* = 30)	Before RB	8.4	4.1	22.2^a	15.3
	After RB	8.8	4.1	18.8^b	
Central region					
Buffaloes (*n* = 26)	Before RB	6.1^a	6.5^a	25.3^c	19.4
	After RB	6.6^b	6.8^b	20.4^d	

[a,b]Values with different superscript in a column differ significantly ($P < 0.05$)

[c,d]Values with different superscript in a column differ significantly ($P < 0.01$)

2013b; Kannan et al. 2010, 2011; Kannan and Garg 2009). Mohini and Singh (2010) have also reported lower CH_4 emissions (197.46 versus 223.45 g/day and 29.92 versus 40.04 g/kg milk yield) after balancing the ration of cows.

18.14 How Ration Balancing Reduces Methanogenesis

18.14.1 Electron Sink

Methane is the main electron sink in ruminal fermentation. Methanogens serve as an essential electron sink for all microbes, thereby maintaining a low partial pressure of H_2 in the rumen which in turn promotes maximal yields of ATP to support microbial growth. It would be beneficial both for the efficiency of production and the environment to divert reducing equivalents from ruminal methanogenesis into alternative electron sinks with a nutritional value for the host animal (e.g. by enhancing propionate formation). In our studies, balancing of nutrients has shifted the rumen fermentation pattern towards higher microbial cell production, which might have resulted in lower acetate and butyrate production, whereas higher propionate production thereby reduced CH_4 production. It is reported that animals on imbalanced rations produce more CH_4 as most of the dietary OM is fermented to produce acetate and butyrate, resulting into more CH_4 production (Khochare et al. 2010; Mohini and Singh 2010). If the rations are balanced for all essential nutrients, OM is fermented to produce more microbial biomass and less of CH_4 (Garg 2011; Leng 1991). Changing plane of nutrition through balanced feeding has improved nutrient use efficiency and thus reduced methanogenesis in lactating cows and buffaloes. Therefore, feeding a balanced ration (i.e. closely matching animal requirements and dietary nutrient supply) could be a practical approach for reducing methanogenesis in tropical feeding systems. Figure 18.7 describes the inverse relationship between microbial N supply and methane emissions.

18.14.2 Microbial Nitrogen Supply

Microbial N supply to the duodenum is an important indicator of efficiency of rumen functions. Urinary excretion of allantoin has been successfully used to estimate microbial protein synthesised in the rumen and subsequently digested in

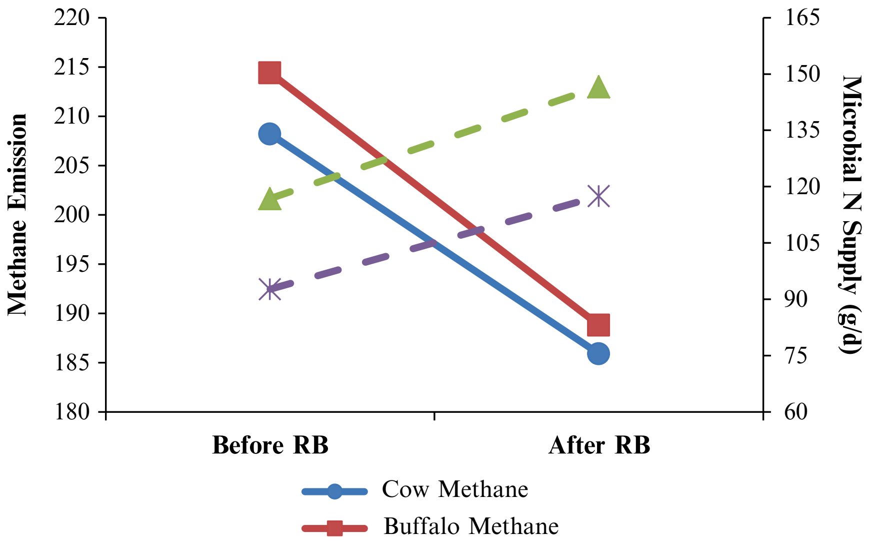


Fig. 18.7 An inverse relationship between microbial N supply and methane emissions

the lower gut of ruminants (Dipu et al. 2006; Pimp et al. 2001; Ramgaokar et al. 2008; Srinivas and Singh 2010). Makkar and Chen (2004) have reported that the supply of adequate nutrients increases the excretion of urinary purine derivatives, synthesis of rumen microbial N and enhances the supply of protein post-ruminally to support production. Microbial N synthesis depends upon a balanced ruminal supply of ammonia, energy and carbon (C) skeletons for amino acid synthesis (Khandaker et al. 2012; Wanapat et al. 2009). A deficiency of feed N leads to spillage of ATP released on the digestion of feed C and suboptimum synthesis of microbial protein and release of feed C as CH_4, while a deficiency of feed C results in non-assimilation of ammonia by rumen microbes, again resulting in suboptimum microbial N synthesis (Blummel et al. 2010). In addition, ammonia in the rumen passes into the blood through the rumen wall and is detoxified by the liver to urea in an energy-demanding process, which will decrease animal productivity. In our studies, an inverse relationship between microbial N supply and methane emissions has been observed. An inverse relationship between microbial protein production and its efficiency of production with CH_4 emissions has also been reported by many authors (Blummel 2000; Waghorn and Hegarty 2011).

18.15 Conclusion

Mixed feeding systems in tropical regions are the most important systems worldwide since they produce significant amount of milk and meat. The majority of farmers in these systems are smallholder poor farmers, who lack resources and skills to nutritionally balance their animals' diets. Livestock in most of the tropical countries are fed mainly on by-products of various food crops, oil seeds and locally grown fodder. In some situations these by-products, especially oil seed cakes or meals, are not available in sufficient quantity to meet the entire demand of the livestock population. Limited land available for meeting the needs of an ever-growing human population in developing countries cannot be spared for growing additional green fodder and coarse grains for feeding livestock. Even the available resources are not utilised judiciously as the majority of the animals in these countries are fed imbalanced rations, resulting in milk yields below their genetic potential. If the increased demand for milk caused by an increase in population, urbanisation and buying capacity is to be met, the productivity of dairy animals must be improved coupled with greater efficiency of the use of the available feed resources. The challenge for the tropical countries is to adapt, deploy and integrate basic and scientific feeding practices, meeting the nutrient requirement of dairy animals to address the future demand of milk and climate change issues.

Feeding is the foundation of livestock systems and accounts for more than 70 % of the total cost of milk production. Balanced feeding can play a pivotal role in improving animals' productivity and reducing methanogenesis in ruminants. A ration balancing programme as being implemented in India could likely be replicated in other tropical countries and may be a powerful way to improve productivity of dairy animals in a sustainable manner, while realising the full genetic potential of animals to lift smallholder farmers out of poverty. Ration balancing improves the productivity of animals, by way of increasing nutrient use efficiency, and thereby reduces methanogenesis in ruminants. In view of this, optimising rumen functions for higher microbial protein synthesis through ration balancing, matching the physiological stage of an animal and enhancing the overall efficiency of dietary nutrients use is considered to be the most practical approach for reducing methanogenesis in tropical feeding systems.

References

Baker SK (1997) Gut microbiology and its consequences for the ruminant. Proc Nutr Soc Aust 21:6–13

Baker SK (1999) Rumen methanogens, and inhibition of methanogenesis. Aust J Agric Res 50:1293–1298

Bayat A, Shingfield KJ (2012) Overview of nutritional strategies to lower enteric methane emissions in ruminants. In: Maataloustieteen Päivät, pp 1–7

Beauchemin KA, McGinn SM, Petit HV (2007) Methane abatement strategies for cattle: lipid supplementation of diets. Can J Anim Sci 87:431–440

Beauchemin KA, McAllister TA, McGinn SM (2009) Dietary mitigation of enteric methane from cattle. CAB Rev 4:1–18

Beever DE, Drackley JK (2013) Feeding for optimal rumen and animal health and optimal feed conversion efficiency: the importance of physical nutrition. In: Proceedings of the FAO symposium, 27 November 2012, Bangkok, Thailand. FAO animal production and health proceedings, No. 16. FAO and Asian-Australasian Association of Animal Production Societies, Rome

Blummel M (2000) Predicting the partitioning of fermentation products by combined *in vitro* gas volume and true substrate degradability measurements: opportunities and limitations. In: Proceedings of the British Society of Animal Science on gas production: fermentation kinetics for feed evaluation and to assess microbial activity, Midlothian EH260RZ, United Kindom, pp 48–58

Blummel M, Wright IA, Hegde NG (2010) Climate change impacts on livestock production and adaptation strategies: a global scenario. In: National symposium on climate change and rainfed agriculture, CRIDA, Hyderabad, India, pp 136–145

Boadi D, Benchaar C, Chiquette J, Massé D (2004) Mitigation strategies to reduce enteric methane emissions from dairy cows: update review. Can J Anim Sci 84:319–335

Castillo AR, Kebreab E, Beever DE, Barbi JH, Sutton JD, Kirby HC, France J (2001) The effect of protein supplementation on nitrogen utilization in lactating dairy cows fed grass silage diets. J Anim Sci 79:247–253

Chen XB, Gomes TYJ (1992) Estimation of microbial protein supply to sheep and cattle based on urinary excretion of purine derivatives. International Feed Resources Unit, Rowett Research Institute Aberdeen, Aberdeen

Colman DR, Beever DE, Jolly RW, Drackley JK (2011) Gaining from technology for improved dairy cow nutrition: economic, environmental, and animal health benefits. Prof Anim Sci 27:505–517

Cottle DJ, Nolan JV, Wiedemann SG (2011) Ruminant enteric methane mitigation: a review. Anim Prod Sci 51:491–514

de Klein CAM, Eckard RJ (2008) Targeted technologies for nitrous oxide abatement from animal agriculture. Aust J Exp Agric 48:14–20

Devendra C, Leng RA (2011) Feed resources for animals in Asia: issues, strategies for use, intensification and integration for increased productivity. Asian-Australas J Anim Sci 24(3):303–321

Dipu MT, George SK, Singh P, Verma AK, Mehra UR (2006) Measurement of microbial protein supply in Murrah buffaloes (*Bubalus bubalis*) using urinary purine derivatives excretion and PDC index. Asian-Australas J Anim Sci 19:347–355

Dutta N, Sharma K, Pattanaik AK, Singh A, Narang R (2010) Effect of strategic supplementation of limiting macro nutrients on the lactation performance of buffaloes. In: Proceedings of the VII animal nutrition association conference, Bhubaneshwar, India, p 27

Eckard RJ, Grainger C, de Klein CAM (2010) Options for the abatement of methane and nitrous oxide from ruminant production: a review. Livest Sci 130:47–56

Ellis JL, Dijkstra J, Kebreab E, Bannink A, Odongo NE, McBride BW, France J (2008) Aspects of rumen microbiology central to mechanistic modelling of methane production in cattle. J Agric Sci 146:213–233

FAO (2012) Balanced feeding for improving livestock productivity – increase in milk production and nutrient use efficiency and decrease in methane emission, by M R Garg. FAO Animal Production and Health Paper No. 173, Rome

Flachowsky G, Kamphues J (2012) Carbon footprints for food of animal origin: what are the most preferable criteria to measure animal yields? Animal 2:108–126

Garg MR (2011) Methane emission reduction in lactating animals through balanced feeding. National Training Programme Compendium on "Recent advances in methane estimation and mitigation strategies in ruminants", NIANP, Bangalore, 5–18 August

Garg MR, Sherasia PL, Shelke SK, Phondba BT (2012a) Productivity enhancement and methane emission reduction through ration balancing. Indian Dairyman, 64(8):54–58. Indian Dairy Association, New Delhi

Garg MR, Kannan A, Phondba BT, Shelke SK, Sherasia PL (2012b) A study on the effect of ration balancing for improving milk production and reducing methane emission in lactating buffaloes under field conditions. Indian J Dairy Sci 65:250–255

Garg MR, Sherasia PL, Bhanderi BM, Phondba BT, Shelke SK, Makkar HPS (2013a) Effect of feeding balanced rations on animal productivity, feed conversion efficiency, feed-nitrogen use efficiency, rumen microbial protein supply, parasitic load, immunity and enteric methane emission to milch animals under field conditions. Anim Feed Sci Technol 179:24–35

Garg MR, Sherasia PL, Phondba BT, Shelke SK, Patel CT (2013b) Effect of feeding balanced ration on milk production, enteric methane emission and metabolic profile in crossbred cows under field conditions. Indian J Dairy Sci 66:113–119

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G (2013) Tackling climate change through livestock – a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome

Goel G, Makkar HPS (2012) Methane mitigation from ruminants using tannins and saponins. Trop Anim Health Prod 44:729–739

Haldar C, Rai SN (2003) Effects of energy and mineral supplementation on nutrient digestibility and efficiency of milk production in lactating goats. Indian J Anim Nutr 20:244–251

Hegarty R, Gerdes R (1998) Hydrogen production and transfer in the rumen. Rec Adv Anim Nutr 12:37–44

Herrero M, Thornton PK, Notenbaert AM, Wood S, Msangi S, Freeman HA, Bossio D, Dixon J, Peters M, van de Steeg J, Lynam J, Parthasarathy Rao P, MacMillan S, Gerard B, McDermott J, Sere C, Rosegrant M (2010) Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science 327:822–825

Hristov AN, Oh J, Firkins JL, Dijkstra J, Kebreab E, Waghorn G, Makkar HPS, Adesogan AT, Yang W, Lee C, Gerber PJ, Henderson B, Tricarico JM (2013) Special topics – mitigation of methane and nitrous oxide emissions from animal operations: I. A review of enteric methane mitigation options. J Anim Sci 91:5045–5069

IPCC (1990) Methane emissions and opportunities for control – workshop results of intergovernmental panel on climate change. EPA/400/9-90/007, Canberra

Janssen PH (2010) Influence of hydrogen on rumen methane formation and fermentation balances through microbial growth kinetics and fermentation thermodynamics. Anim Feed Sci Technol 160:1–22

Johnson KA, Johnson DE (1995) Methane emissions from cattle. J Anim Sci 73:2483–2492

Johnson KA, Huyler MT, Westberg HH, Lamb BK, Zimmerman P (1994) Measurement of methane emissions from ruminants livestock using a SF_6 tracer technique. Environ Sci Technol 28:359–362

Jones WJ (1991) Diversity and physiology of methanogens. In: Roger JE, Whitman WB (eds) Microbial production and consumption of greenhouse gases: methane, nitrous oxides and halomethanes. Academic, New York

Jones WJ, Nagle DP, Whitman WP (1987) Methanogens and the diversity of archaebacteria. Microbiol Rev 53:135–177

Kannan A, Garg MR (2009) Effect of ration balancing on methane emission reduction in lactating animals under field conditions. Indian J Dairy Sci 62:292–296

Kannan A, Garg MR, Singh P (2010) Effect of ration balancing on methane emission and milk production in lactating animals under field conditions in Raebareli district of Uttar Pradesh. Indian J Anim Nutr 27:103–108

Kannan A, Garg MR, Mahesh Kumar BV (2011) Effect of ration balancing on milk production, microbial protein synthesis and methane emission in crossbred cows under field conditions in Chittoor district of Andhra Pradesh. Indian J Anim Nutr 28:117–123

Kearl LC (1982) Nutrient requirements of ruminants in developing countries. International Feedstuffs Institute, Utah Agricultural Experiment Station, Utah State University, Logan

Kebreab E, Clark K, Wagner-Riddle C, France J (2006) Methane and nitrous oxide emissions from Canadian animal agriculture: a review. Can J Anim Sci 86:135–158

Khandaker ZH, Uddin MM, Sultan MN, Peters KL (2012) Effect of supplementation of mustard oil cake on intake, digestibility and microbial protein synthesis of cattle in a straw based diet in Bangladesh. Trop Anim Health Prod 44:791–800

Khochare AB, Kank VD, Gadegaonkar GM, Salunke SC (2010) Strategic supplementation of limiting nutrients to medium yielding dairy animals at field level. In: Proceedings of the VII animal nutrition association conference, Bhubaneswar, p 30

Leng RA (1982) Modification of rumen fermentation. In: Hacker JB (ed) Nutritional limits to animal production from pastures. CAB, Farnham Royal, pp 427–453

Leng RA (1991) Improving ruminant production and reducing methane emissions from ruminants by strategic supplementation. EPA/400/1-91/004, Washington, DC

Makkar HPS, Beever D (2013) Optimization of feed use efficiency in ruminant production systems. In: Proceedings of the FAO symposium, 27 November 2012, Bangkok, Thailand. FAO Animal Production and Health Proceedings, No. 16. FAO and Asian-Australasian Association of Animal Production Societies, Rome

Makkar HPS, Chen XB (2004) Estimation of microbial protein supply in ruminants using urinary purine derivatives, IAEA-CN-110, Vienna

Martin C, Morgavi DP, Doreau M (2010) Methane mitigation in ruminants: from microbe to the farm scale. Animal 4:351–365

McAllister TA, Newbold CJ (2008) Redirecting rumen fermentation to reduce methanogenesis. Aust J Exp Agric 48:7–13

McAllister TA, Okine EK, Mathison GW, Cheng KJ (1996) Dietary, environmental and microbiological aspects of methane production in ruminants. Can J Anim Sci 76:231–243

Mekonnen MM, Hoekstra AY (2012) A global assessment of the water footprint of farm animal products. Ecosystems 15:401–415

Mohini M, Singh GP (2010) Effect of supplementation of urea molasses mineral block on the milk yield and methane production in lactating cattle on different plane of nutrition. Indian J Anim Nutr 27:96–102

Moss AR, Jouany JP, Newbold J (2000) Methane production by ruminants: its contribution to global warming. Ann Zootech 49:231–253

Muñoz C, Yan T, Wills DA, Murray S, Gordon AW (2012) Comparison of the sulphur hexafluoride tracer and respiration chamber techniques for estimating methane emissions and correction for rectum methane output from dairy cows. J Dairy Sci 95:3139–3148

NRC (2001) Nutrient requirements of dairy cattle, 7th edn. National Research Council, National Academy of Sciences, Washington, DC

Pimp O, Liang JB, Jelan ZA, Abdullah N (2001) Urinary excretion of duodenal purine derivatives in Kedah-Kelantan cattle. Anim Feed Sci Technol 92:203–214

Poulsen M, Schwab C, Jensen BB, Engberg RM, Spang A, Canibe N, Hølbetg O, Milinovich G, Fragner L, Schleper C, Weckwerth W, Lund P, Schramm A, Urich T (2012) Methylotrophic methanogenic Thermoplasmata implicated in reduced methane emissions from bovine rumen. Nat Commun. doi:10.1038/ncomms2432

Ramgaokar JS, Verma AK, Singh P, Mehra UR (2008) Effect of dietary protein levels on urinary excretion and plasma concentration of purine derivatives in crossbred bulls. Anim Nutr Feed Technol 8:25–34

Sansoucy R (1995) Livestock- a driving force for food security and sustainable development. World Anim Rev 84–85:5–17

Shahjalal MD, Bishwas MAA, Tareque AMM, Dohi H (2000) Growth and carcass characteristics of goats given diets varying protein concentration and feeding level. Asian-Australas J Anim Sci 13:613–618

Smith RH, McAllen AB (1971) Nucleic acid metabolism in the ruminant 3. Amount of nucleic acids and total ammonia nitrogen in digesta from the rumen duodenum and ileum of calves. Br J Nutr 25:181–190

Srinivas B, Singh NP (2010) Optimization of nutrient utilization and microbial nitrogen production in ewes in relation to dietary N and energy retention. Indian J Anim Nutr 27:208–210

Van Soest PJ (1982) Gastro-intestinal fermentations. In: Nutritional ecology of the ruminant. Ruminant metabolism, nutritional strategies, the cellulolytic fermentation and the chemistry of forages and plant fibers. Cornell University Press, Ithaca, pp 152–177

Van Soest PJ (1994) Nutritional ecology of the ruminant. Cornell University Press, Ithaca

Waghorn GC, Hegarty RS (2011) Lowering ruminant methane emissions through improved feed conversion efficiency. Anim Feed Sci Technol 166–167:291–301

Wanapat M (2009) Potential uses of local feed resources for ruminants. Trop Anim Health Prod 41:1035–1049

Wanapat M, Polyorach S, Boonnop K, Mapato C, Cherdthong A (2009) Effects of treating rice straw with urea or urea and calcium hydroxide upon intake, digestibility, rumen fermentation and milk yield of dairy cows. Livest Sci 125:238–243

Werner GB (1979) Factors affecting growth yields of micro-organisms in the rumen. Trop Anim Prod 4:1

Yasuo Kobayashi (2010) Abatement of methane production from ruminants: trends in the manipulation of rumen fermentation. Asian-Aust J Anim Sci 23(3):410–416

Alternate H_2 Sinks for Reducing Rumen Methanogenesis

19

P.K. Malik, Raghavendra Bhatta, Emma J. Gagen,
Veerasamy Sejian, N.M. Soren, and Cadaba S. Prasad

Abstract

Greenhouse gas (GHG) emissions from livestock is about 7,516 million metric tons CO_2-eq. year^{-1} and has multiple components that include enteric methane emissions, methane and nitrous oxide emissions from manure and carbon dioxide emissions associated with feed production and grazing. An uninterruptedly increasing concentration (155 % more than preindustrial level), a comparatively high global warming potential and a short half-life of methane make it a bit more important than any other GHG in the control of global warming and climate change. Enteric methane mitigation is not only important from a global warming point but also for saving animal dietary energy which is otherwise lost in the form of methane. Due to the central regulatory role of H_2, it is generally referred as the *currency of fermentation* and most of the mitigation strategies revolve around its production or disposal in such a way as to ensure the conservation of energy into desirable end products. In the chapter, an attempt is made to address the prospects of some emerging approaches to redirect metabolic H_2 away from methanogenesis and serve as potential alternate sink for H_2 in the rumen for conserving energy. The prospects of alternate sinks, for instance, sulphate and nitrate reduction and reductive acetogenesis and propionogenesis, are debated in the chapter along with the anticipated benefits that can be achieved from the practically feasible 20 % enteric methane reduction.

P.K. Malik (✉)
Bioenergetics and Environmental Sciences Division,
ICAR-National Institute of Animal Nutrition
and Physiology, Adugodi, Hosur Road, Bangalore,
Karnataka 560030, India
e-mail: malikndri@gmail.com

R. Bhatta • C.S. Prasad
ICAR-National Institute of Animal Nutrition and
Physiology, Adugodi, Hosur Road, Bangalore,
Karnataka 560030, India

E.J. Gagen
School of Earth Sciences, The University
of Queensland, Brisbane, QLD, Australia

V. Sejian
Animal Physiology Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India

N.M. Soren
Animal Nutrition Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_19, © Springer India 2015

Keywords

Alternate sinks • Enteric CH_4 mitigation • Reductive acetogenesis • Sulphate reduction

19.1 Introduction

Animal agriculture globally affects the environment through the emission of greenhouse gases. In one estimate, ILRI (2011) reported that agriculture is accountable for about 25–32 % of greenhouse gas emissions, wherein crop and livestock contribute 14 and 11–18 % of the greenhouse gas emissions, respectively (FAO 2006; PBL 2011). FAO (2006) estimated that greenhouse gas emissions from livestock is about 7,516 million metric tons CO_2-eq. year^{-1}, but if we also include the byproducts in the sector, the emissions reach up to 51 % (32,564 million tons of CO_2-eq. year^{-1}) of total greenhouse gas emissions (Goodland and Anhang 2009), far more than that estimated by FAO. GHGs emissions from livestock sector arise from multiple sources including enteric methane emissions, methane and nitrous oxide emissions from manure and carbon dioxide emissions associated with feed production and grazing. Apart from this, livestock production is also accountable for methane production from faecal storage and processing and nitrogen emission in the form of ammonia and nitrates. CH_4 emissions from the faecal component depends on the storage methods varying from lagoons in developed countries to heaps in the developing world. In the present chapter, emphasis is given to enteric methane emissions as discussing the emissions associated with excreta and feed production is beyond the boundaries of this chapter and will be dealt with elsewhere in the book.

The high global warming potential (GWP) of methane, i.e. 25 times more than CO_2 (IPCC 2013) on equal mass basis, uninterruptedly increasing concentration {155 % more than its preindustrial level (IPCC 2007; Malik et al. 2012a)}, and short half-life make methane more important than any other GHG in the control of global warming and climate change phenomenon. As portrayed earlier, livestock are an important source of methane, producing 37 %, i.e. 103 million tons of anthropogenic methane year^{-1}. Enteric methane emissions from livestock, as a result of anaerobic fermentation in the foregut and large intestine, add a major portion to the anthropogenic methane pool to the tune of 90 million metric tons (Clark et al. 2005; FAO 2006; Key and Tallard 2012), and the rest comes from excreta storage and processing systems. Figure 19.1 describes the percentage of GHG emissions from livestock sector. Of the total enteric methane, 87 % is produced in the rumen during the course of enteric fermentation and is burped out in the atmosphere (Murray et al. 1976), and the remaining 13 % is yielded from hind gut fermentation (Moss et al. 2000). Livestock enteric methane mitigation is not only important from a global warming perspective but more importantly due to the significant loss (6–12 %) of dietary energy in the form of enteric methane (Mathison et al. 1998; Takahashi 2001; Malik et al. 2012a). This loss is sizable especially in the developing world, where most countries are facing acute feed and fodders shortage and, by reducing enteric methane emissions to a signifi-

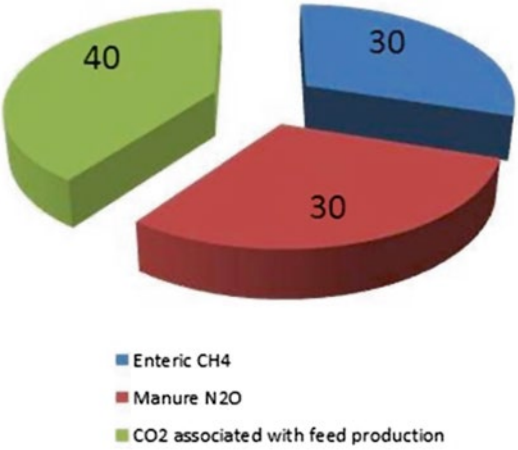


Fig. 19.1 Percentage of GHG emissions from livestock sector (FAO 2006)

cant extent, this saved energy may be utilized for additional milk production or feeding of extra livestock as exemplified in the subsequent section of the chapter.

19.2 H_2: The Currency of Fermentation

Despite all the goods from livestock sector, the world's 3.6 billion ruminants emit 90 Tg CH_4 years^{-1} due to enteric fermentation. Divergent microbes in the rumen act on the ingested feed and degrade it into various end products, viz., volatile fatty acids, ammonia, microbial protein, etc., along with CO_2 and H_2 as major gases. Hydrogen (H_2) is a central metabolite in enteric fermentation where its partial pressure determines the intensity of methanogenesis and the possible extent of oxidation of feedstuffs (Hegarty and Gerdes 1999). H_2 due to its central regulatory role is also referred as *currency of fermentation* (Hegarty and Gerdes 1999). H_2 generated from microbial fermentation of feed is used as an energy source by methanogenic archaea. Formate can be used by methanogens in the rumen, but is less important than H_2 as CH_4 precursor (Hungate et al. 1970). H_2 removal from the rumen is considered to play a chief role in continuing and improving the rumen fermentation (Hungate 1967) by eliminating the inhibitory effect of H_2 on microbial degradation of plant material (McAllister and Newbold 2008). Though the methanogens constitute only a small part of the rumen microbial community, they are very crucial in utilizing H_2 (Janssen and Kirs 2008). H_2 utilizing methanogen growth rates in the rumen and the prevailing H_2 concentrations are dynamically linked (Janssen 2010).

Reduced cofactors such as NADH, NADPH and free protons are three key states of H_2 for methanogenesis in the rumen. Concentration of dissolved H_2 in bulk rumen fluid varies between 90 and 250 µM at 39 °C (IUPAC 1981). Janssen (2010) stated that concentrations of dissolved H_2 diverge over a range of 0.1–50 µM in a normally functioning rumen. Rumen H_2 concentrations reported in various studies for cattle and sheep fed on different diets are compiled in Table 19.1 where it is evidenced that dissolved H_2 concentration in the rumen of both species remains <3.5 µM on roughage-based diets. However, the concentration of H_2 on grain-based diets may be higher than when the animals are fed on forage diet.

Rumen H_2 concentrations do not remain the same throughout the day; rather, a high level is reported after feeding (Barry et al. 1977; Smolenski and Robinson 1988), and it drops to a steady state 1–5 h after feeding depending on the fermentation substrates (Czerkawski and Breckenridge 1971; Robinson et al. 1981). Pelchen and Peters (1998) anticipated that 100 L of H_2 is produced daily from the sheep rumen which is adequate to generate 25 L of CH_4 day^{-1} considering that 4 moles of H_2 are required mole^{-1} of CH_4. Normally, low H_2 concentration in the rumen reflects utilization of H_2 by methanogens (Janssen 2010). The conditions resulting in increased passage rate and more propionate production also lead to a higher H_2 concentration in the rumen (Stanier and Davies 1981). The increased H_2 concentration does not account for

Table 19.1 Rumen H_2 concentration in different animal species

Species	Diet	H_2(µM)	Reference
Cows	Alfalfa	0.4	Olson and Whitehead (1940)
Cows	Sweet clover	2.3	Olson and Whitehead (1940)
Cow	Alfalfa hay	0.6–1.3	Hungate (1967)
Sheep	Hay	0.2–0.7 (Avg. 0.4)	Barry et al. (1977)
Sheep	Grain	0.2–28 (Avg. 3.3)	Barry et al. (1977)
Sheep	Processed grass nuts	0.6–3.4	Hillman et al. (1985)
Cattle	Forage	1–1.4	Smolenski and Robinson (1988)
Sheep	Silage + conc.	15 ppm (breath conc.)	Takenaka et al. (2008)
Sheep	Silage	2 ppm (breath conc.)	Takenaka et al. (2008)
–	–	0.1–50	Janssen (2010)

decrease in CH_4; rather, higher H_2 concentrations affect the fermentation of the feed so that less H_2 is formed and so the CH_4 emissions (Janssen 2010).

19.3 Is Rumen Methanogenesis an Obligation?

From the discussion so far, it is clear that the removal of metabolic H_2 generated in anaerobic fermentation is essentially required for fermentation and normal functioning of the rumen. Accumulation of fermentative gases, especially $H_{2,}$ in the rumen may cause the complete cessation of fermentation and rumen functioning. Therefore, nature has blessed these animals with safe disposal mechanisms to take detrimental fermentative gases away from the animal system.

Methane synthesis cannot be understood or controlled without understanding all of the processes that produce substrates or remove products from the system (Kohn 2015). The principal reaction in the rumen which provides energy is the conversion of glucose to acetate, but this reaction also produces substantial metabolic H_2 as shown below:

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2$$

Another major reaction that produce reducing equivalents is the conversion of glucose to butyrate:

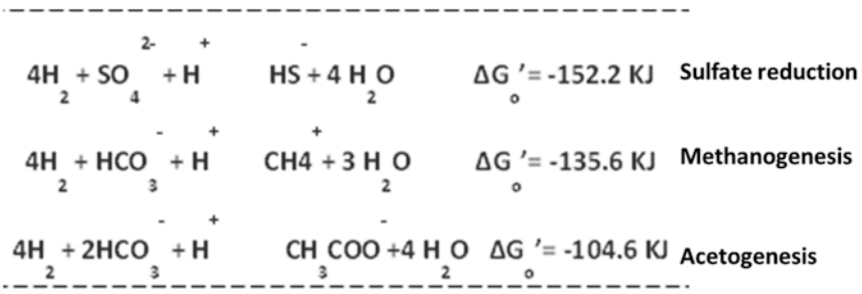
$$C_6H_{12}O_6 \rightarrow CH_3CH_2CH_2COOH + 2CO_2 + 2H_2$$

H_2 does not accumulate in the rumen system as it is readily directed to be used in various pathways including formation of methane and propionate (Kohn 2015) as per the reactions illustrated below:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \{\text{Methanogenesis}\}$$

$$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2H_2O \{\text{Propionogenesis}\}$$

Although, there are many sinks for the safe disposal of metabolic H_2 available in the rumen, of all these, methanogenesis is the primary and chief route of H_2 elimination from the rumen (Wolin et al. 1997). Though the sulphate reducers are the most efficient in utilizing H_2 in the rumen, the extent or possibility of this reductive process depends on the sulphate availability in the rumen (Oren 2012). Sulphate reducers obtain the energy from H_2 oxidation, and their affinity for H_2 is much higher than methanogenic archaea (Kristjansson et al. 1982). Reductive acetogenesis is another pathway for H_2 utilization in the rumen where the same substrates, i.e. CO_2 and H_2, are converted into acetate. Gibbs free energy change (thermodynamics) under standard conditions determines the chance of the three competing processes, namely, sulphate reduction, reductive acetogenesis and methanogenesis for utilizing metabolic H_2 and the safe removal of H_2 from the rumen (Oren 2012). Thermodynamics of all the three major competitive processes is given in Fig. 19.2. When sulphate is limited, methanogens will dominate the role of H_2 removal from the rumen. The lower energy yield of acetogenesis is probably accountable for making the reductive acetogenesis a less favourable



$4H_2 + SO_4^{2-} + H^+ \quad HS^- + 4\,H_2O \quad \Delta G_o' = -152.2$ KJ **Sulfate reduction**

$4H_2 + HCO_3^- + H^+ \quad CH4 + 3\,H_2O \quad \Delta G_o' = -135.6$ KJ **Methanogenesis**

$4H_2 + 2HCO_3^- + H^+ \quad CH_3COO^- + 4\,H_2O \quad \Delta G_o' = -104.6$ KJ **Acetogenesis**

Fig. 19.2 Thermodynamics of three major competitive H_2 processes (Oren 2012) route for H_2 removal from the system in the presence of methanogens.

In general, methanogenesis is the main route of H_2 removal from the rumen (Beauchemin et al. 2008); therefore, methanogenesis is generally regarded as necessary but wasteful process from the animal nutritionist's point of view. If we are to successfully reduce enteric CH_4 emission, H_2 must be disposed through other routes in order to keep the rumen functional and the animal alive. Propionogenesis and reductive acetogenesis theoretically seem promising alternative sinks for H_2 in the rumen as these pathways end up with metabolically beneficial products that lead to energetic gain for host animal (Joblin 1999; Molano et al. 2008).

Until now, due to the low H_2 threshold of archaea, methanogenesis is primary hydrogenotrophic sink for large H_2 clearance from the rumen; therefore, this pathway is an obligatory but wasteful mechanism leading to a substantial loss of feed energy. Complete inhibition of methanogenesis is neither possible nor practical due to the highly dynamic and diverse archaeal community. Our efforts should focus on targeting the prominent methanogens, which have a low hydrogen threshold level, and as such do not allow the naturally resident acetogens to utilize hydrogen. At the same time, efforts should be made to identify and promote those acetogens with maximum H_2-utilizing capacity. The possibilities of all the alternate H_2 sinks in the rumen are debated in the subsequent sections of the chapter.

19.4 Enteric Methane Mitigation

Practical strategies to reduce agricultural greenhouse gas emissions are urgently sought, particularly for ruminant enteric CH_4 (Pinares Patino et al. 2009). The most successful strategies will be those which lead to a profitable increase in animal productivity, as well as reduce enteric CH_4 emission. Strategic options for controlling livestock CH_4 production are delineated in Fig. 19.3, which clearly demonstrates that enteric CH_4 emissions and its mitigation are directly related with H_2 utilization, suppression and diversion towards a productive process. Researchers are trying to explore the best possible options for the eradication of enteric CH_4 emission through feeding- and management-based approaches, redirecting H_2 towards productive process, and through biological control of rumen archaea (Malik et al. 2012a). Under the anaerobic conditions of the rumen, surplus-reduced cofactors must be reoxidized by electron transfer to continue fermentation in the rumen (Leng 2008). In this chapter, an attempt is made to address those approaches which have a potential to redirect the metabolic H_2 (alternate sinks) away from methanogenesis and at the same time lead to an energetic gain for the host animal.

19.4.1 Sulphate Reduction

It is clear from the discussion so far that among three competitive process, the removal of H_2 through sulphate reduction is thermodynamically most favourable provided that adequate sulphate is available for receiving the reducing equivalents. The major source of sulphur in grazing ruminants is S-containing amino acids in protein. Excess sulphur than required for microbial protein synthesis is reduced to H_2S which has limited solubility and quickly enters the gas phase before it is eructated and inhaled into the lungs where a proportion is absorbed and converted to sulphate in the liver (Leng 2008). H_2S levels in rumen fluid are low often about 0.1 mM (Leng 2008).

Sulphur in the form of sulphate-, sulphite- and sulphur-containing amino acids is rapidly reduced to sulphide (Morvan et al. 1996) by microbial activity, and electron flow is diverted away from CO_2 reduction thus inhibiting methanogenesis in the rumen (Anderson and Rasmussen 1998). Sulphate reduction to H_2S in the rumen by sulphate-reducing bacteria (SRB) is presented in Fig. 19.4. Sulphide is present as HS^- and/or H_2S (gaseous form) in the rumen which can be absorbed across the rumen wall and later be detoxified via oxidation (Drewnoski et al. 2012). H_2S can be eructated from the rumen; however,

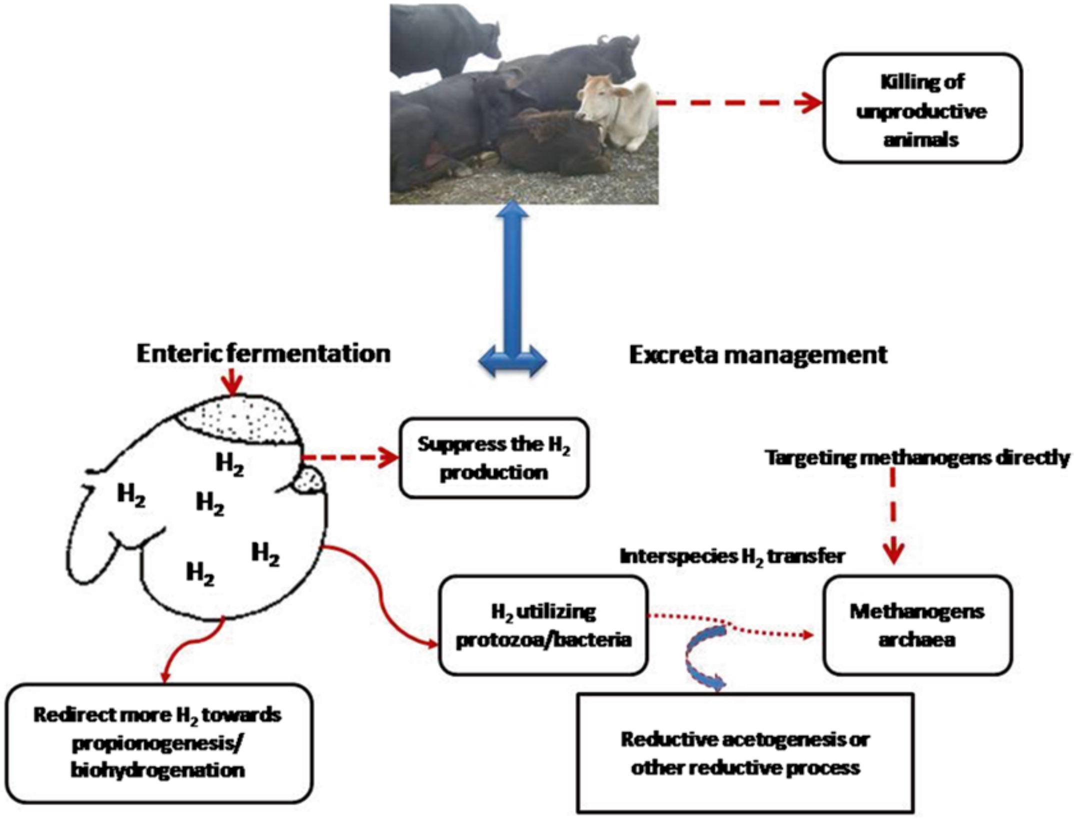


Fig. 19.3 Strategic options for controlling the livestock methane (Malik et al. 2015)

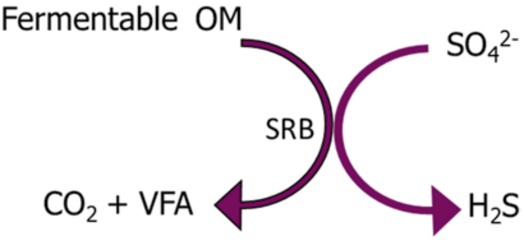


Fig. 19.4 Sulphate reduction: an alternate sink for H_2 removal from the rumen (Leng 2008)

eructated H_2S may be inhaled and absorbed through the lungs and is thought to cause polioencephalomalacia (Loneragan et al. 2005) (Fig. 19.4).

Sulphate-reducing bacteria (SRB) dwellings in the rumen are strict anaerobes, mostly Gram-negative and rod shaped (Cummings et al. 1995), and show wide population fluctuations in sheep, cattle, buffalo and deer (Morvan et al. 1996). The number of SRB was found to be greater in sheep and cattle than in deer and buffalo in a study conducted by Morvan et al. (1996). *Desulfovibrio* spp., namely, *D. desulfuricans* and *D. vulgaris*, are the most commonly isolated species of SRB (Cummings et al. 1995; Gould 1998). The total rumen bacterial biomass particularly of SRB increases on sulphate inclusion in the diet as observed by van Zijderveld et al. (2010). *Desulfotomaculum* is another sulphate-reducing bacteria found in the gastrointestinal tract of ruminants; however, *Desulfovibrio* spp. remain the major sulphate-reducing bacteria in the rumen (Howard and Hungate 1976).

Van Zijderveld et al. (2010) reported 16 % reduction in CH_4 emission from sheep supplemented with 2.6 % sulphate. They further stated that this level of sulphate supplementation was more effective in inhibiting CH_4 emission (47 %) when given in combination with nitrate.

However, the level of 2.6 % sulphate can cause disturbances in the O_2 absorption in the blood. Lower levels of sulphur supplementation appear to stimulate fermentation and therefore may actually increase the methane output. But, sulphate additions at higher level will provide the extra sulphur for receiving the reduced equivalents. Silivong et al. (2011) also reported reduced CH_4/CO_2 ratio in crossbred goats fed on Mimosa foliage supplemented with sodium sulphate at a level of 0.8 %. In one study, it was found that methanogenesis cannot be inhibited by sulphate levels below 20 mM; the reduction may be enhanced when sulphate is >20 mM (Ohashi et al. 1996); however, 90 % of the electrons are still utilized for methanogenesis even at the highest level of sulphate (Ohashi et al. 1996). They concluded that the association of methanogens with H_2-producing microbes cannot be replaced by SRB.

The product of sulphate/sulphur reduction (sulphide) is toxic at high concentrations for microorganisms as well as for the host animal. This toxicity is the major limiting factor in using sulphur/sulphate as an alternate H_2 sink in the rumen. High concentrations of S from dietary sources including the byproducts from ethanol industry-induced polioencephalomalacia (PEM) attributed to the production of H_2S gas in the rumen (Crawford 2007). Cattle fed on high-forage diets are less prone to S-PEM than those fed on high-concentrate diets (NRC 2005). The reason for this was the increase in the gaseous form of sulphide (H_2S) with decreasing rumen pH (Drewnoski et al. 2012) associated with concentrate feeding. Other toxicity symptoms include reduced rumen motility and nervous and respiratory distress (Backman 2012). H_2S probably also blocks cytochrome-c oxidase enzyme in the electron transport chain and causes cellular energy deficiency (Dorman et al. 2002). However, some recent *in vitro* work has suggested that cytotoxicity caused by H_2S may involve a reactive S species that depletes reduced glutathione (GSH) and activates oxygen to form reactive oxygen species (Truong et al. 2006).

Drewnoski et al. (2012) concluded that factors other than S intake alone appear to contribute to concentrations of ruminal H_2S, and roughage level in the diet seems to have a significant effect on H_2S concentrations. They also reported increased concentration of oxidized glutathione in the liver of cattle fed with high-S diet, suggesting that this leads to oxidative stress, but further investigation is warranted to confirm this (Drewnoski et al. 2012). Passive immunization approach that specifically targets sulphate-reducing bacteria could be one way to tackle H_2S toxicity in the rumen (DiLorenzo et al. 2008), thus, exploring the use of sulphate/sulphur as a potential H_2 sink in the rumen without any adverse impact on ruminal microbes or host animal is warrant under different feeding regimens.

19.4.2 Nitrate Reduction

In rumen, nitrate is largely reduced to nitrite by NADPH–nitrate reductase enzyme and then to ammonia via hydroxylamine (Takahashi 2011). The reduction of nitrate to nitrite and ammonia yields more energy than the reduction of CO_2 to CH_4 (Ungerfeld and Kohn 2006). The process of nitrate reduction in the rumen may be the principal route for H_2 disposal away from the methanogenesis (Takahashi 1986). Nitrate has a greater affinity for H_2 than does CO_2, and so, when nitrate is present in the rumen, nitrite and ammonia formation are favoured over methane production (Ungerfeld and Kohn 2006; Nolan et al. 2010).

Nitrate reduction in anaerobic systems occurs by three distinct pathways: dissimilatory nitrate reduction to nitrogen gas (denitrification), dissimilatory nitrate reduction to ammonia and assimilatory nitrate reduction to ammonia (Leng 2008). Generally, denitrification does not occur in the rumen, but when nitrate is present in rumen fluid, small amounts of nitrogen oxides may be produced (Leng 2008). Dissimilatory nitrate reduction is the chief pathway for the production of ammonia through the reduction of nitrate and/or nitrite by reducing equivalents. Dissimilatory nitrate reduction occurs when the redox potential values in the medium are low (Knowles 1982), often in the presence of sulphide (Brunet and

Table 19.2 Effect of nitrate addition on *in vivo* methane emission

Animal species	Nitrate source and level	Methane reduction (%)	Reference
Cattle	5 % potassium nitrate	43	Sophal et al. (2013)
Cattle	22 g nitrate kg^{-1} DM	32	Hulshof et al. (2012)
Cattle	6 % KNO_3	27	Inthapanya et al. (2012)
Cattle	6 % KNO_3	30	Phuong et al. (2011)
Cattle	21 g nitrate kg^{-1} DM	16	van Zijderveld et al. (2011)
Cattle	2.38 % calcium ammonium nitrate	~41	Ascensao (2010)
Sheep	25–30 g $NaNO_3$		Takahashi and Young (1991)
Sheep	2.6 % nitrate	32	van Zijderveld et al. (2010
Sheep	4 % KNO_3	23	Nolan et al. (2010)
Goat	5 % $CaNO_3$	–	

Garcia-Gil 2006) or high organic matter concentrations (Akunna et al. 1993). Dissimilatory reduction is unaffected by ammonia in the culture medium, and rapid conversion of nitrate to ammonia occurs even at high concentrations of ammonia. Its primary function appears to be to reoxidize reduced pyridine nucleotides (e.g. NADH). Assimilatory nitrate reductase involves enzymes that catalyse the reduction of nitrate to nitrite then to ammonia. In this, nitrate is reduced to nitrite by NADH reduction, and nitrite is reduced to ammonia by assimilatory nitrite ammonification which is coupled to ATP formation (Simon et al. 2002). *Wolinella succinogenes* isolated from the bovine rumen are able to carry out assimilatory or respiratory nitrite ammonification (Simon et al. 2002) suggesting that nitrate-reducing bacteria (NRB) can play a role in fermentation especially when ammonia is limiting. The predominant pathway of nitrate metabolism in the rumen is uncertain but has always been assumed or even asserted to be dissimilatory nitrate reduction to ammonia as shown below:

$$NO_3^- + 2H^+ \rightarrow H_2O + NO_2$$

$$NO_2 + 6H^+ \rightarrow H_2O + NH_3$$

During the course of nitrate reduction, 8 reducing electrons are consumed which is theoretically adequate to lower the methane production by 1 mol or 16 g (Leng 2008). In addition, ammonia generated from the process will also be an important source of fermentable N in protein-deficient diets where low rumen ammonia is the major constraint for microbial protein synthesis. Since 2010, many *in vivo* studies have been conducted to investigate the effect of nitrate addition on CH_4 emissions. Findings from these studies are compiled and presented in Table 19.2, where it is shown that the addition of nitrate in ruminant diets reduces *in vivo* CH_4 emissions somewhere around 20–40 %. Leng (2008) suggested that dietary conditions like easily fermentable carbohydrate, low soluble protein fraction, adequate sulphur level and a source of bypass protein favour the utilization of nitrate to lower the methane production. Nitrate and sulphate reductions, even if successfully explored as alternative H_2 sinks in rumen, do not incorporate reducing equivalents into energy sources available to ruminants (Ungerfeld 2013) as done in reductive acetogenesis.

The sudden introduction of nitrate in the diet may lead to the oxidation of the ferric iron in haemoglobin resulting in methaemoglobinaemia and adversely affecting oxygen transport (van Zijderveld et al. 2011). The intermediate product of nitrate reduction, i.e. nitrite, is possibly toxic if exceeding the permissible limit. Recent research shows that the apparent toxicity problems associated with methaemoglobinaemia may be minimized with a 2-week adaptation with gradual inclusion of nitrate in the diet and adequate sulphur available (Phuc et al. 2009). Gradual introduction of nitrate into the diet allows the rumen microbes to adapt and increase their capability to reduce nitrite.

19.4.3 Reductive Acetogenesis

Acetogenic microbes exist in diverse environments ranging from sediments, wastewater and soils to animal gut systems (Bernalier et al. 1996) and are likely to be a natural part of the rumen microbiota (Drake et al. 2008). Due to their hydrogenotrophic ability, acetogens received significant attention in the last few years and could be an alternative sink for H_2 in the rumen (McSweeney et al. 2009). Acetogens are a phylogenetically diverse group of bacteria that have the ability to use the acetyl–CoA pathway for the reduction of CO_2 to acetyl–CoA for energy conservation and the assimilation of CO_2 into cell carbon (Drake et al. 2008; Gagen et al. 2015). The initiation and escalation of reductive acetogenesis in the rumen will not only ensure the alternate disposal of H_2 away from the methanogenesis but also result in an energetic gain to the host animal due to the formation of acetate which is absorbed across the rumen wall (Morvan et al. 1994; Joblin 1999; Olsson et al. 2006). Although reductive acetogenesis is not a significant H_2 sink in the rumen naturally, in the absence of methanogenesis, acetogens can contribute significantly to hydrogen capture and can sustain a functional rumen (Fonty et al. 2007; Gagen et al. 2012). The reductive pathway through which acetate is produced on receiving the reducing equivalents is known as the Wood–Ljungdahl pathway (Ragsdale and Pierce 2008). The microbes capable of using acetyl–CoA pathway for producing the acetate as reduced product of CO_2 and H_2 are known as homoacetogens (Drake 1994).

The reductive acetogenesis pathway contains eastern and western branches as shown in Fig. 19.5. In reductive acetogenesis, acetogens reduce 2 mol of CO_2 to acetate by oxidation of H_2 as follows: $2CO_2+4H_2CH_3 \rightarrow COOH+2H_2O$. Flow of CO_2 to reductive acetogenesis takes place through the methyl or carbonyl branch (Fig. 19.5).

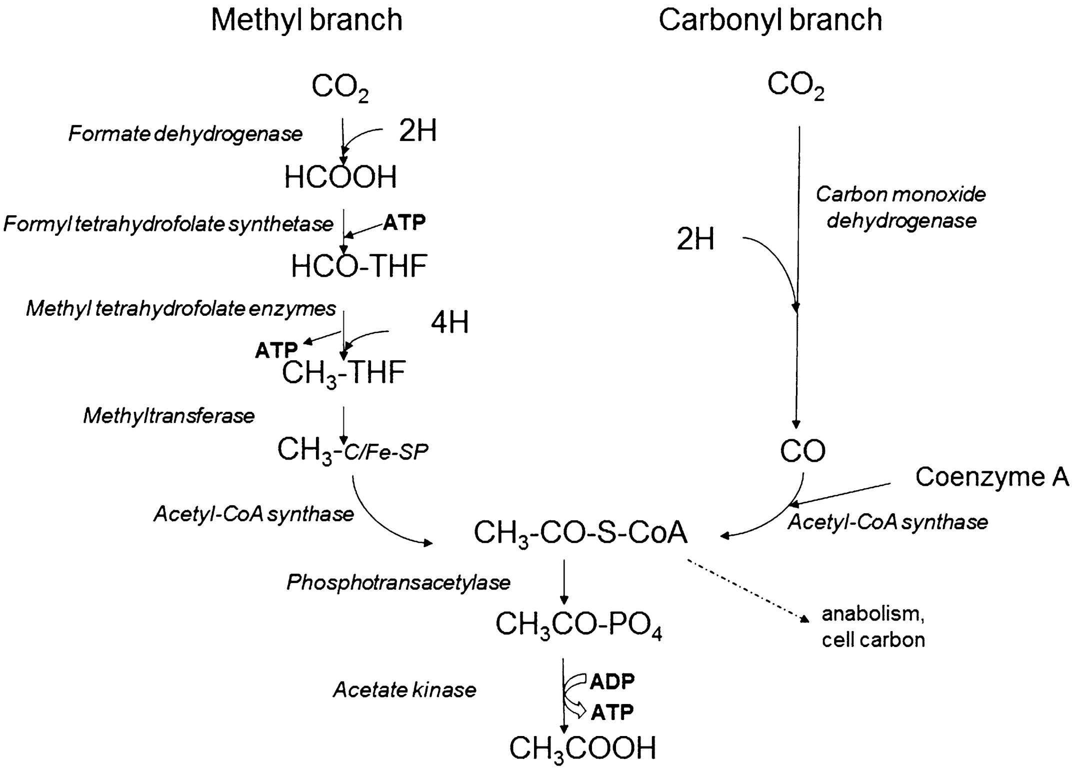


Fig. 19.5 Reductive acetogenesis pathway (Drake 1994; Gagen et al. 2015)

The methyl branch of the pathway is folate dependent, where CO_2 is reduced to formate and finally to methyltetrahydrofolate (Ragsdale and Pierce 2008), while CO_2 that enters the carbonyl branch is reduced to CO which in turn condenses with methyl group to produce acetyl–CoA.

The comparatively low H_2 threshold of methanogens and more Gibbs free energy change (−135 KJ) make the methanogenesis thermodynamically more favourable for H_2 disposal than reductive acetogenesis under normal rumen conditions. The H_2 threshold of acetogens is 10–100-fold higher than methanogens (Breznak and Kane 1990) despite the fact that the H2-VMax/Km values of these two groups of hydrogenotrophic bacteria are in the same range. H_2 thresholds of acetogens vary from 340 to 8,060 ppm, and in rumen acetogens, it is reported in the range of 342–4,200 ppm (Breznak and Kane 1990; Morvan et al. 1996). Methanogenic archaea never allow the H_2 partial pressure in the rumen to reach a level at which it is available for reductive acetogenesis. In a fully functional and developed rumen, methanogens outcompete acetogens and utilize most of the electrons for methanogenesis. Acetogens are apparently dominating hydrogenotrophic microbes before the establishment of archaea in the rumen, and their numbers decrease proportionally as methanogens colonize in the rumen (Gagen et al. 2012). Reports are available which suggest that acetogenesis is a major hydrogenotrophic pathway in kangaroos, wallabies and termite hindgut (Gagen et al. 2010; Elizabeth and Leadbetter 2011) where it replaces methanogenesis. Most reductive acetogens are capable of heterotrophic growth and readily utilize substrates other than CO_2 and H_2 and use diverse electron acceptors (Joblin 1999).

An updated list of the rumen acetogens isolated from different ruminant species and compiled by Gagen et al. (2015) is given in Table 19.3. It is evidenced from the isolated acetogens that *Blautia*, *Clostridium*, *Acetitomaculum* and *Eubacterium* spp. constitute the major segment of this hydrogenotrophic group, although many unidentified acetogens are also isolated from the dairy/beef cattle, sheep, lambs, bison, deer, etc. (Table 19.3).

Klieve and Joblin (2007) studied the comparative efficiency of ruminal acetogen isolates (Se5, Se8, CA6 and SA11), marsupial isolates (YE255, YE257 and YE266) and two reference isolates (*Acetitomaculum ruminis* and *Eubacterium limosum*) for H_2 utilization and acetate production in H_2/CO_2 containing rumen fluid medium. From the study, they concluded that the marsupial isolates and two of the ruminal isolates (ser5 and ser8) are more efficient in utilizing H_2 as a

Table 19.3 Rumen acetogens isolated from different ruminant species

Isolate	Source	References
Acetitomaculum ruminis	Steer rumen	Greening and Leedle (1989)
Blautia coccoides (8F)	Methanogen-free lambs	Fonty et al. (2007)
Blautia producta	Calf rumen	Bryant et al. (1958)
Blautia schinkii	Young lamb	Rieu-Lesme et al. (1996)
Clostridium difficile-like	Newborn lambs	Rieu-Lesme et al. (1998)
*Clostridium symbiosum**	Methanogen-free lambs	Fonty et al. (2007)
*Enterococcus gallinarum**	Methanogen-free lambs	Fonty et al. (2007)
Eubacterium limosum	Sheep rumen	Genthner and Bryant (1987)
*Propionibacterium australiense**	Methanogen-free lambs	Fonty et al. (2007)
Se8 and Se5 Cluster XIV Clostridia	Young lamb	Morvan et al. (1994) and Fonty et al. (2007)
Unidentified	Dairy or beef cattle	Boccazzi and Patterson (2011)
Unidentified	Deer	Rieu-Lesme et al. (1995)
Unidentified	Cow rumen	Joblin (1999)
Unidentified	Sheep rumen	Joblin (1999)
Unidentified coccoid spore-forming bacteria	Lambs, llamas and bison	Rieu-Lesme et al. (1996)

Adapted from Gagen et al. (2015)
*Isolated as reductive acetogens, but did not retain the acetogenic capacity after subculture

substrate than the other two ruminal isolates (CA6 and SA11). Further, they reported that recognized acetogen reference (*Acetitomaculum ruminis* and *Eubacterium limosum*) showed very poor ability in using H_2. A high population density of ruminal acetogens was reported in methanogen-free lambs (Fonty et al. 2007); however, H_2 capture in methanogen-free lambs was low (28–46 %). Reductive acetogenesis was not reported a significant part of fermentation in conventional lambs, but contributed 21–25 % to the fermentation in methanogen-free meroxenic lambs (Fonty et al. 2007), demonstrating that reductive acetogenesis can be an alternate H_2 sink in the partial or complete inhibition of rumen methanogens, and if the rumen ecosystem is altered from the early developmental stage, the magnitude of reductive acetogenesis may be increased to a significant extent. Addition of the reductive acetogen *Peptostreptococcus productus* to an *in vitro* reactor simulating the human gut (inoculated with human faeces) resulted in a decrease in methanogenesis to a level below the detection limit (Nollet et al. 1997b), but did not affect methanogenesis in ruminal incubations (Nollet et al. 1997a). Ruminants should be screened at different developmental stages and on different feeding regimes to explore the maximum reductive acetogen population. Molecular work done at our institute indicates that the acetogens present in Indian sheep are quite different from reported acetogens (Malik et al. 2012b); this difference may be attributed to the entirely different feeding conditions and geographical locations. We should make an effort to suppress the methane emission through nutritional or biological interventions, and at the same time, the magnitude of reductive acetogenesis should also be augmented through rumen ecosystem manipulations.

19.4.4 Supplemental Fat

Supplementation of fat and oils mitigates enteric CH_4 production by redirecting hydrogen towards biohydrogenation as an alternate sink to methanogenesis. Furthermore, fatty acids are not fermented in the rumen, and hence they do not contribute H_2 and other required substrates for methanogenesis (Morgavi et al. 2011). Many researchers have observed a 2–4 % reduction in CH_4 emission for every percent increase in lipid content of animal diet (Eugene et al. 2008; Martin et al. 2010; Grainger and Beauchemin 2011). Beauchemin et al. (2008) reviewed the effects of dietary lipid levels on CH_4 emissions and concluded that for each 10 g kg^{-1} DM fat addition, there is a proportional decrease of 0.056 g kg^{-1} DMI. The unsaturated fatty acids are converted to more saturated end products through biohydrogenation in the rumen, and these products flow to the intestines. However, disposal of H_2 through biohydrogenation process in the rumen is always debated and usually reported to be very small (<5 %) in comparison to methane and propionate production (Jenkins et al. 2008).

Addition of fat particularly unsaturated fat to the rumen decreases methane production; however, the extent of methane suppression is dosage dependent and influenced by the type of fatty acid. The extent of methane reduction through lipid supplementation mainly depends on the quantity, degree of unsaturation and the chain length (Johnson et al. 2002). It appears that the effect of degree of unsaturation is relatively small, and the effect is mainly due to digestion depression (Johnson and Johnson 1995; Mathison et al. 1998). Certain oils such as coconut oil seem to reduce CH_4 possibly by suppressing protozoa (Machmuller et al. 1998).

Johnson and Johnson (1995) stated that the amount of H_2 used in biohydrogenation process of unsaturated fatty acids is insignificant for a significant reduction in CH_4 emissions, and considerable effects of lipids supplementation are likely to occur only when basal digestion is inhibited. However, Dong et al. (1997) found that it is not necessary that CH_4 reduction is always accompanied with depressed digestion. For enteric CH_4 reduction, medium-chain fatty acids are more effective than long chain fatty acids (Johnson and Johnson 2002). Dietary fat supplements, especially those containing unsaturated fatty acids, can reduce enteric CH_4 emissions, but oil production for animal feed is usually associated with increased net greenhouse gas emissions (Beauchemin et al. 2008; Grainger et al. 2010) which should also be taken into account. Eicosahexanoic acid (EPA or C20:5) and docosahexaenoic acid (DHA or C22:6), the major bioactive unsaturated fatty acids found in fish oil and marine algae (Givens et al. 2000), decreased CH_4 production up to 80 % in *in vitro* studies (Fievez et al. 2003). As stated earlier, fat and oil contribute very little towards H_2 disposal in the course of biohydrogenation, and the methane-inhibiting action is mainly due to the triggering of a toxic effect on ruminal microorganisms particularly on H_2-producing microbes and methanogens, suppressing rumen protozoa liable for interspecies H_2 transfer to archaea and depressing enteric digestion.

19.4.5 Propionogenesis as an Alternate Sink

Roughage-based diets are typically associated with high CH_4 production mol^{-1} of hexose fermented in the rumen as increased acetate production leaves more reducing equivalents to be utilized in methanogenesis, while the reverse happens on concentrate feeding where reducing equivalents are incorporated into propionate formation (Czerkawski 1986; Wolin et al. 1997). Both starch and cellulose are hydrolysed to glucose; however, the fermentation pattern of starch results in lower acetate to propionate ratio compared to cellulose (Bannink et al. 2006). When methanogenesis is inhibited, reducing equivalents are diverted into alternative electron sinks. Dihydrogen incorporation into a useful electron sink is a necessary part of an integral methanogenesis inhibition strategy, because it minimizes gaseous digestible energy (DE) losses and avoids fermentation inhibition. Some of these alternative electron sinks are typical to ruminal fermentation, like propionate (Wolin et al. 1997; Janssen 2010). An outline of the fermentation pathway is given in Fig. 19.6, exhibiting the production or utilization of electrons during the synthesis of volatile fatty acids (VFAs). The partial or complete inhibition of rumen methanogenesis is known to increase the partial H_2 pressure which thermodynamically favours the incorporation of

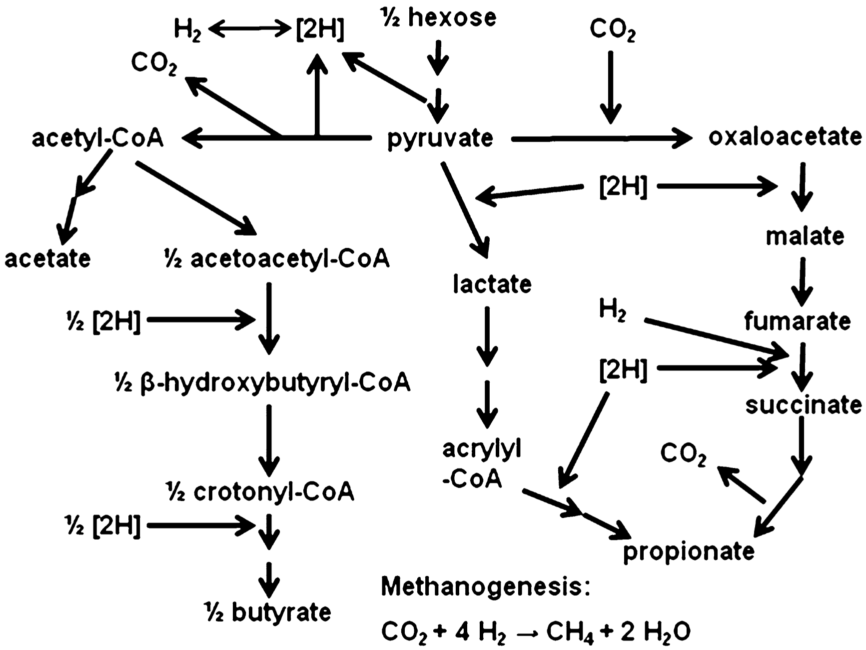


Fig. 19.6 Fermentation pathway in the rumen (Adapted from Ungerfeld 2013)

reducing equivalents into propionate or disposal through other alternate pathways. Nevertheless, the incorporation of reducing equivalents spared from methanogenesis into propionate is not complete (Czerkawski 1986), and H_2 accumulates especially if CH_4 production is strongly inhibited as demonstrated in many of the studies (Mitsumori et al. 2012).

Ungerfeld (2013) discussed the energetic and nutritional consequences of fixing reducing electrons into propionate formation when methanogenesis is inhibited. Each mol of acetate that is not produced from fermentation prevents the release of 2 mol of reducing equivalents. For the formation of 1 mol of acetate, 2 mol of CO_2 is reduced with 4 mol of H_2 that results in a gain of heat of combustion equal to 876 kJ or 219 kJ/mol H_2 (Ungerfeld 2013), whereas incorporation of 3 mol of H_2 to produce 1 mol of propionate at the expense of 1 mol of acetate not being produced results in a gain in heat of combustion equal to (1,529–876 kJ)/3 mol H_2 = 218 kJ/mol H_2 in propionate per electron-pair incorporated (Ungerfeld 2013).

Incorporation of H_2 into either reductive acetogenesis or propionate production results in an increase in heat of combustion in VFA of about 12 % with respect to the corresponding fermentation with CH_4 as main electron sink. In totality, all the reducing equivalents left behind after the inhibition of methanogenesis are not incorporated into propionate production. Addition of metabolism intermediates that finally reduce to propionate through succinate or acrylate pathway will redirect the reducing equivalents away from the methanogenesis (Fig. 19.6) and into propionate production (Ungerfeld et al. 2007). Asanuma et al. (1999) concluded that *Fibrobacter succinogenes*, *Selenomonas ruminantium* ssp. *ruminantium*, *Selenomonas ruminantium* ssp. *lactilytica*, *Veillonella parvula* and *Wolinella succinogenes* are accountable for the oxidation of H_2 using fumarate as a final electron acceptor, suggesting that these bacteria compete with methanogens for electrons. However, the affinity of these bacteria for H_2 is lower than the affinity of methanogens which restricts the diversion of electrons for propionate production. Furthermore, microbial adaptation to fumarate metabolism is also important for rechanneling the electrons for the reduction of fumarate to succinate. Biotic agents such as fumarate-reducing bacteria which are hydrogenotrophs can be used as an alternate sink for H_2 disposal in rumen. Mamuad et al. (2012) isolated a strain of fumarate-reducing bacteria that is closely related to *Mitsuokella jalaludinii* from a Korean black goat. This isolate was found to harbour the *frd*A gene, which contains the succinate dehydrogenase/fumarate reductase flavoprotein subunit. Recently, Mamuad et al. (2014) in a study found that the supplementation of *Mitsuokella jalaludinii* reduces the methane production, increases the succinate and changes the rumen microbial diversity; however, the difference in propionate production was not substantial. Therefore, any strategy which simultaneously targets the methanogens and ensures the incorporation of electrons in energy-saving product like propionate will certainly reduce enteric CH_4 emission with an energetic gain to host animal.

19.5 Anticipated Returns from Methane Reduction

Among the GHGs, CO_2 remains the major anthropogenic GHG accounting for 76 % of the anthropogenic emissions, while CH_4 is next to CO_2 adding 16 % (7.8 Gt CO_2-eq. year^{-1}) to the anthropogenic pool of GHGs (IPCC 2014). Livestock is the major source of anthropogenic CH_4 emissions contributing ~90 Tg methane to global emissions. The reduction of enteric CH_4 emission is obligatory not only from a global warming point but also required for improving the productive efficiency of animals especially under the scenario of feed and fodder deficit prevailing in most of the world's developing countries today (Malik et al. 2015). Climate change is a collective action problem at the global scale, because most GHGs accumulate over time and mix globally, and emissions by any agent (e.g. individual, community, company, country) affect the others; hence, the effective mitigation of GHGs requires cooperation between continents, area and communities (IPCC 2014).

Table 19.4 Expected benefits from 20 % reduction in enteric methane emission-World & India

Attributes	Values
World's livestock enteric methane	90 Tg
Desirable reduction 20 %	18 Tg
CO_2-eq.	450 Tg
Methane emission after attaining the reduction level	72 Tg
Additional feeding (adult cattle*)	~60 Million
Extra milk**	~210 M Mt.
India	
Enteric methane emissions	10 Tg
Desirable reduction 20 %	2 Tg
Additional feeding (adult cattle*)	~7 Million
Extra milk	~23 MMT
CO_2eq	50 Tg

Malik et al. (2015)

*400 kg body weight and maintenance requirement of 121 Kcal/kg$^{0.75}$ is taken into consideration for calculation; **A requirement of 1.144 mcal for 1 kg milk was taken into consideration for calculation purpose

The reimbursements arising from the 20 % reduction in enteric CH_4 emission are projected theoretically here in Table 19.4. A 20 % reduction in CH_4 emission will reduce the emission of CO_2-eq. GHG by around 450 Tg year^{-1}. Apart from this, 20 % reduction in methane emissions could also produce ~210 million metric tons additional milk production or fulfil the maintenance requirement for energy of about 60 million adult cattle worldwide through saved energy from methane (Table 19.4). In this way, a 20 % reduction looks very promising especially for the developing world where acute shortage of feeds and fodders is a general phenomenon.

19.6 Conclusion

Strategies that lead to a significant reduction in enteric methane mitigation and also increase the animal productivity are urgently sought. Researchers worldwide are trying to explore the best possible option for controlling the CH_4 emission in practically possible and natural ways. As rumen methanogenesis is directly related to H_2 production in rumen, redirecting H_2 through energy conservative sinks which divert H_2 from the methanogenesis will certainly have an impact in reducing enteric methane emission to a desirable level. Sulphate and nitrate reduction, reductive acetogenesis, fat supplementation and intensifying propionogenesis are some of the ways to ensure the fermentative H_2 disposal through these alternative sinks in the rumen. These alternate sinks can be a potential contrivance in the rumen for plummeting methane emission. In addition, clearance of H_2 through pathways like reductive acetogenesis and propionogenesis also has the advantage of energy conservation into end products which are useful for the host animal. Although, the thermodynamics of the competitive process, low H_2 threshold level of archaea and sometimes toxic intermediary compounds (in case of nitrate) are a few of the major concerns which need to be addressed through continuous research in these areas. There is a need to design or formulate the combination of interventions which can target the rumen archaea and promote/intensify the other competitive process (alternate sinks) in the rumen for reducing electron clearance.

References

Akunna JC, Bizeau C, Moletta R (1993) Nitrate and nitrite reductions with anaerobic sludge using various carbon sources– glucose, glycerol, acetic acid, lactic acid and methanol. Water Res 27:1303–1312

Anderson RC, Rasmussen MA (1998) Use of a novel nitrotoxin-metabolizing bacterium to reduce ruminal methane production. Bioresour Technol 64:88–95

Asanuma N, Iwamoto M, Hino T (1999) Effect of the addition of fumarate on methane production by ruminal microorganisms in vitro. J Dairy Sci 82:780–787

Ascensão AMD (2010) Effects of nitrate and additional effect of probiotic on methane emissions and dry matter intake in Nellore bulls. Dissertation, Universidade de Trás-os-Montes e Alto Douro

Backman K (2012) The effect of additional nitrate and sulfur in the diet on the methane production in cattle. Degree project, Swedish University of Agricultural Sciences. http://stud.epsilon.slu.se/4760/11/backman_K_120917.pdf. Assessed 15 May 2014

Bannink A, Kogut J, Dijkstra J, France J, Kebreab E, Van Vuuren AM, Tamminga S (2006) Estimation of the stoichiometry of volatile fatty acid production in the rumen of lactating cows. J Theor Biol 238:36–51

Barry TN, Thompson A, Armstrong DG (1977) Rumen fermentation studies on two contrasting diets. 2. Comparison of the performance of an in vitro continuous culture fermentation with in vivo fermentation. J Agric Sci 89:197–208

Beauchemin KA, Kreuzer M, O'Mara F, McAllister TA (2008) Nutritional management for enteric methane abatement: a review. Aust J Exp Agric 48:21–27

Bernalier A, Collins MD, Leclerc M, Rochet V, Willems A (1996) *Ruminococcus hydrogenotrophicus* sp. nov., a new H2/CO2-utilizing acetogenic bacterium isolated from human feces. Arch Microbiol 166:176–183

Boccazzi P, Patterson JA (2011) Using hydrogen limited anaerobic continuous culture to isolate low hydrogen threshold ruminal acetogenic bacteria. Agric Food Anal Bacteriol 1:33–44

Breznak JA, Kane MD (1990) Microbial H2/CO2 acetogenesis in animal guts: nature and nutritional significance. FEMS Microbiol Rev 7:309–313

Brunet RC, Garcia-Gil LJ (2006) Sulfide-induced dissimilatory nitrate reduction to ammonia in anaerobic freshwater sediments. FEMS Microbiol Ecol 21:131–138

Bryant MP, Small N, Bouma C, Robinson I (1958) Studies on the composition of the ruminal flora and fauna of young calves. J Dairy Sci 41:1747–1767

Clark H, Pinares-Patino CS, deKlein C (2005) Methane and nitrous oxide emissions from grazed grasslands. In: McGilloway DA (ed) Grassland: a global resource. Wageningen Academic Publishers, Wageningen, pp 279–294

Crawford GI (2007) Managing sulfur concentrations in feed and water. In: Proceeding of the Minnesota nutrition conference, St. Paul, pp 80–93

Cummings BA, Gould DH, Caldwell DR, Hamar DW (1995) Ruminal microbial alterations associated with sulfide generation in steers with dietary sulfate-induced polioencephalomalacia. Am J Vet Res 56:1390–1395

Czerkawski JW (1986) An introduction to rumen studies. Pergamon Press, New York, 172 p

Czerkawski JW, Breckenridge G (1971) Determination of concentration of hydrogen and some other cases dissolved in biological fluids. Lab Pract 20:403

DiLorenzo N, Dahlen CR, Diez-Gonzalez F, Lamb GC, Larson JE, DiCostanza A (2008) Effects of feeding polyclonal antibody preparations on rumen fermentation patterns, performance, and carcass characteristics of feedlot steers. J Anim Sci 86:3023–3032

Dong Y, Bae HD, McAllister TA, Mathison GW, Cheng KJ (1997) Lipid-induced depression of methane production and digestibility in the artificial rumen system (RUSITEC). Can J Anim Sci 77:269–278

Dorman DC, Moulin FJ, McManus BE, Mahle KC, James RA, Struve MF (2002) Cytochrome oxidase inhibition induced by acute hydrogen sulfide inhalation: correlation with tissue sulfide concentrations in the rat brain, liver, lung, and nasal epithelium. Toxicol Sci 65:18–25

Drake HL (1994) Introduction to acetogenesis. In: Drake HL (ed) Acetogenesis. Chapman and Hall, New York/London, pp 3–60

Drake HL, Gossner AS, Daniel SL (2008) Old acetogens, new light. Ann NY Acad Sci 1125:100–128. doi:10.1196/annals.1419.016

Drewnoski ME, Richter EL, Hansen SL (2012) Dietary sulfur concentration affects rumen hydrogen sulfide concentrations in feedlot steers during transition and finishing. J Anim Sci 90:4478–5078

Eugene M, Masse D, Chiquette J, Benchaar C (2008) Meta-analysis on the effects of lipid supplementation on methane production in lactating dairy cows. Can J Anim Sci 88:331–334

Elizabeth AO, Leadbetter JR (2011) Formyltetrahydrofolate synthetase gene diversity in the guts of higher termites with different diets and life styles. Appl Environ Microbiol 77(10):3461–3467

FAO (2006) Livestock's long shadow: environmental issues and options. Food and Agriculture Organization, Rome. http://ftp.fao.org/docrep/fao/010/a0701e/a0701e.pdf. Assessed 15 May 2014

Fievez V, Dohme F, Danneels M, Raes K, Demeyer D (2003) Fish oils as potent rumen methane inhibitors and associated effects on rumen fermentation in vitro and in vivo. Anim Feed Sci Technol 104:41–58

Fonty GF, Joblin K, Chavarot M, Roux GN, Michallon F (2007) Establishment and development of ruminal hydrogenotrophs in methanogen-free lambs. Appl Environ Microbiol 73:6391–6403

Gagen EJ, Denman SE, Padmanabha J, Zadbuke S, Al Jassim R, Morrison M (2010) Functional gene analysis suggests different acetogen populations in the bovine rumen and tammar wallaby forestomach. Appl Environ Microbiol 76:7785–7795

Gagen EJ, Mosoni P, Denman SE, Al Jassim R, McSweeney CS, Forano E (2012) Methanogen colonisation does not significantly alter acetogen diversity in lambs isolated 17 h after birth and raised aseptically. Microb Ecol 64:628–640

Gagen EJ, Denman SE, McSweeney CS (2015) Acetogenesis as an alternative to methanogenesis in the rumen. In: Malik PK, Bhatta R, Takahshi J, Kohn RA, Prasad CS (eds) Livestock production and climate change. CABI, Wallingford, pp 292–303

Genthner BRS, Bryant MP (1987) Additional characteristics of one-carbon-compound utilization by *Eubacterium limosum* and *Acetobacterium woodii*. Appl Environ Microbiol 53:471–476

Givens DI, Cottrill BR, Davies M, Lee PA, Mansbridge RJ, Moss AR (2000) Sources of *n*-3 polyunsaturated fatty acids additional to fish oil for livestock diets: a review. Nutr Abstr Rev Ser B 70:3–19

Goodland R, Anhang J (2009) Livestock and climate change: what if the key actors in climate change are cows, pigs and chickens? World Watch, November/December 2009. http://www.worldwatch.org/files/pdf/Livestock%20and%20Climate%20Change.pdf. Assessed 15 May 2014

Gould DH (1998) Polioencephalomalacia. J Anim Sci 76:309–314

Grainger C, Beauchemin KA (2011) Can enteric methane emissions from ruminants be lowered without lowering their production? Anim Feed Sci Technol 166–167:308–320

Grainger C, Williams R, Clarke T, Wright ADG, Eckard RJ (2010) Supplementation with whole cottonseed causes long-term reduction of methane emissions from lactating dairy cows offered a forage and cereal grain diet. J Dairy Sci 93:2612–2619

Greening RC, Leedle JAZ (1989) Enrichment and isolation of *Acetitomaculum ruminis* gen. Nov., sp. Nov.: acetogenic bacteria from the bovine rumen. Arch Microbiol 151:399–406

Hegarty RS, Gerdes R (1999) Hydrogen production and transfer in the rumen. Recent Adv Anim Nutr 12:37–44

Hillman K, Lloyd D, Williams AG (1985) Use of a portable quadrupole mass spectrometer for the measurement of dissolved gas concentrations in ovine rumen liquor in situ. Curr Microbiol 12:335–340

Howard BH, Hungate RE (1976) Desulfovibrio of the sheep rumen. Appl Environ Microbiol 32:598–602

Hulshof RBA, Berndt A, Gerrits WJJ, Dijkstra J, van Zijderveld SM, Newbold JR, Perdok HB (2012) Dietary nitrate supplementation reduces methane emission in beef cattle fed sugarcane-based diets. J Anim Sci 90:2317–2323

Hungate RE (1967) Hydrogen as an intermediate in the rumen fermentation. Arch Microbiol 59:158–164

Hungate RE, Smith W, Bauchop T, Ida Y, Rabinowitz JC (1970) Formate as an intermediate in the bovine rumen fermentation. J Bacteriol 102:389

ILRI (2011) More on getting credible figures for livestock emissions of greenhouse gases. http://www.ilri.org/ilrinews/index.php/page/7?s=%25. Assessed 15 May 2014

Inthapanya S, Preston TR, Leng RA (2012) Biochar increases biogas production in a batch digester charged with cattle manure. Livest Res Rural Dev 24:Article #212. http://www.lrrd.org/public-lrrd/proofs/lrrd2412/sang24212.htm. Assessed 15 May 2014

IPCC (2007) Climate change 2007: synthesis report. Contribution of working group I, II & III to the Fourth Assessment Report of the IPCC, Geneva, Switzerland, p 104

IPCC (2013) Climate change 2013: the physical science basis. Working group I contribution to the fifth assessment report of the IPCC. http://www.climatechange2013.org/images/report/wg1ar5_all_final.pdf. Assessed 15 May 2014

IPCC (2014) IPCC fifth assessment report, first order draft synthesis report. http://www.docstoc.com/docs/168836735/Climate-Change-2014-Synthesis-Draft-Restricted-ipcc-draft-14-0421pdf. Assessed 15 May 2014

IUPAC (1981) Solubility Data Series. In: Young CL (ed) Hydrogen and deuterium, vol 5/6. Pergamon Press, Oxford

Janssen PH (2010) Influence of hydrogen on rumen methane formation and fermentation balances through microbial growth kinetics and fermentation thermodynamics. Anim Feed Sci Technol 160:1–22

Janssen PH, Kirs M (2008) Structure of the archaeal community of the rumen. Appl Environ Microbiol 74:3619–3625

Jenkins TC, Wallace RJ, Moate PJ, Mosley EE (2008) Recent advances in biohydrogenation of unsaturated fatty acids within the rumen microbial ecosystem. J Anim Sci 86:397–412

Joblin KN (1999) Ruminal acetogens and their potential to lower ruminant methane emissions. Aust J Agric Res 50:1307–1313

Johnson KA, Johnson DE (1995) Methane emissions from cattle. J Anim Sci 73:2483–2492

Johnson D, Johnson K (2002) Recent developments in understanding enteric methane production by ruminants: implications for mitigation. In: International Non-CO_2 GHG mitigation workshop. Washington, DC

Johnson KA, Kincaid RL, Westberg HH, Gaskins CT, Lamb BK, Cronrath JD (2002) The effect of oilseeds in diets of lactating cows on milk production and methane emissions. J Dairy Sci 85:1509–1515

Key N, Tallard G (2012) Mitigating methane emissions from livestock: a global analysis of sectoral policies. Clim Change 112(2):387–414

Klieve AV, Joblin KN (2007) Comparison in hydrogen utilization of ruminal and marsupial reductive acetogens. In: Third international greenhouse gases and animal agriculture conference, Christchurch, New Zealand, pp 34–35

Knowles R (1982) Denitrification. Microbiol Rev 46:43–70

Kohn RA (2015) Thermodynamic and kinetic control of methane emissions from ruminants. In: Malik PK, Bhatta R, Takahshi J, Kohn RA, Prasad CS (eds) Livestock production and climate change. CABI, Wallingford, pp 245–262

Kristjansson JK, Schönheit P, Thauer RK (1982) Different Ks values for hydrogen of methanogenic bacteria and sulfate reducing bacteria: an explanation for the apparent inhibition of methanogenesis by sulfate. Arch Microbiol 131:278–282

Leng RA (2008) The potential of feeding nitrate to reduce enteric methane production in ruminants. Report to Department of Climate Change, Commonwealth Government, Canberra. http://www.penambulbooks.com/Downloads/Leng-Final%20Modified%20%2017-9-2008.pdf. Assessed 15 May 2014

Loneragan GD, Gould J, Wagner FG, Thoren M (2005) The magnitude and patterns of ruminal hydrogen sulfide production, blood thiamine concentration, and mean pulmonary arterial pressure in feedlot steers consuming water of different sulfate concentrations. Bovine Pract 39:16–22

Machmuller A, Ossowski DA, Wanner M, Kreuzer M (1998) Potential of various fatty feeds to reduce methane release from rumen fermentation in vitro (RUSITEC). Anim Feed Sci Technol 71:117–130

Malik PK, Singhal KK, Deshpande SB, Siddique RA (2012a) Mitigation strategies for enteric methane emission with special emphasis on biological approaches: a review. Indian J Anim Sci 82:794–804

Malik PK, Thulasi A, Soren NM, Prasad KS (2012b) FTHFS functional gene based diversity analysis of rumen acetogens in cattle and sheep fed on conventional diet. In: Proceeding of the 8th biennial conference of animal nutrition association held at Bikaner, Rajasthan, India during 28–30 Nov 2012

Malik PK, Bhatta R, Soren NM, Sejian V, Mech A, Prasad KS, Prasad CS (2015) Feed based approaches in enteric methane amelioration. In: Malik PK, Bhatta R, Takahshi J, Kohn RA, Prasad CS (eds) Livestock production and climate change. CABI, Wallingford, pp 336–359

Mamuad LL, Kim SH, Lee SS, Cho KK, Jeon CO, Lee SS (2012) Characterization, metabolites and gas formation of fumarate reducing bacteria isolated from Korean native goat (*Capra hircuscoreanae*). J Microbiol 50:925–931

Mamuad L, Kim SH, Jeong CD, Choi YJ, Jeon CO, Lee SS (2014) Effect of fumarate reducing bacteria on in vitro rumen fermentation, methane mitigation and microbial diversity. J Microbiol 52:120–128

Martin C, Morgavi DP, Doreau M (2010) Methane mitigation in ruminants: from microbe to the farm scale. Animals 4:351–365

Mathison GW, Okine EK, McAllister TA, Dong Y, Galbraith J, Dmytruk OIN (1998) Reducing methane emissions from ruminant animals. J Appl Anim Res 14:1–28

McAllister TA, Newbold CJ (2008) Redirecting rumen fermentation to reduce methanogenesis. Aust J Exp Agric 48:7–13

McSweeney CS, Kang S, Gagen E, Davis C, Morrison M, Denman S (2009) Recent developments in nucleic acid based techniques for use in rumen manipulation. Rev Bras Zootec 38:341–351

Mitsumori M, Shinkai T, Takenaka A, Enishi O, Higuchi K, Kobayashi Y, Nonaka I, Asanuma N, Denman SE, McSweeney CS (2012) Responses in digestion, rumen fermentation and microbial populations to inhibition of methane formation by a halogenated methane analogue. Br J Nutr 108:482–491

Molano G, Knight TW, Clark H (2008) Fumaric acid supplements have no effect on methane emissions per unit of feed intake in wether lambs. Aust J Exp Agric 48:165–168

Morgavi DP, Eugene M, Martin C, Doreau M (2011) Reducing methane emissions in ruminants: is it an achievable goal? In: Ranilla MJ, Carro MD, Ben Salem H, Morand-Fehr P (eds) Challenging strategies to promote the sheep and goat sector in the current global context. CIHEAM/CSIC/Universidad de León / FAO Options Méditerranéennes: Série A. Séminaires Méditerranéens, Zaragoza, pp 65–73

Morvan B, Dore J, Rieu-Lesme F, Foucat L, Fonty G, Gouet P (1994) Establishment of hydrogen-utilizing bacteria in the rumen of the newborn lamb. FEMS Microbiol Lett 117:249–256

Morvan B, Bonnemoy F, Fonty G, Gouet P (1996) Quantitative determination of H2 utilizing acetogenic and sulphate reducing bacteria and methanogenic archaea from the digestive tract of different mammals. Curr Microbiol 32:129–133

Moss AR, Jouany JP, Newbold J (2000) Methane production by ruminants: its contribution to global warming. Ann Zootech 49:231–253

Murray RM, Bryant AM, Leng RA (1976) Rates of production of methane in the rumen and large intestine of sheep. Br J Nutr 36:1–14

Nolan JV, Hegarty RS, Hegarty J, Godwin IR, Woodgate R (2010) Effects of dietary nitrate on fermentation, methane production and digesta kinetics in sheep. Anim Prod Sci 50:801–806

Nollet L, Demeyer D, Verstraete W (1997a) Effect of 2-bromoethanesulfonic acid and *Peptostreptococcus productus* ATCC 35244 addition on stimulation of reductive acetogenesis in the ruminal ecosystem by selective inhibition of methanogenesis. Appl Environ Microbiol 63:194–200

Nollet L, Vande VI, Verstraete W (1997b) Effect of the addition of Peptostreptococcus productus ATCC35244 on the gastro-intestinal microbiota and its activity, as simulated in an *in vitro* simulator of the human gastro-intestinal tract. Appl Microbiol Biotechnol 48:99–104

NRC (2005) Mineral tolerance of animals, 2nd edn. National Academy Press, Washington, DC

Ohashi Y, Ushida K, Miyasaki K, Kojima Y (1996) Effect of initial sulfate level on electron partition between methanogenesis and sulfate reduction in the rumen. Ann Zootech 45:320

Olson OE, Whitehead EI (1940) Nitrate content of some South Dakota plants. Proc S D Acad Sci 20:95–101

Olsson K, Evans P, Joblin KN (2006) Ruminal acetogens in dairy cows: dietary effects and quantification of E. limosum. In: Reproduction nutrition development. EDP Sciences, Aberdeen, S109

Oren A (2012) There must be an acetogen somewhere. Front Microbiol 3:1–2. doi:10.3389/fmicb.2012.00022

PBL Netherlands Environmental Assessment Agency (2011) Long term trend in global CO_2 emissions: 2011 report. Available at http://www.pbl.nl/en/publications/2011/long-term-trend-in-global-co2-emissions-2011-report

Pelchen A, Peters KJ (1998) Methane emissions from sheep. Small Rumin Res 27:13750

Phuc HT, Quang DH, Preston TR, Leng RA (2009) Nitrate as a fermentable nitrogen supplement for goats fed forage based diets low in true protein. Livst Res Rural Dev 21. http://www.lrrd.org/lrrd21/1/trin21010.htm. Assessed 15 May 2014

Phuong Le TB, Preston TR, Leng RA (2011) Mitigating methane production from ruminants; effect of supplementary sulphate and nitrate on methane production in an in vitro incubation using sugar cane stalk and cassava leaf meal as substrate. Livst Res Rural Dev 23. http://www.lrrd.org/lrrd23/2/phuo23022.htm. Assessed 15 May 2014

Pinares-Patiño CS, Waghorn GC, Hegarty RS, Hoskin SO (2009) Effects of intensification of pastoral farming on greenhouse gas emissions in New Zealand. N Z Vet J 57:252–261

Ragsdale SW, Pierce E (2008) Acetogenesis and the Wood-Ljungdahl pathway of CO(2) fixation. Biochim Biophys Acta 1784:1873–1898

Rieu-Lesme F, Fonty G, Dore J (1995) Isolation and characterization of a new hydrogen-utilizing bacterium from the rumen. FEMS Microbiol Lett 125:77–82

Rieu-Lesme F, Morvan B, Collins MD, Fonty G, Willems A (1996) A New H2/CO2 using acetogenic bacterium from the rumen: description of Ruminococcus schinkii sp. nov. FEMS Microbiol Lett 140:281–286

Rieu-Lesme F, Dauga C, Fonty G, Dore J (1998) Isolation from the rumen of a new acetogenic bacterium phylogenetically closely related to *Clostridium difficile*. Anaerobe 4:89–94

Robinson JA, Strayer RF, Tiedje JM (1981) Method for measuring dissolved hydrogen in anaerobic ecosystems: application to the rumen. Appl Environ Microbiol 41:545–548

Silivong P, Preston TR, Leng RA (2011) Effect of sulphur and calcium nitrate on methane production by goats fed a basal diet of molasses supplemented with Mimosa (*Mimosa pigra*) foliage. Livest Res Rural Dev 23:Article #047

Simon J, Eichler R, Pisa R, Biel S, Gross R (2002) Modification of heme c binding motifs in the small subunit (NrfH) of the Wolinella succinogenes cytochrome c nitrite reductase complex. FEBS Lett 522:83–87

Smolenski WJ, Robinson JA (1988) In situ rumen hydrogen concentrations in steers fed eight times daily, measured using a mercury reduction detector. FEMS Microbiol Lett 53(2):95–100

Sophal C, Khang DN, Preston TR, Leng RA (2013) Nitrate replacing urea as a fermentable N source decreases enteric methane production and increases the efficiency of feed utilization in Yellow cattle. Livest Res Rural Dev 25. http://www.lrrd.org/lrrd25/7/soph25113.htm. Assessed 15 May 2014

Stanier G, Davies A (1981) Effects of the antibiotic monensin and an inhibitor of methanogenesis on in vitro continuous rumen fermentations. Br J Nutr 45:567–578

Takahashi J (1986) Control of ruminal nitrate reduction by sulfur compounds. Asian-Australas J Anim Sci 2:530–532

Takahashi J (2001) Nutritional manipulation of methanogenesis in ruminants. Asian-Australas J Anim Sci 14:131–135

Takahashi J (2011) Some prophylactic options to mitigate methane emission from animal agriculture in Japan. Asian-Australas J Anim Sci 24:285–294

Takahashi J, Young BA (1991) Prophylactic effect of L cysteine on nitrate- induced alterations in respiratory exchange and metabolic rate in sheep. Anim Feed Sci Technol 35:105–113

Takenaka A, Mitsumori M, Pinares-Patino CS, Ronimus R, Joblin KN (2008) Methane and hydrogen concentrations in the breath of sheep. Aust J Exp Agric 48:lxxxvii–lxxxvii

Truong DH, Eghbal MA, Hindmarsh W, Roth SH, O'Brien PJ (2006) Molecular mechanisms of hydrogen sulfide toxicity. Drug Metab Rev 38:733–744

Ungerfeld EM (2013) A theoretical comparison between two ruminal electron sinks. Front Microbiol 4:319

Ungerfeld EM, Kohn RA (2006) The role of thermodynamics in the control of ruminal fermentation. In: Sejrsen K, Hvelplund T, Nielsen MO (eds) Ruminant physiology. Wageningen Academic Publishers, Wageningen, pp 55–85

Ungerfeld EM, Rust SR, Burnett R (2007) Increases in microbial nitrogen production and efficiency *in vitro* with three inhibitors of ruminal methanogenesis. Can J Microbiol 53:496–503

van Zijderveld SM, Gerrits WJ, Apajalahti JA, Newbold JR, Dijkstra J, Leng RA, Perdok HB (2010) Nitrate and sulfate: effective alternative hydrogen sinks for mitigation of ruminal methane production in sheep. J Dairy Sci 93:5856–5866

van Zijderveld SM, Fonken B, Dijkstra J, Gerrits WJJ, Perdok HB, Fokkink W, Newbold JR (2011) Effects of a combination of feed additives on methane production, diet digestibility, and animal performance in lactating dairy cows. J Dairy Sci 94:1445–1454

Wolin MJ, Miller TL, Stewart CS (1997) Microbe-microbe interactions. In: Hobson PJ, Stewart CS (eds) The rumen microbial ecosystem, 2nd edn. Blackie Acad Profess, London, pp 467–491

20 GHG Emission from Livestock Manure and Its Mitigation Strategies

Mohamed Samer

Abstract

This study focuses on greenhouse gas (GHG) emission from livestock manure. In addition to the global warming potential of the GHGs (e.g., CH_4, N_2O, NO, CO_2), ammonia (NH_3) emissions contribute to global warming when NH_3 is converted to nitrous oxide (N_2O). Therefore, this chapter addresses in detail the GHG and NH_3 emissions from livestock manure and their mitigation strategies. This chapter illustrates several mitigation strategies for reducing emissions from manure management continuum, for example, manure storage abatement techniques, use of additives, manipulation of manure pH, implementation of inhibitors, anaerobic treatment, thermochemical conversion of manure, and implementation mitigation policies (e.g., emission tax, emission cap, livestock extensification). Additionally, several innovative mitigation strategies were discussed, for instance, manure treatment methods to produce value-added products and bioenergy and abate emissions, the biorefinery approach, and life cycle analysis to improve the productivity and use of resources and abate emissions.

Keywords

Mitigation strategies • Emission abatement techniques • Greenhouse gases • Methane • Nitrous oxide • Ammonia • Manure management • Slurry treatment

20.1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto protocol (the protocol set binding obligations on industrialized countries to reduce their emissions of GHG) which is aimed at achieving the stabilization of GHG concentrations in the atmosphere

---

M. Samer, Dr.sc.agr (✉)
Associate Professor, Department of Agricultural Engineering, Faculty of Agriculture, Cairo University, El-Gammaa Street, 12613 Giza, Egypt
e-mail: msamer@agr.cu.edu.eg; samer@cu.edu.eg

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*, DOI 10.1007/978-81-322-2265-1_20, © Springer India 2015

at a level that would prevent dangerous anthropogenic interference with the climate system. Under this protocol, several countries committed themselves to a reduction of the GHGs (e.g., CH_4, N_2O, NO, CO_2). The protocol was adopted on December 11, 1997, in Kyoto, Japan, and entered into force on February 16, 2005. As of September 2011, 191 states had signed and ratified the protocol. Following the adoption of the United Nations Economic Commission for Europe (UNECE) Gothenburg protocol, the members struggled to achieve significant reduction in national ammonia (NH_3) emissions. The Gothenburg protocol is a multi-pollutant protocol designed to reduce acidification, eutrophication, and ground-level ozone by setting emission ceilings for several pollutants including NH_3. Sectors that are sources of emissions include energy generation; industrial processes and product use; agriculture, forestry, and other land uses; and waste. Agriculture (with its two main sectors: plant and animal production) is one of the main sources of GHG emissions and the main source of NH_3 emissions. The reduction of emissions is subject to international conventions, which include reporting of emission levels in accordance with guidelines. Thus, reducing GHG and NH_3 emissions from the agricultural sector is essential. Consequently, it is crucial to develop mitigation strategies to reduce GHG and NH_3, which should be preceded by inventorying these emissions. There are two emission inventory guides: the air pollutant emission inventory guidebook of the European Environment Agency (EEA) and the Cooperative Programme for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) and the guidelines of the Intergovernmental Panel on Climate Change (IPCC).

Livestock and manure are the major sources of GHG and ammonia emissions from the animal production sector. Livestock manure management is a source of nitrous oxide (N_2O) emissions. N_2O is produced as part of the nitrogen cycle through nitrification and denitrification of organic nitrogen substances contained in livestock manure and urine. Livestock manure is also a source of methane (CH_4) emissions, which are produced during the anaerobic decomposition of manure. Enteric fermentation and manure management account for 35–40 % of the total anthropogenic CH_4 emissions and 80 % of CH_4 release from agriculture (FAO 2006). Livestock activities account for 65 % of the global anthropogenic N_2O emissions, and this represents 75–80 % of the total emission from agriculture (FAO 2006). CH_4 and N_2O are GHG with global warming potentials (GWP) of 23 and 296 times that of CO_2, respectively (IPCC 2007a). The contribution that manure management makes to total national agricultural emissions of N_2O and CH_4 may vary, but can exceed 50 % in countries reporting to the UNFCCC in 2009 (Chadwick et al. 2011). About 94 % of global anthropogenic emissions of NH_3 to the atmosphere originate from the agricultural sector of which close to 64 % is associated with livestock management (FAO 2006). However, Reinhardt-Hanisch (2008) stated that around 75 % of NH_3 emissions come from livestock production. Excessive levels of NH_3 emissions contribute to the eutrophication and acidification of water, soils, and ecosystems (Schuurkes and Mosello 1988). In addition to the global warming potential of the GHGs, NH_3 emissions contribute to global warming when NH_3 is converted to N_2O (Berg 1999; Sommer et al. 2000). It is important to consider that indirect N_2O losses (i.e., derived from NO_3^- leaching and NH_3 volatilization) can at times be larger than direct N_2O losses (Chadwick et al. 2011). As a result, reducing NO_3^- leaching and NH_3 volatilization should also contribute to reductions in total N_2O emissions.

Manure management affects the potential for N_2O and NH_3 emissions and the balance between both gases. The interaction between N_2O and NH_3 may be positive (e.g., both emissions are reduced by an airtight cover during storage and increased by composting) or negative (e.g., direct N_2O emissions from soil will potentially increase if losses of NH_3 are prevented during storage or field application). Emissions of N_2O and NH_3 negatively affect N use efficiency and the GHG balance of livestock production. A precise determination of overall N_2O and NH_3 emissions requires consideration of the complex interactions between C and N transformations at each stage of the manure management chain. This needs to be done in a time scale that is relevant for management practices such as retention time in housing and storage, treatment to optimize nutrient management, and timing of field application (Petersen and Sommer 2011). The heterogeneity in the distribution of O_2 demand and supply affects the determination of N_2O emissions from field-applied manure.

Manure is animal excreta (feces and urine) collected from animal buildings, whereas slurry is a mixture of scraped animal excreta and flushing water and is collected from animal buildings. Hence, slurry is a mixture of manure and water. On the other hand, litter is animal excreta and bedding material collected from animal buildings (Samer 2011a). Livestock excreta stored in manure stores, in housing, in feedlots, or in cattle hardstandings are the most important sources of GHG and NH_3 in the atmosphere. The storage of dry manure produces large emissions of N_2O, while the storage of liquid manure produces large emissions of CH_4 (Janzen et al. 2008). A detailed knowledge of the processes of GHG and NH_3 mass transfer from the manure and its transport to the atmosphere will contribute to the development of emission abatement techniques and housing designs that will contribute to the reduction of gaseous emissions into the atmosphere (Sommer et al. 2006). Inventories have shown that stored animal manure, animal housing, and exercise areas account for about 69–80 % of the total emission of NH_3 in Europe (ECETOC 1994; Hutchings et al. 2001).

Several algorithms for calculating CH_4 and N_2O emissions from manure management have been developed. The biogenic emissions of CH_4 and N_2O from animal manure are stimulated by the degradation of volatile solids (VS) which serve as an energy source and a sink for atmospheric oxygen. Algorithms which link carbon and nitrogen turnover in a dynamic prediction of CH_4 and N_2O emissions during handling and use of liquid manure (slurry) have been developed. These algorithms include (1) a sub-model for CH_4 emissions during storage that relates CH_4 emissions to VS, temperature, and storage time and estimates the reduction in VS and (2) a second sub-model that estimates N_2O emissions from field-applied slurry as a function of VS, slurry N, and soil water potential, but emissions are estimated using default emission factors. Additionally, simple algorithms to account for ambient climatic conditions may significantly improve the prediction of CH_4 and N_2O emissions from animal manure (Sommer et al. 2004, 2006). Several algorithms have been developed for determining NH_3 emission from buildings housing cattle and pigs and from manure stores.

Cattle production (beef and dairy) produces the greatest portion of GHG emissions. The small ruminant share is approximately 12.3 %. The total GHG emission from livestock's enteric and manure CH_4 and manure N_2O is 9.45 kg CO_2 equivalent per kg body weight. The respective values for cattle, pigs, and poultry are 5.45, 3.97, and 3.25, respectively (Zervas and Tsiplakou 2012). Taking into account the positive and negative impacts of small ruminant production systems to the environmental aspects in general, it is recommended that a number of potentially effective measures should be taken and the appropriate mitigation technologies should be applied in order to reduce GHG emissions to the atmosphere. This needs to be achieved with no adverse effects on livestock intensification and productivity of small ruminant production systems. Growth in livestock populations is projected to occur mainly in intensive production systems, where the largest potentials for GHG mitigation may be found. Ongoing intensification and specialization of livestock production leads to increasing volumes of manure that needs to be managed. Emissions of CH_4 and N_2O result from a multitude of microbial activities in the manure microenvironment. These emissions depend not only on manure composition and local management practices with respect to treatment, storage, and field application but also on ambient climatic conditions (Petersen et al. 2013). The diversity of manure properties and environmental conditions calls for the development of a modeling method for improving the estimation of GHG emissions and for predicting the effects of management changes on GHG mitigation.

A livestock farm is a complex system with different interacting components. Generally, whole-farm approaches distinguish at least an animal component and a soil–crop component. Whole-farm models are able to give an accurate representation of the internal cycling of materials and its constituents as well as the exchanges between the farming system and its environment (Schils et al. 2007). Further research is needed to understand the factors limiting livestock producers adopting mitigating strategies to reduce emissions since a whole-farm system approach can provide a modeling framework to evaluate the feasibility and cost-effectiveness of abatement measures (Carew 2010). A whole-farm approach is a powerful tool for the development of cost-effective GHG mitigation options as it reveals relevant interactions between the various farm components.

The main objective of a number of current research projects is the evaluation of the consequences of predicted climate change on different aspects of the environment and human life. These studies base their estimations on the current predictions of GHG emissions and temperature rise reported in the literature that will determine the extent of the consequences (Kuczynski et al. 2011). The assessment of climate change requires a global perspective and a very long time horizon that covers periods of at least a century. As the exact knowledge of future anthropogenic GHG emissions is impossible, emission scenarios become a major tool for the analysis of potential long-range developments. According to IPCC (2007b), scenarios are a plausible and often simplified description of how the future may develop, based on a coherent set of assumptions about driving forces and key relationships. Scenarios are images of the future, or alternative futures. They are neither predictions nor forecasts. Rather, each scenario is one alternative image of how the future might unfold. Emission scenarios are a central component of any assessment of climate change. Scenarios facilitate the assessment of future developments in complex systems that are either inherently unpredictable or have high scientific uncertainties.

The large difference between predictions of the different scenarios indicates the complexity involved in making such predictions and the large amount of uncertainty inherent in climate change models (Kuczynski et al. 2011). A general global warming trend was presented in the IPCC report (2007c): (a) for the next two decades, a warming of about 0.2 °C per decade is projected for a range of emission scenarios; (b) if GHG emissions are kept constant at current rates, a further global warming trend would occur over the next two decades at a rate of about 0.1 °C per decade, due mainly to the slow dynamic response of the oceans; (c) continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the twenty-first century that would very likely be larger than those observed during the twentieth century (IPCC 2007c). Regarding the geographical distribution of the climate change, projected warming in the twenty-first century shows scenario-independent geographical patterns similar to those observed over the past several decades (Kuczynski et al. 2011). Furthermore, the Special Report on Emissions Scenarios (SRES 2000) projected global average surface warming and developed relevant emission scenarios.

Therefore, it is crucial to consider climate change, global warming, emission scenarios, emission inventories, livestock population and geographical distribution, farm components and farming systems, and manure management and handling system when developing mitigation strategies for reducing noxious gas emissions. The objective of this chapter was to discuss the different mitigation strategies for reducing GHG and NH_3 emissions from livestock manure, mitigation policies, and industrial (animal production as an industry) and geographical focus mitigation potentials.

20.2 Theoretical Considerations

20.2.1 Biochemical Analysis of Manure

The biochemical analysis of dairy manure provided details of the typical pollution parameters (Table 20.1), the chemical composition of fresh manure (Table 20.2), and the organic compounds (Table 20.3).

Table 20.1 Pollution parameters of dairy manure

Parameter	Production (kg/1,000 kg body weight)	Concentration (mg/L)
Total solids	12.0	130,000
Volatile solids	10.0	110,500
BOD	1.6	20,000
COD	11.0	136,000
Total nitrogen	0.4	5,000

Table 20.2 Chemical composition of fresh manure (Abdelsalam et al. 2015)

Parameter	Fresh manure
TS (%)	17.0
VS (%)	13.1
Ash (%)	3.9
Organic carbon (% from VS)	44.5
Total nitrogen	1.7
C/N ratio	1:26
pH	6.87

Table 20.3 Organic compounds in dairy manure

Parameter	Value (% TS)
Crude protein	13.2
True protein	12.6
Nonprotein	0.6
Crude fiber	11.5
Neutral detergent fiber	7.6
Acid detergent fiber	3.9
Carbohydrate	74.0
Cellulose	23.4
Hemicellulose	19.3
Lignin	14.9
Cell walls	6.2
Sugar	10.2
Fat	1.7
Gross energy (MJ/kg TS)	15.9

20.2.2 Nitrous Oxide and Ammonia

Nitrous oxide is an important GHG primarily produced by microbial nitrification and denitrification processes. Emissions of N_2O also occur indirectly when nitrogen (N) is lost through NH_3 volatilization or nitrate (NO_3^-) leaching and subsequently converted to N_2O in another location. Direct and indirect N_2O emissions represent an unproductive N loss from agricultural systems, and therefore, reducing emissions has benefits for GHG mitigation and improving N use efficiency (VanderZaag et al. 2011). The main sources of N_2O are nitrogen fertilizers, land-applied animal manure, and urine deposited by grazing animals.

20.2.2.1 Nitrification and Denitrification

Nitrification is the bacterial oxidation of ammonium salts to nitrites (NO_2^-) and further oxidation of nitrites to nitrates (NO_3^-) leads to N_2O emissions. On the other hand, *denitrification* is the loss or removal of nitrogen or nitrogen compounds. Precisely, *denitrification* is the bacterial reduction of nitrates or nitrites which results in the emission of NO, N_2O, and N_2 into the air (Fig. 20.1). It is crucial to consider that the optimal temperature range for nitrification is 30–35 °C; in contrast, however, the optimal temperature for denitrification is 10 °C or lower. Therefore, cooling manure to 20 °C would reduce N_2O emissions.

20.2.2.2 Nitrogen Cycle

The bacterial decomposition of manure, feces, and urine generates NH_3 and N_2 which follows a cycle known as the nitrogen cycle. Figure 20.2 shows the nitrogen cycle through which amino acids, peptone, peptide, NH_3, NO_2^-, NO_3^-, N_2, and bacterial protein are generated by bacterial decomposition of manure.

Intensification of livestock production in many parts of the world has led to increasing atmospheric N in connection with storage and field application of manure (Petersen and Sommer 2011). Both types of emissions are influenced by manure organic matter content via mechanisms such as composting, crust formation, mineralization–immobilization turnover, and water retention.

20.2.2.3 Total Ammoniacal Nitrogen

Ammoniacal nitrogen (NH_3-N) is a measure for the amount of NH_3 in manure, liquid organic wastes, and sewage. The total ammoniacal nitrogen (TAN) is the amount of nitrogen that is ready to be transformed to ammonium (NH_4^+). Ammonium is an ionized form of NH_3, where

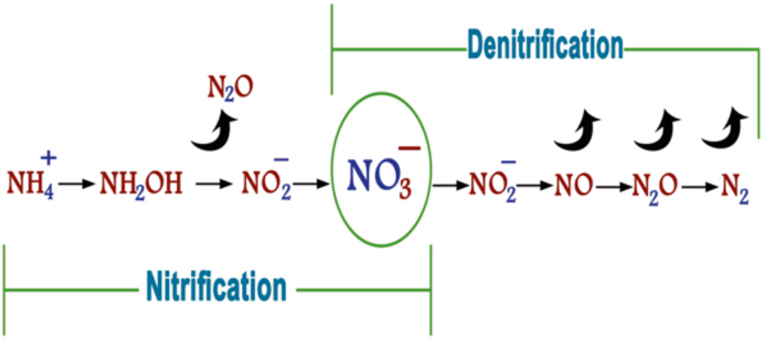


Fig. 20.1 Chemical processes of nitrification and denitrification

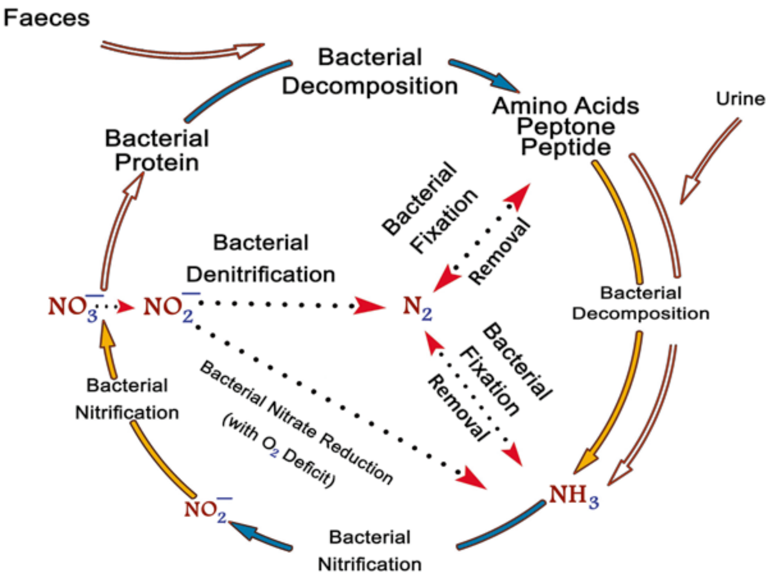


Fig. 20.2 Nitrogen cycle (*Translated and amended* after Hartung 1995 and Jensen 1974)

$$NH_3 + H_2O \leftrightarrow NH_4^+ + OH^-$$

Therefore, the NH_3 increases with increasing alkalinity of dissolved ammonium in water, whereas ammonium ions are formed with increasing acidity of dissolved NH_3 in water. The total ammoniacal (ammonium) nitrogen is measured in g N kg^{-1} fresh mass or in mg NH_3-N L^{-1}. For instance, the typical liquid manure scraped from a dairy farm, after separation from the solids, is ca. 1,600 mg NH_3-N L^{-1}.

20.2.2.4 Total Kjeldahl Nitrogen

The Kjeldahl method or Kjeldahl digestion is a method used for the quantitative determination of nitrogen in chemical substances. The total Kjeldahl nitrogen (TKN) is the sum of organic nitrogen, NH_3, and NH_4^+ in the chemical analysis of manure, wastewater (e.g., sewage), water, or soil.

20.2.3 Methane

The rumen is the most important source of CH_4 production, especially in cattle. Less, but still substantial, amounts of CH_4 are produced from cattle manure. In pig and poultry production, most CH_4 originates from manure. Anaerobic decomposition of manure produces mainly CH_4 and CO_2 with traces of hydrogen sulfide (H_2S), H_2, N_2, and NH_3 as shown in Fig. 20.3.

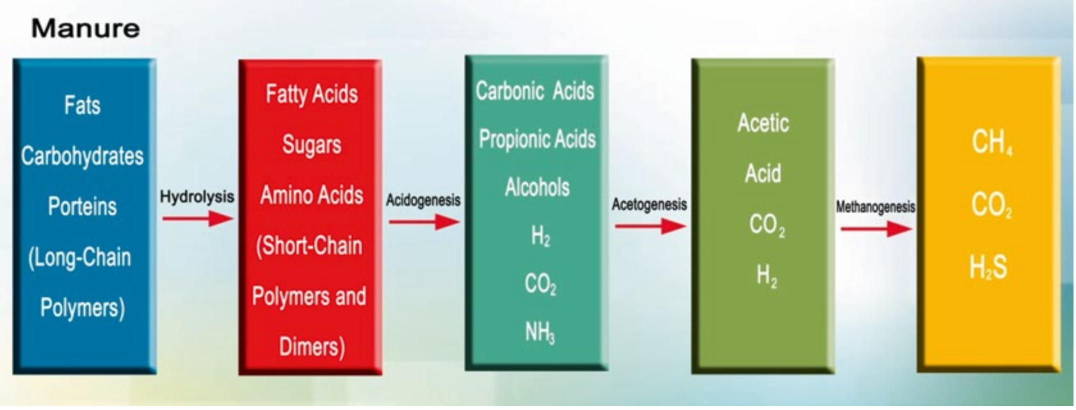


Fig. 20.3 Anaerobic decomposition of manure

20.2.4 Diffusion and Convection Mass Transfer

The GHGs (CH_4, N_2O, NO, and CO_2), NH_3, H_2S, and volatile organic compounds (VOCs) include volatile fatty acids (VFAs) that are transferred within manure through diffusion and from manure to ambient air by convection mass transfer (Fig. 20.4). Generally, this process follows the concept of mass transfer which is the transfer of mass from high concentration to low concentration. This involves molecular and convective transport of atoms and molecules within physical systems, following Fick's law of diffusion and Newton's viscosity law which deals with molecular momentum transport.

The release of gases from manure can be minimized by controlling the following factors: (1) minimizing release surface area, (2) separating urine and feces, (3) limiting storage period, (4) lowering the temperature of the manure, (5) lowering nitrogen concentration in manure, and (6) decreasing air velocity and volumetric airflow rate above surface. In addition to the previous factors, lowering the pH value of the manure is crucial to reduce NH_3 emissions.

20.2.5 Manure Management Continuum

The stages of the manure management continuum are animal housing, exercise yards or corrals, manure storage and treatment, and land spreading of manure (Fig. 20.5). Chadwick et al. (2011) stated that the sources of pollutants are as follows: (1) housing, (a) slurry handling system with no bedding and (b) solid manure handling system with straw, sawdust, or wood shavings as bedding materials; (2) manure storage, (a) slurry stored in lagoons and aboveground tanks and (b) solid manure stored in field heaps or heaps in yards; (3) treatment, (a) slurry treatment, e.g., aeration, separation, and anaerobic digestion, and (b) solid manure treatment, e.g., active composting and anaerobic digestion; and (4) spreading, (a) slurry spreading as either surface spreading (broadcasting, trailing hose/shoe) or injection (shallow open/closed slot, deep) and (b) solid manure spreading with or without incorporation (plow, harrow, and tines).

20.3 Mitigation Strategies

Manure management involves various technologies for collection, handling, storage, treatment, and land application (Powell et al. 2010) which are chosen based on the size of the herd, soil type, climate, and other factors such as available labor (Tomasula and Nutter 2011). Liquid manure storage facilities are sources of gaseous emissions of NH_3 and GHGs especially CH_4 and N_2O. CH_4 is the most predominant GHG emission from liquid manure storage facilities (Samer et al. 2014a; Berg et al. 2006a). Therefore, several studies have

Fig. 20.4 Release of CH_4, N_2O, NO, CO_2, NH_3, H_2S, VOCs, and VFAs from manure storage

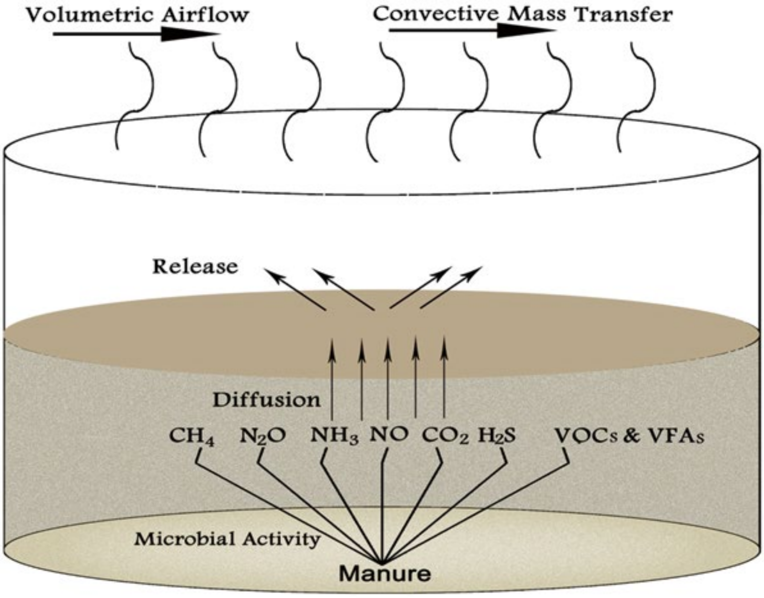
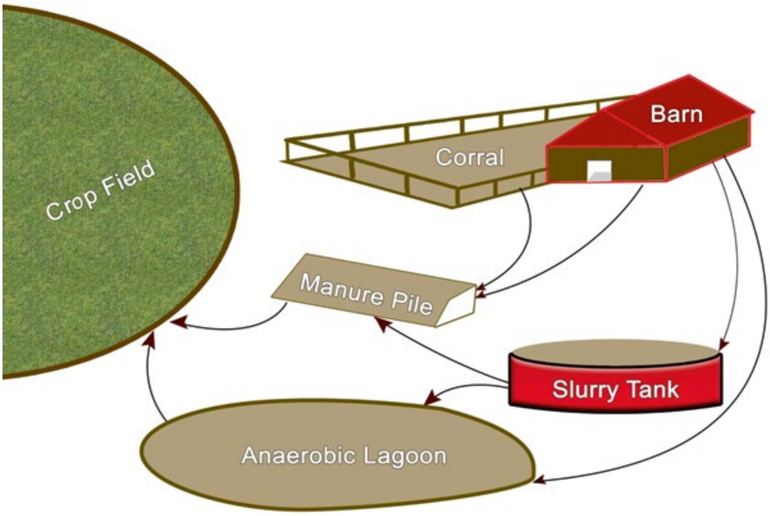


Fig. 20.5 Manure management continuum



investigated different mitigation strategies for reducing GHG and NH_3 emissions from the different stages of the manure handling continuum. Emissions occur at all stages of manure management: from buildings housing livestock, during manure storage, following manure application to land, and from urine deposited by livestock on pastures during grazing. Ammoniacal nitrogen (total ammoniacal nitrogen, TAN) in livestock excreta is the main source of NH_3. At each stage of manure management, TAN may be lost, mainly as NH_3, and the remainder passed to the next stage. Hence, measures to reduce NH_3 emissions at the various stages of manure management are interdependent, and the accumulative reduction achieved by combinations of measures is not simply summated. This TAN flow concept enables rapid and easy estimation of the consequences of NH_3 abatement at one stage of manure management (upstream) on NH_3 emissions at later stages (downstream) and gives unbiased assessment of the most cost-effective measures. It is important to remember that *NH3 can be converted to N2O at any stage of manure management*.

The EMEP/EEA air pollutant emission inventory guidebook provides GHG emission abatement measures for animal production and manure management in the form of best available technique (BAT) for each case, type of manure, land use, limits of applicability, emission reduction (%), and availability for different farms (EMEP/EEA 2009). On the other hand, the Executive Body for the Convention on Long-Range Transboundary Air Pollution (2007a, b) provided a guidance document on control techniques for preventing and abating emissions of NH_3. Moreover, the European Commission (2003) provided an integrated pollution prevention and control (IPPC) reporting on the BAT for intensive rearing of poultry and pigs.

The changes in manure management can induce significant changes in CH_4 and N_2O emissions and carbon sequestration, and the effect of introducing environmental technologies may vary significantly with livestock farming practice and interact with climatic conditions. Shortening the in-house manure storage time reduces GHG emissions by 40 %. The largest GHG reductions can be obtained with a combination of slurry separation and incineration, the latter process contributing to a positive GHG balance of the system by substituting fossil fuels. The amount and composition of volatile solids (VS) and nitrogen pools are the main drivers in performing the calculations. Nevertheless, the GHG emission estimates will be unrealistic, if the assumed manure management or climatic conditions do not properly represent a given country or region. The mitigation potential of specific manure management strategies and technologies varies depending on current management and climatic conditions (Sommer et al. 2009). Several mitigation measures were reported (Petersen and Sommer 2011), such as reduced N intake, slurry acidification, anaerobic digestion, slurry separation, slurry store with crust, slurry store with lid, manure heap with airtight cover, acidification with slurry separation and using a cover, and anaerobic digestion with a cover. Previous studies (Samer et al. 2014a; Wheeler et al. 2011a, b; Reinhardt-Hanisch 2008; Berg et al. 2006a) have evaluated different treatments and additives for reducing gaseous emissions from manure and slurry in laboratory using glass jars or plexiglass tanks and a multi-gas monitor.

20.3.1 Diet Manipulation

The most promising options for reducing GHG emissions at the livestock management level involve either the improvement of animal production through dietary changes and genetic improvement or the reduction of the replacement rate. The control of the protein intake of animals is an effective means to reduce gaseous emissions of nitrogen (Novak and Fiorelli 2010). Nitrogen (N) excretion rates, which affect N_2O emissions from manure, are based on dry matter intake (DMI) through diet (Vergé et al. 2012). Therefore, diet manipulation to improve animal N utilization efficiency is one of the most effective measures to reduce livestock NH_3 emissions compared to housing and manure storage techniques (Carew 2010). Similarly, it is an effective measure to reduce N_2O emissions. On the other hand, the reliance of beef production on roughages makes enteric CH_4 a major term in the GHG budget of beef cattle (Capper 2012; IPCC 2006). There is currently no effective mitigation for enteric CH_4 emissions (Cottle et al. 2011). However, more grain in the cattle diet reduces the intensity of enteric CH_4 emissions (Capper 2012). Lowering the pH of feed also reduces NH_3 emissions.

On the other hand, the primary source of NH_3 is nitrogen in the feed. The better nitrogen is utilized by an animal, the less nitrogen will be excreted by the animal. It is recommended that the exact amount of amino acids in the diet be provided to meet the nitrogen requirements of the animals. However, these requirements change with age and weight (CIGR 1994). Model calculations underlined the relationship between farm gate N surplus and GHG emissions and thus the possibility to use N surpluses as an indicator for GHG emissions (Schils et al. 2007). Generally, the reduction of N surplus reduces the emissions of NH_3 and N_2O.

20.3.2 Manure Storage Techniques

Considering the manure handling chain, mitigation options involve housing, storage, and application. An optimized lifetime efficiency of dairy farms reduces GHG emissions by up to 13 % compared to baseline model farms. The frequent removal of manure from animal housing into outside covered storage reduces farm GHG emissions by up to 7.1 %. Scraping of fouled surfaces is not an effective option since the reduction in GHG emissions from animal housing is more than outweighed by increased emissions from the storage and after field application (Weiske et al. 2006). For housing, an increase in the amounts of straw used for bedding reduces NH_3 emissions, while the limitation of CH_4 emissions from deep litter is achieved by avoiding anaerobic conditions. During the storage of solid manure, composting could be an efficient mitigation option, depending on its management. Addition of straw to solid manure was shown to reduce CH_4 and N_2O emissions from manure heaps. During the storage of liquid manure, emptying the slurry store before late spring is an efficient mitigation option to limit both CH_4 and NH_3 emissions. Addition of a wooden cover also reduces these emissions more efficiently than a natural surface crust alone, but may increase N_2O emissions (Novak and Fiorelli 2010). Technologies that have been proposed to reduce CH_4 emissions include cooling the emissions from manure stored in lagoons or tanks, using lined and covered manure storage, separating solids from slurry, and capturing emitted CH_4 (Smith et al. 2007). Synthetic cover, solid cover (lid, tent), and floating crust for liquid storage decrease NH_3 emissions but might increase N_2O emissions. Using airtight covers (FYM, fiber fraction) for heaps decreases both NH_3 and N_2O emissions.

Adjusting the housing system and the manure management has the potential to decrease the emissions. For instance, using organic laying hen husbandry in aviary systems instead of single-tiered systems has the potential to reduce emissions of NH_3, N_2O, and CH_4; further reductions might be realized by changes in litter management (Dekker et al. 2011). Regarding manure management, daily flushing of slurry from cattle houses would reduce the total annual CH_4 and N_2O emissions by 35 % CO_2 equivalent, and cooling of pig slurry in-house would reduce the total annual CH_4 and N_2O emissions by 21 % CO_2 equivalent (Sommer et al. 2004). CH_4 emissions can be significantly reduced by complete slurry removal between the fattening periods and subsequent cleaning of the slurry pits in pig housing. Additionally, the release of CH_4 from indoor slurry storage can be influenced by the availability of oxygen and volatile solids, pH value, substrate temperature, retention time, and presence of inhibiting compounds. These factors should be further investigated to develop suitable emission abatement techniques. *Special considerations should be given to the avoidance of increasing specific gas emissions while abating another one* (Haeussermann et al. 2006). For instance, abating agricultural emissions of NH_3 may cause releases of N_2O from this sector up to 15 % more than in the case of no NH_3 control (Brink et al. 2001). Increased knowledge of the factors that affect emissions from livestock housing may lead to a better understanding of daily (between different days) and diurnal (within a specific day) variations in emissions, an improvement of mitigation methods, and a refinement of emission models. Animal activity, animal weight, indoor air temperature, relative humidity, air velocity, and volumetric airflow rate have influence on CO_2, CH_4, and NH_3 emissions. Emission variations emphasized the need for measurements during different times within the day and during the growing period in order to obtain reliable data for assessing abatement techniques (Ngwabie et al. 2011).

In order to mitigate N_2O emissions from manure stores, the following are the best mitigation methods: keeping the stores anaerobic (e.g., cover and compact), adopting a slurry-based system compared to a straw of deep litter-based system, and adding additional straw to immobilize ammonium N. On the other hand, in order to mitigate CH_4 emissions from manure stores, the following are the best mitigation methods: instant removal of slurry from the slurry store, minimizing slurry volume stored during summer months, cooling slurry, aerating solid manure heaps and composting, anaerobic digestion, and enhancing crust formation (Chadwick et al. 2011).

Mathematical models and computer programs were developed to be implemented in constructing manure tanks and manure handling systems (Samer 2011a, Samer et al. 2008a) as well as biogas plants (Samer 2010). The location of such systems in the farm vicinity was specified to be downwind to avoid gas transmission and immission into the different farm facilities. A minimum distance was specified between the farm and any adjacent residential communities, roads, and ecosystems (Samer et al. 2008b). On the other hand, manure pits for temporary manure storage in livestock buildings form another effective source of gaseous emissions as shown in different emission inventories (Samer 2013a). Airflow profiles affect the gas emission rates which increase with the increasing air volumetric flow rates and air velocities, where free airstreams allow more gas release through convection mass transfer (Samer et al. 2011a, 2014b; Samer 2012a; Samer and Abuarab 2014). Additionally, gaseous emissions increase with increasing temperatures (Samer et al. 2011b, 2012; Samer 2011b). The implementation of proper waste management which is safe to the surroundings fulfills the green building specifications (Samer 2013b). While biofilters, air scrubbers, and urine/feces separation techniques offer potential opportunities to lower emissions (Carew 2010), these options are expensive and impractical to implement in commercial farms. Samer (2014) prototyped a biological–chemical filter, by implementing nanotechnology and laser radiation, for reducing gas, odor, and dust emissions from livestock buildings.

A survey should be accomplished for farms in a specific focus on different manure management systems. This allows the effects of the variability of farm and manure management parameters among farms on the GHG and NH_3 emissions to be fully taken into account. Weighing the emission factors per animal for several livestock categories and different farm classes can be used to develop emission inventory and to upscale available national inventory (Reidy et al. 2008a). The stratified sampling and the individual farm calculations allow the comparison of emissions from specific regions and altitudes and the study of the variability among farms. This approach permits a more detailed analysis of the regional distribution of GHG and NH_3 emissions as well as a more robust and standardized monitoring of the future development of emissions. The emission inventory can be then analyzed and implemented to develop effective GHG and NH_3 mitigation strategies focusing on the largest emission sources.

Uncertainties of estimated emission factors (EF) should be assessed in order to update the annual CH_4 and N_2O emissions. Additionally, emissions from manure management have the largest uncertainty due to the high natural variability of manure. The more animal accurate data are available, the lowest uncertainty is expected. This is the case in the intensified production systems (Merino et al. 2011). Several flow models were used to calculate GHG and NH_3 emissions from litter-based systems and slurry-based systems. The variability of emissions found in practice is likely to be much greater for straw-based systems than for slurry-based systems. The differences in estimates of NH_3 emissions decreased as estimates of immobilization and other N losses increased. Since immobilization and denitrification depend also on the C:N ratio in manure, there would be advantages to include C flows in mass flow models. This would also provide an integrated model for the estimation of emissions of CH_4, non-methane VOCs, and CO_2. Estimation of these would also enable an estimate of mass loss, calculation of the N and TAN concentrations in litter-based manures, and further validation of model outputs (Reidy et al. 2008b, 2009). GHG emissions from slurry are mainly caused by CH_4 emissions during storage and by N_2O emissions after field application. NH_3 emissions mainly occur after field application. Mitigation of GHG emissions can be achieved by reducing slurry dry matter content and degradable organic matter content.

20.3.3 Additives

Liquid manure storage facilities are sources of gaseous emissions of NH_3 and GHGs especially

CH_4 and N_2O. Additives can reduce gaseous emissions from swine waste lagoons and pits. The additives have the potential to reduce CH_4 emissions from anaerobic swine lagoons (Shah and Kolar 2012). Amendments can be practical and cost-effective for reducing NH_3 and GHG emissions from dairy manure. Amendment products that act as microbial digest, oxidizing agent, masking agent, or adsorbents can significantly reduce NH_3 by more than 10 %. Microbial digest/enzymes with nitrogen substrate are effective in reducing CH_4 fluxes. For both CH_4 and CO_2 fluxes, aging the manure slurry for 30 days can significantly reduce gas production (Wheeler et al. 2011b, c). Some amendments can also reduce odor emission; this is dependent on the storage period.

The effectiveness of the microbial digest additive for reducing odor and pollutant gas emission from a swine gestation–farrowing operation was evaluated (Rahman et al. 2011), where the additive was used to treat the deep pits to be compared with other untreated pits. However, no significant differences were found in terms of odor, NH_3, and H_2S concentrations and emissions between treated and untreated units. Overall, this microbial treatment has very little effect in reducing odor, NH_3, and H_2S emissions.

20.3.4 Manipulating the pH Value of Manure

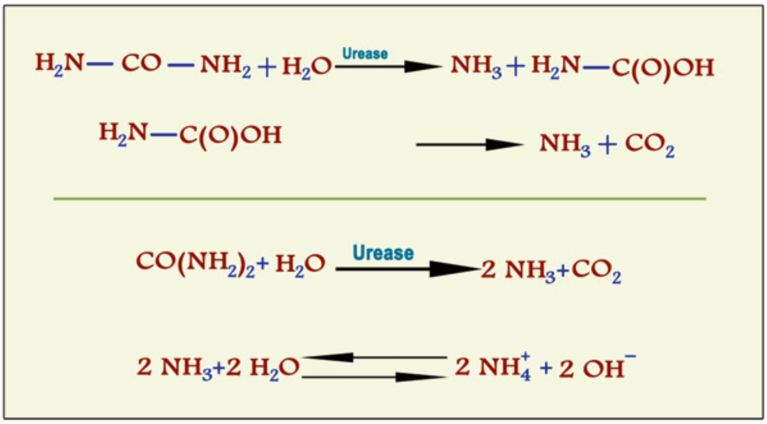
Manipulating the balance between NH_3 and NH_4^+ by lowering the pH of slurry is another measure that may be used to reduce emissions (Stevens et al. 1989; Oenema and Velthof 1993; Hendriks and Vrielink 1997; Kroodsma and Ogink 1997; Martinez et al. 1997; Beck and Burton 1998; Pedersen 2003). CH_4 and NH_3 emissions can be controlled by slurry pH. Manipulating the pH of slurry has an effect on the balance between NH_3 and NH_4^+. The pH of untreated slurries ranges between 7 and 8. From former investigations, it is known that a slurry pH of around 5.5 can reduce NH_3 emission by 80–90 % (Al-Kanani et al. 1992; Berg et al. 2006a, b; Husted et al. 1991; Li et al. 2006; Pain et al. 1990; Stevens et al. 1989). The pH level influences the activities of microorganisms. Higher CH_4 production occurs, when the pH is between 6 and 7 (Lay et al. 1997). A slurry pH below 6 is necessary to reduce CH_4 emission and below 5 to impede CH_4 formation (Berg et. al 2006a, b). A slurry pH below 4.5 nearly avoids NH_3 emission (Hartung and Phillips 1994). Whereas the use of inorganic acids has several disadvantages, organic acid use is a promising possibility for the reduction of NH_3, CH_4, and N_2O emissions (Berg and Hoernig 1997; Berg and Pazsiczki 2003; Berg 2003).

Manure treatment with acidic liquid biowastes is an effective mitigation measure for emissions from manure as they naturally contain organic acids. The hypothesis of treating manure with acidic liquid biowastes (e.g., wastes of citrus and milk industries) is that the organic acids in the liquid biowastes will reduce the pH of manure which consequently mitigates gaseous emissions. Eventually, this process is an integrated waste management system of both manure and acidic liquid biowastes. Therefore, Samer et al. (2014) investigated the possibility of reducing gas emissions (CH_4, N_2O, and NH_3) from dairy manure by adding low-pH food industry wastes and found it to be an effective emission abatement technique.

20.3.5 Inhibitors

The effect of NI dicyandiamide (DCD) on the transformation of N to nitrate (NO_3^-) was investigated by Giltrap et al. (2010). These authors showed that there was a reduction in N_2O emissions from a grazed pasture system receiving cow urine. The application of DCD decreased the nitrification rate. Based on this study, an issue can be raised: can the DCD be used as an inhibitor of N_2O emissions from floors inside livestock buildings?

The use of urease inhibitors has been shown to be effective in reducing NH_3 emissions from cattle and pig slurry. The basic investigations conducted by Reinhardt-Hanisch (2008) on urease inhibitors afforded an important contribution to the expansion of knowledge in this area. This will lead to the development of new techniques to



$$H_2N-CO-NH_2 + H_2O \xrightarrow{\text{Urease}} NH_3 + H_2N-C(O)OH$$
$$H_2N-C(O)OH \longrightarrow NH_3 + CO_2$$
$$CO(NH_2)_2 + H_2O \xrightarrow{\text{Urease}} 2\,NH_3 + CO_2$$
$$2\,NH_3 + 2\,H_2O \rightleftharpoons 2\,NH_4^+ + 2\,OH^-$$

Fig. 20.6 Chemical equations show how ammonia is produced from urea

reduce the NH_3 emissions from livestock housing. The following chemical equations (Fig. 20.6) illustrate how NH_3 is produced from urea which is excreted in urine, where the urease is an important catalyst to form NH_3. Therefore, urease inhibitors were designed to inhibit the urease noting that urease is an enzyme that catalyzes the hydrolysis of urea, forming NH_3 and CO_2.

20.3.6 Covering Materials for Manure Storage Facilities

Different materials for covering liquid manure storage facilities have been investigated and are in use for mitigating odor and NH_3 emissions (Sommer et al. 1993; Williams 2003). These materials also abate CH_4 and N_2O emissions. Different materials for covering liquid manure storage facilities to reduce gaseous emissions were investigated on a laboratory scale: perlite, lightweight expanded clay aggregate, and chopped straw – both used individually and combined with lactic acid or saccharose, respectively (Berg et al. 2006a). Covering pig manure with pulverized lignite (Figs. 20.7 and 20.8) reduces NH_3 emissions by 70 % and odor emissions by 50 % with no mitigation of GHG (Berg and Samer 2010). N_2O is typically emitted at one-tenth the rate of CH_4. However, N_2O emission can be increased by using commonly used cover materials (straw and granules) which are effective at reducing NH_3 emissions. The higher N_2O emission rates occur when manure tank has a dry encrusted surface. Hence, the strongest encrustation delivers the highest N_2O emission fluxes (Berg et al. 2006a). Adding water to the encrusted surface, simulating rainfall, could reduce N_2O emission.

20.3.7 Anaerobic Treatment

Anaerobic digesters (ADs) break down organic wastes using bacteria that produce CH_4, which can be collected and combusted to generate electricity. ADs also reduce odors and pathogens that are common with manure storage, and the digested manure can be used as a fertilizer. ADs are likely to become competitive in producing electricity in 2025 in Europe, when they receive CH_4 reduction credits and electricity from fossil fuels becomes more expensive (Zaks et al. 2011). Anaerobic digestion is the most promising way to reduce the overall GHG emission from manure storage and land spreading, without increasing NH_3 emissions (Novak and Fiorelli 2010). Anaerobic digestion increases NH_3 emissions and decreases N_2O emissions.

Several studies discussed the plan and design of biogas plants and household units (Samer 2010, 2012b). Anaerobic digestion of manure demonstrated that biogas production could be a very efficient and cost-effective option to reduce GHG emissions. The efficiency of this mitigation measure depends on the amount and quality of

Fig. 20.7 Laboratory experiments (Berg and Samer 2010)

Fig. 20.8 On-site experiments (Berg and Samer 2010)

organic matter used for co-digestion and how much of the thermal energy produced is exploited. A reduction of GHG emissions by up to 96 % can be achieved when all thermal energy produced is used to substitute fossil fuels (Weiske et al. 2006). In order to comprehensively estimate the significance of biogas utilization on rural energy development and GHG emission reduction, Yu et al. (2008) analyzed all types of energy sources, including straw, fuelwood, coal, refined oil, electricity, liquefied petroleum gas (LPG), natural gas, and coal gas, which were substituted by biogas, based on the amount of consumption. Energy substitution and manure management working in combination, i.e., coupled issues of environment and energy, reduce the GHG emission efficiently. By the employment of biogas digesters, reduction of GHG (CH_4, N_2O, and CO_2) was estimated to be 49.7 % of CO_2 equivalents (CO_2 eq.).

The effects of anaerobic digestion on mitigating GHG emissions are mainly through replacing fossil fuel consumption followed by reductions in emissions due to reduced inorganic fertilizer production and manure management. Kaparaju and Rintala (2011) estimated renewable energy production from farms producing 2,000 m^3 of dairy cow, 2,000 m^3 of sow, and 2,500 m^3 of pig manures which would be 62.8, 21.8, and 47.7 MWh of electricity $year^{-1}$ and 115.2, 36.3, and 79.5 MWh of heat $year^{-1}$, respectively, in a CHP unit. Adoption of AD technology could avoid annually 177, 87.7, and 125.6 Mg of CO_2 eq. emissions from dairy, sow, and pig farms, respectively.

The generally positive impacts of anaerobic and aerobic treatments on the reductions of CH_4 and volatile organic compounds (VOCs) are well known. However, the effects of anaerobic and aerobic treatments vary over the time of storage, especially for VOCs. In order to achieve significant reductions in VOC emissions, the storage time of anaerobic digester or aerobic reactor effluent should be limited to no more than 84 days (Zhang et al. 2008). Slurry separation increases both NH_3 and N_2O emissions. Although composting of solid manure increases NH_3, it decreases N_2O emissions. Using airtight cover for manure heaps reduces the emissions of both NH_3 and N_2O.

Anaerobic digestion of slurry and organic waste produces CH_4 at the expense of VS. Algorithms and models predicted a 90 % reduction of CH_4 emissions from outside stores with digested slurry and more than 50 % reduction of N_2O emissions after spring application of digested slurry as opposed to untreated (Sommer et al. 2004, 2006). Anaerobic digestion of livestock manures offers both treatment of manure and production of CO_2 neutral renewable energy. It supports the reduction of GHG emissions due to the replacement of fossil fuels, manure management, and inorganic fertilizer use and its production.

20.3.8 Thermochemical Conversion of Manure

Thermochemical conversion (TCC) uses high temperatures to break apart the bonds of organic matter and reform the intermediates into oil, gas, and char (Cantrell et al. 2008; Wingsley 2007). There are three types of TCC: pyrolysis, gasification, and direct liquefaction. Pyrolysis involves burning biomass in the absence of oxygen at temperatures greater than 400 °C. The products of pyrolysis are bio-oil and biochar. The bio-oil maybe converted to diesel fuel, and the biochar has a value as a substitute for activated carbon and as a soil amendment which may enhance soil carbon sequestration (Tomasula and Nutter 2011). Thermochemical conversion of livestock manures offers both treatment of manure and production of CO_2 neutral renewable energy (bio-oil). This process supports the reduction of GHG emissions, where (1) fossil fuels are replaced by biocrude oil, (2) manure management is replaced by thermochemical treatment, and (3) inorganic fertilizer production and use is replaced by biochar production and use.

20.3.9 Manure Incorporation into Soils

Emission mitigation strategies for reducing emissions from the land spreading of manure offer the greatest potential to achieve target levels (Hyde et al. 2003). At the application stage, NH_3 emissions may be reduced by spreading manure during the coolest part of the day, incorporating it quickly and in narrow bands. The mitigation options for crop production focus on limiting CO_2 and N_2O emissions. The introduction of perennial crops or temporary leys of longer duration is a promising option to limit CO_2 emissions by storing carbon in plants or soils. Reduced tillage or no tillage and the incorporation of crop residues also favor carbon sequestration in soils, but these practices may enhance N_2O emissions. Besides, the improvement of crop N use efficiency through effective management of manure and slurry, by growing catch crops or by delaying the plowing of leys, is of prime importance in the reduction of N_2O emissions. In terms of grassland and grazing management, permanent conversion from arable to grassland provides high soil carbon sequestration, while increasing or decreasing the livestock density seems not to be an appropriate mitigation option (Novak and Fiorelli 2010). Potential mitigation strategies are shifting autumn manure application to spring and incorporating all manure within 1 day of application. If both mitigation strategies are adopted, N_2O emissions from field-applied manure could be reduced by 17 % (VanderZaag et al. 2011).

Rapid incorporation of manure into arable land is one of the most cost-effective measures to reduce NH_3 emissions, while covering manure stores and applying slurry by injection are more cost-effective than measures to reduce emissions from buildings. These measures are likely to rank high in most European countries (Webb et al. 2005). Land spreading technique to inject or incorporate manure into the soil is one of the most effective measures to reduce livestock NH_3 emissions compared to housing and manure storage techniques (Carew 2010). Although direct injection reduces NH_3 emissions, it might increase N_2O emissions. On the other hand, the use of trail hoses, pre- or post-application cultivation, reduction in slurry viscosity, choice of application rate and timing, and slurry injection are considered as emission reduction techniques. The most effective methods of reducing NH_3 emissions were concluded to be the incorporation of the animal slurry and farmyard manure or slurry injection. Incorporation should be as close to the application as possible, especially after slurry application, as loss rates are high in the first hours after application. Injection is a very efficient reduction technique, provided the slurry is applied at rates that can be contained in the furrows made by the injector tine (Sommer and Hutchings 2001). Manure application by trail hose and injection, respectively, reduces farm GHG emissions on average by 0.7 and 3.2 % compared to broadcasting (Weiske et al. 2006). Generally, trail hose application reduces both NH_3 and N_2O emissions.

20.4 Mitigation Policies

There are several mitigation policies that are useful in the reduction of GHG emissions such as emission tax, emission cap, nitrogen fertilizer tax, and livestock extensification. Emission caps and taxes would directly address GHG emissions from agricultural systems (N_2O, CH_4, and CO_2) by applying market mechanisms to reduce compliance costs. Nitrogen taxes would provide an incentive for the control of N_2O emissions and thus reduce GHG emissions. Livestock extensification, i.e., limitation of livestock unit density (LUD) by achieving a 20 % decrease of the initial LUD in order to reach the GHG emission reduction goal, is so far mainly seen as a measure to increase environmental protection and to reduce surplus production, but it would also effectively reduce GHG emissions in the agricultural sector. A tax on the emission of GHGs from agricultural production (E-tax) will raise production costs according to the specific GHG emissions of the production chains. The farmers will therefore tend to reduce emissions where this is cheaper than paying the tax. Emission caps are quite similar to E-taxes, except that the regulator (i.e., the state) defines an upper emission level and does not receive taxes (Neufeldt and Schaefer 2008). Other measures, such as carbon sequestration or biofuel production, have been suggested in the context of GHG mitigation in the agricultural sector.

To mitigate livestock CH_4, incentive policies based on producer-level emissions are generally not feasible because of high administrative costs and producer transaction costs. In contrast, incentive policies based on sectoral emissions are likely administratively feasible, even in developing countries. There are two sectoral mitigation policies of global agriculture: “carbon tax” and “emission trading scheme” based on average national CH_4 emissions per unit of commodity. Consequently, the composition and location of livestock production and emissions may change in response to the policies. This illustrates the importance of global mitigation efforts: when policies are limited to Annex 1 countries, increased CH_4 emissions in non-Annex 1 countries offset approximately two-thirds of Annex 1 emission reductions. While non-Annex 1 countries face substantial disincentives to enacting domestic carbon taxes, developing countries could benefit from participating in a global sectoral emission trading scheme. Key and Tallard (2012) illustrated one scheme in which non-Annex 1 countries collectively earned USD 2.4 billion annually from CH_4 emission permit sales when CH_4 is priced at USD 30/t CO_2 eq.

20.5 Geographical Focus Mitigation Potentials

Emissions are higher in areas characterized by intensive livestock production with diet manipulation and land spreading offering the greatest potential for abatement options (Carew 2010). One key issue is to inventory the gaseous emissions, and as a consequence emission databases will be available for making decisions on implementing suitable mitigation strategies. The objectives of such investigations are to develop national emission inventories for domestic livestock and to identify possible abatement techniques to reduce these emissions. The inventory can be developed using data derived from farm surveys and national statistical records in a country over several years, as well as Tier 1 and 2 emission factors for enteric fermentation and manure management as proposed by the Intergovernmental Panel on Climate Change (IPCC). When an emission inventory is developed, it can be then used to develop abatement/mitigation strategies for livestock farms. This depends on the implemented farming system at a farm level as well as at a national level. The mitigation strategy will then focus on abating the highest emission levels that are released through determined stages of manure management (from barn to field), thus adhering to the commitments imposed by the Gothenburg and Kyoto protocols.

20.6 Industrial Focus Mitigation Potentials

Considering animal production as an industry (whole-farm system) allows developing effective industrial focus mitigation policies. The potential for reducing GHG in systems that are used to produce livestock commodities can be explored by implementing a *life cycle analysis. Improvements in productivity* and *efficient use of resources* are the best options for reducing GHG (Audsley and Wilkinson 2014). A *life cycle assessment* (LCA), also known as life cycle analysis, of a product or process begins with an inventory of the energy and environmental flows associated with a product from “cradle to grave.” It provides information on the raw materials used from the environment, energy resources consumed, and air, water, and solid waste emissions generated. GHGs and other wastes, sinks and emissions may then be assessed (Sheehan et al. 1998). The net GHG emissions calculated from an LCA are usually reported per unit of product or as the carbon footprint (Tomasula and Nutter 2011).

Considerable GHG mitigation can be achieved by farming with high precision and applying optimal animal management to maximize efficiency and minimize wastage (Beukes et al. 2010). Schader et al. (2013) quantified GHG emissions and energy consumption at farm level using a life cycle assessment approach. It was found that the farms’ total GHG emissions could be determined by technical means and agronomic measures. Technical means include the use of photovoltaics and heat recovery from milk cooling devices. The agronomic measures include conversion to full-grazing systems, composting livestock manure, and the use of dual-purpose cattle breeds.

20.7 Discussion

The Kyoto protocol, an international treaty, sets binding obligations on the ratifying countries to achieve the stabilization of GHG concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. The Gothenburg protocol, a convention on long-range transboundary air pollution, is a multi-pollutant protocol aimed at reducing acidification and eutrophication by setting emission ceilings for several pollutants, where NH_3 is one of them. In addition to the global warming potential of the GHGs (e.g., CH_4, N_2O, NO, CO_2), NH_3 emissions contribute to global warming when NH_3 is converted to

N_2O. Therefore, the emission sources should be first identified, and the emission factors and rates should be quantified in order to develop suitable and effective mitigation strategies for reducing harmful gas emissions. Therefore, national emission inventory should be developed by each country, where databases on anthropogenic emissions will be available for making decisions on developing and implementing effective mitigation strategies. Several sectors that are sources of emissions should be considered while inventorying emissions, and they are energy; industrial processes and product use; agriculture, forestry, and other land uses; and waste. Agriculture is divided into two main sectors, which are plant production and animal production. In this study, the animal production sector was considered. Emissions from animal production are generated from enteric fermentation and manure.

Manure, farmyard manure, and slurry are an inevitable consequence of livestock products generated from housed animals. These manures are recycled back to land for plants to use the nutrients they contain. However, since they contain inorganic N, microbially available sources of C and water, they provide the essential substrates required for the microbial production of N_2O and CH_4 (Chadwick et al. 2011). These GHGs can be produced and emitted at each stage of the "manure management continuum," namely, the livestock housing (barn, corral), manure tanks, manure piles, and manure spreading to land. On farm management, decisions interact with environmental controls such as temperature and water availability of key microbial processes (i.e., nitrification, denitrification, methanogenesis, CH_4 oxidation), affecting the magnitude of emissions at each stage of the manure management continuum.

Potential manure treatment methods (Fig. 20.9) to produce value-added products and bioenergy are as follows: gasification, pyrolysis, biogas production, composting, biodiesel production, and fermentation for animal feed production. These different treatment methods are effective emission abatement techniques.

Reduced fertilizer nitrogen input, optimal fertilizer form, nitrification inhibitor addition, land drainage management, and reduced land compaction by restricted grazing are the best ways to mitigate N_2O emissions from farmland, whereas management of bedding material and solid manure reduces N_2O emissions from housing and storage. Mitigation measures for N_2O interact with other important environmental issues, like reduction of nitrate leaching and NH_3 emission. On the other hand, the most effective mitigation strategies for CH_4 comprise a source approach, i.e., changing animals' diets toward greater efficiencies. CH_4 emissions can also be effectively reduced by optimal use of the gas produced from manures, e.g., for energy production. Frequent and complete manure removal from animal housing, combined with on-farm biogas production, is an example of an integrated on-farm solution (Monteny et al. 2006). From the point of view of animal science, options found to reduce GHG in livestock production are increased fertility, fecundity, and longevity of breeding females, increased annual milk yield per dairy cow, improved feed conversion ratio (FCR) in meat animals, and immediate incorporation of slurry following its application to land giving reductions ranging between 7 % and 21 % (Audsley and Wilkinson 2014).

The average GHG emission on the commercial dairy farms is 1.08 kg CO_2 equivalents per kg milk. A total mitigation of 310–360 g CO_2 equivalents per kg milk is achievable (Vellinga et al. 2011). Farmers tend to choose mitigation options that are relatively simple and either cost-effective or with only relatively small additional costs. The most promising mitigation options with respect to cost-effectiveness are less replacement of dairy cattle and replacement of concentrates by single by-products grown in the vicinity of the farm. The preferred mitigation options are an increase of the milk production per cow, replacement of concentrates with single by-products, the use of more maize in animal feeding, heat reuse from milk by a heat pump, and reduction of the fertilizer N input.

Manure treatment with low-pH food industry wastes contains organic acids that reduce the pH (value equal to 4.5) of the manure which inhibits the bacterial activities. Most of the bacterial activities are impeded at a pH of 4.5, and

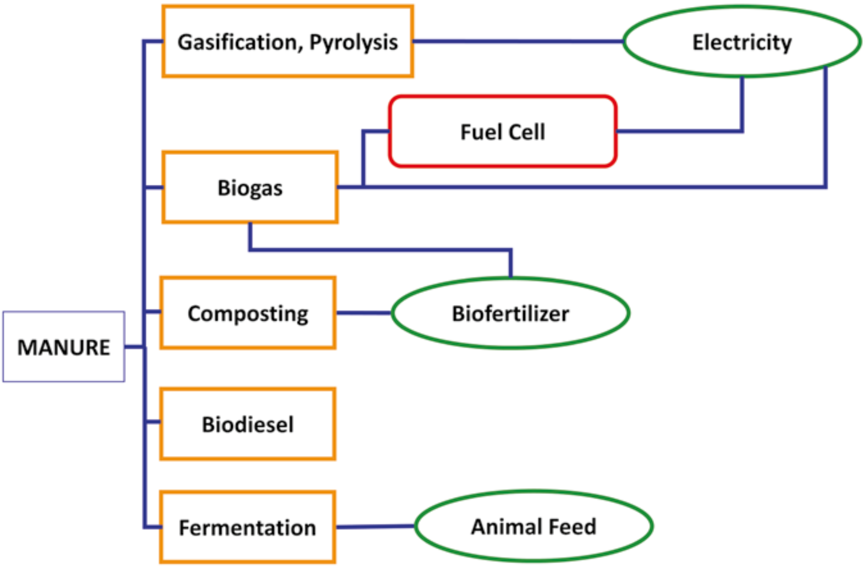


Fig. 20.9 Manure treatment to produce value-added products and bioenergy and abate emissions

consequently, this mitigates the gaseous emissions from manure. Manure treatment with biomaterials avoids the disadvantages of the mineral and inorganic additives which contaminate the soils and increase salt content when the manure is distributed as fertilizer for plants. This treatment provides cost-effective and safe biofertilizers (manure treated with food industry wastes) free of soil contaminants with lower GHG and NH_3 emissions (Samer et al. 2014a). Consequently, this process is an integrated waste management of both manure and food industry wastes. Important outcomes are complying with the Kyoto protocol by mitigating the emissions of GHGs and conforming to the Gothenburg protocol by abating the NH_3 emissions which allow revising and updating the present emission inventories accordingly when implemented by respective farms. Further investigations should be carried out to determine the effectiveness of this technique to mitigate gas emissions from pig and poultry manures.

Eventually, it is crucial to determine the emission rates, fluxes, and factors before and after deploying an emission abatement technique. This allows an evaluation of the developed technique. A key issue is amending the present emission inventory of a geographic area when the new emission abatement technique is deployed. On the other hand, GHG emissions from manure have large uncertainties, and it is difficult to assess the effectiveness of GHG mitigation strategies under the changing climate conditions in the future. Improving the efficiency and economic feasibility of animal production is essential to cover the food demand, whereas adopting mitigation strategies to reduce GHG emissions is crucial. Such strategies will be required to ensure that animal production will be able to satisfy the growing global demand for food with a minimal impact on the environment.

The problems associated with the current development and production systems, i.e., agro-industrial systems, are resource use inefficiency, energy use inefficiency, high production costs, unsustainable development, and high environmental risk as GHG emissions, air and water pollutants (e.g., NH_3), and detrimental wastages. A solution would be the implementation of the biorefinery approach and amending the present agro-industrial systems to bioindustrial systems. Precisely, redesigning the current animal production systems of dairy cattle, beef cattle, poultry, sheep, and pig by applying ecological models, where the natural indigenous systems that provide sustainable models are mimicked, to provide integrated bioindustrial systems that apply the concept of sustainable development which consists of the following concepts: eco-efficiency or eco-design, cleaner production, zero emission, industrial ecology, implementation of life cycle analysis, and integrated biosystems (industrial symbiosis, i.e., integrated bioindustrial systems). This would be achieved by designing the agro-industrial infrastructures as a series of interlocking man-made ecosystems through (1) maximizing energy use efficiency; (2) reducing cost, i.e., improving economical feasibility; (3) reducing environmental risk, i.e., reduction of emissions and wastes; (4) identifying new opportunities, i.e., conversion of waste into value-added products and bio-products; and (5) maximizing resource (e.g., raw materials) use efficiency, i.e., sustainability.

The bioindustrial systems can be integrated through (1) designing cyclical production and consumption systems by increasing efficiencies of resource and energy uses and providing energy and resources required for future growth, (2) creating a more ecologically sound and healthy environment by generating less waste at each level of production and converting waste into value-added products, and (3) placing more emphasis on improving socioeconomic development by providing new technologies and products as well as employment opportunities.

The biorefinery approach is a promising emission abatement strategy. The concept of biorefinery is transforming an environmental risk into economic opportunities, e.g., the conversion of biowaste into bioenergy, biofertilizers, and value-added bioproducts. A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power, heat, and value-added chemicals from biomass. The International Energy Agency, Bioenergy Task 42 on Biorefineries, has defined biorefining as the sustainable processing of biomass into a spectrum of bio-based products (food, feed, chemicals, and materials) and bioenergy (biofuels, power, and/or heat). The advantages of the biorefinery approach are as follows:

1. By producing multiple products, a biorefinery takes advantage of the various components in biomass and their intermediates therefore maximizing the value derived from the biomass feedstock.
2. A biorefinery could, for example, produce one or several low-volume, but high-value, chemical or nutraceutical products and a low-value, but high-volume, liquid transportation fuel such as biodiesel or bioethanol.
3. At the same time, a biorefinery generates electricity and process heat, through combined heat and power (CHP) technology, for its own use and perhaps enough for sale of electricity to the local utility.
4. The high-value products increase profitability, the high-volume fuel helps meet energy needs, and the power production helps to lower energy costs and reduce *GHG emissions* from traditional power plant facilities.

The following issues related to biorefining processes should be addressed:

1. Risk of an excessive consumption of food crop
2. Risk of deterioration of organic quality and mineral content of soil
3. Excessive utilization of fertilizers and pesticides to improve production levels
4. Competition between food and biorefinery
5. Risk of deforestation on the long run

Therefore, the biorefinery approach should be deployed with the perspective that is implemented as annexed facility to amend an agro-industrial system to a bioindustrial system, where the biorefinery treats the biowastes to produce bioenergy, value-added products, and bioproducts and to reduce the GHG emissions from the agro-industry. It is crucial to avoid the implementation of biorefinery as a stand-alone system, where in this case it would compete with food production, deteriorate the natural resources, and lead to deforestation.

20.8 Conclusions

According to the issues discussed in this chapter, it can be further concluded that:

(a) Developing mitigation strategies to reduce GHG and NH_3 emissions from livestock manure should be preceded with developing national emission inventories. This will provide databases on emission sources from which potential emission abatement strategies can be drawn and relevant emission abatement techniques can be applied.

(b) Understanding of the processes of CH_4, CO_2, N_2O, NO, and NH_3 mass transfer from the manure and transport to the free atmosphere will contribute to the development of emission abatement techniques and housing designs and will contribute to the reduction of gaseous emissions to the atmosphere.

(c) It is crucial to determine the emission rates, fluxes, and factors before and after deploying a mitigation strategy. This allows an evaluation of the developed strategy. A key issue is amending the present emission inventory of a geographic area when the new mitigation strategy is deployed. Special considerations should be given to avoid increasing specific gas emissions while abating another.

(d) Mitigation strategies for GHG emissions mainly focus on one gas and are treated as separated activities. The whole-farm approach with the full accounting of GHG emissions should be considered including the relevant direct and indirect emissions of CH_4, N_2O, and CO_2 (including carbon sequestration), the potential trade-off with NH_3 volatilization, and nitrate leaching. The livestock farm should be considered as a chain consisting of animal, housing, manure, soil, crop, and feed.

(e) It is crucial to consider the manure management systems inside the livestock buildings (e.g., slatted floor, manure scrapper, litter-based system), floor type, building design, and ventilation system where these parameters have discernible influence on the emission flow rates. Therefore, each farm should be treated as a special case, where some farms may have applied emission abatement techniques and other farms may have not applied. Therefore, farm survey is necessary to be taken into consideration when inventorying the emissions and before developing mitigation strategies to reduce GHG and NH_3 emissions from livestock manure.

(f) Thermochemical conversion and anaerobic digestion of livestock manures offer both treatment of manure and production of CO_2 neutral renewable energy and support reduction of GHG emissions due to the replacement of fossil fuels, manure management, and inorganic fertilizer use and production.

(g) Optimization of the N content of the diet of the animal is an efficient mitigation method that potentially affects all phases of the manure management continuum, as this reduces N excretion/unit product produced. Diet formulation might also be used to reduce CH_4 emissions from the rumen and the manure store.

(h) Reduced fertilizer nitrogen input, optimal fertilizer form, nitrification inhibitor addition, land drainage management, and reduced land compaction by restricted grazing are the best ways to mitigate N_2O emissions from farmland. Management of bedding material and solid manure reduces N_2O emissions from housing and storage. Mitigation measures for N_2O interact with other important environmental issues, like reduction of nitrate leaching and NH_3 emission. Efficient use of manure as sources of N, P, and K reduces the use of inorganic fertilizers and thus reduces N_2O emissions associated with the manufacture and use of inorganic fertilizers. It also reduces fossil fuel use and associated CO_2 emissions from the manufacturing and transportation of inorganic fertilizers.

(i) Most effective mitigation strategies for CH_4 comprise of a source approach, i.e., changing animals' diets toward greater efficiencies. CH_4 emissions can also be effectively reduced by the optimal use of the gas produced from manures, e.g., for energy production. Frequent and complete manure removal from animal housing, combined with on-farm biogas production, is an example of an integrated on-farm solution.

(j) Land application of livestock manure can increase the C content of soils. Any increase in soil C content can offset some of the GHG emissions associated with manure management.
(k) The potential for reducing GHG in systems which are used to produce livestock commodities can be explored by implementing a *life cycle analysis. Improvements in productivity* and *use of resources* are the best options for reducing emissions. Considerable GHG mitigation can be achieved by farming with high precision, maximizing efficiency and minimizing waste.
(l) The biorefinery approach should be deployed with the perspective that is implemented as annexed facility to amend an agro-industrial system to a bioindustrial system, where the biorefinery treats the biowastes to produce bioenergy, value-added products, and bioproducts and to reduce the GHG emissions from the agro-industry.
(m) It is crucial to evaluate the consequences of predicted climate change on different aspects on the environment and human life. Precisely, it is important to answer two questions: (a) How would animal production (as an industry) increase global warming by emitting GHGs? (b) How would global warming and climate change negatively affect animal production systems?

References

Abdelsalam E, Samer M, Abdel-Hadi MA, Hassan HE, Badr Y (2015) Buffalo dung treatment with paunch fluid for producing biogas. Misr J Agric Eng (in Press)

Al-Kanani T, Akochi E, Mackenzie AF, Alli I, Barrington S (1992) Organic and inorganic amendments to reduce ammonia losses from liquid hog manure. J Environ Qual 21:709–715

Audsley E, Wilkinson M (2014) What is the potential for reducing national greenhouse gas emissions from crop and livestock production systems? J Clean Prod (in press). doi:http://dx.doi.org/10.1016/j.jclepro.2014.01.066

Beck J, Burton C (1998) Manure treatment techniques in Europe – result of a EU concerted action. In: Proceedings of the international conference on agricultural engineering, AgEng 98, Oslo, Norway, 24–27 Aug, pp 211–212

Berg W (1999) Technology assessment – livestock management. Anim Res Dev 50:98–109

Berg W (2003) Reducing ammonia emissions by combining covering and acidifying liquid manure. In: Proceedings of the third international conference on air pollution from agricultural operations, Raleigh, NC, USA, 12–15 Oct, pp 174–182

Berg W, Hoernig G (1997) Emission reduction by acidification of slurry – investigations and assessment. In: Voormans JAM, Monteny GJ (eds) Proceedings of the international symposium on ammonia and odour control from animal production facilities, Vinkeloord, The Netherlands, 6–10 Oct, pp 459–466

Berg W, Pazsiczki I (2003) Reducing emissions by combining slurry covering and acidifying. In: Proceedings of the international symposium on gaseous and odour emissions from animal production facilities, Horsens, Denmark, 1–4 June, pp 460–468

Berg W, Samer M (2010) Emissions from manure tanks. Presented at the international DLG exhibition for animal husbandry and management (EuroTier), 16–19 Nov, Hannover, Germany

Berg W, Brunsch R, Pazsiczki I (2006a) Greenhouse gas emissions from covered slurry compared with uncovered during storage. Agric Ecosyst Environ 112(2–3):129–134

Berg W, Türk M, Hellebrand J (2006b) Effects of acidifying liquid cattle manure with nitric or lactic acid on gaseous emissions. Workshop on agricultural air quality – State of the science. Potomac, MD, USA, 5–8 June 2006, pp 492–498

Beukes PC, Gregorini P, Romera AJ, Levy G, Waghorn GC (2010) Improving production efficiency as a strategy to mitigate greenhouse gas emissions on pastoral dairy farms in New Zealand. Agric Ecosyst Environ 136:358–365

Brink C, Kroeze C, Klimont Z (2001) Ammonia abatement and its impact on emissions of nitrous oxide and methane – part 2: application for Europe. Atmos Environ 35(36):6313–6325

Cantrell KB, Ducey T, Ro KS, Hunt PG (2008) Livestock waste-to-bioenergy generation opportunities. Rev Bioresour Technol 99:7941–7953

Capper JL (2012) Is the grass always greener? Comparing the environmental impact of conventional, natural and grass-fed beef production systems. Animals 2:127–143

Carew R (2010) Ammonia emissions from livestock industries in Canada: feasibility of abatement strategies. Environ Pollut 158(8):2618–2626

Chadwick D, Sommer S, Thorman R, Fangueiro D, Cardenas L, Amon B, Misselbrook T (2011) Manure management: implications for greenhouse gas emissions. Anim Feed Sci Technol 166–167:514–531

CIGR (1994) Aerial environment in animal housing: concentrations in and emissions from farm buildings. Working group report series number 94.1: climatization and environmental control in animal housing. International Commission of Agricultural Engineering (CIGR)

Cottle DJ, Nolan JV, Wiedemann SG (2011) Ruminant enteric methane mitigation: a review. Anim Prod Sci 51(6):491–514

Dekker SEM, Aarnink AJA, de Boer IJM, Groot Koerkamp PWG (2011) Emissions of ammonia, nitrous oxide, and methane from aviaries with organic laying hen husbandry. Biosyst Eng 110(2):123–133

ECETOC (1994) Ammonia emissions to in Western Europe. Technical report 62. European Centre for Ecotoxicology and Toxicology of Chemicals, Brussels

EMEP/EEA (2009) EMEP/EEA air pollutant emission inventory guidebook: animal husbandry and manure management. The European Environment Agency (EEA) and the cooperative programme for monitoring and evaluation of the long-range transmission of air pollutants in Europe (EMEP). http://eea.europa.eu/emep-eea-guidebook

European Commission (2003) Integrated Pollution Prevention and Control (IPPC): intensive rearing of poultry and pigs. Reference document on best available techniques for intensive rearing of poultry and pigs

Executive Body for the Convention on Long-Range Transboundary Air Pollution (2007a) Methods and procedures for the technical review of air pollutant emission inventories reported under the convention and its protocols. Economic Commission for Europe, Economic and Social Council, United Nations

Executive Body for the Convention on Long-Range Transboundary Air Pollution (2007b) Guidance document on control techniques for preventing and abating emissions of ammonia. Economic Commission for Europe, Economic and Social Council, United Nations

FAO (2006) Livestock's role in climate change and air pollution. Available at: ftp://ftp.fao.org/docrep/fao/010/a0701e/A0701E03.pdf. Accessed Dec 2010

Giltrap DL, Singh J, Saggar S, Zaman M (2010) A preliminary study to model the effects of a nitrification inhibitor on nitrous oxide emissions from urine-amended pasture. Agric Ecosyst Environ 136(3–4):310–317

Haeussermann A, Hartung E, Gallmann E, Jungbluth T (2006) Influence of season, ventilation strategy, and slurry removal on methane emissions from pig houses. Agric Ecosyst Environ 112:115–121

Hartung E (1995) Entwicklung einer Messmethode und Grundlagenuntersuchung zur Ammoniakfreisetzung aus Flüssigmist (Development of a measuring method and basic investigation for ammonia release from liquid manure). VDI-MEG Script 275, Dissertation, University of Hohenheim, ISSN-Nr. 0931-6264

Hartung J, Phillips VR (1994) Control of gaseous emissions from livestock buildings and manure stores. J Agric Eng Res 57:173–189

Hendriks JGL, Vrielink MGM (1997) Reducing ammonia emission from pig houses by adding or producing organic acids in pig slurry. In: Voormans JAM, Monteny GJ (eds) Proceedings of the international symposium on ammonia and odour control from animal production facilities, Vinkeloord, The Netherlands, 6–10 Oct, pp 493–501

Husted S, Jensen LS, Jorgensen SS (1991) Reducing ammonia loss from cattle slurry by the use of acidifying additives: the role of the buffer system. J Sci Food Agric 57:335–349

Hutchings NJ, Sommer SG, Andersen JM, Asman WAH (2001) A detailed ammonia emission inventory for Denmark. Atmos Environ 35(11):1959–1968

Hyde BP, Carton OT, O'Toole P, Misselbrook TH (2003) A new inventory of ammonia emissions from Irish agriculture. Atmos Environ 37(1):55–62

IPCC (2006) Intergovernmental panel on climate change, guidelines for national greenhouse gas inventories. Volume 4: agriculture, forestry and other land use. Chapter 10: emissions from livestock and manure management

IPCC (2007a) In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: mitigation. Contribution of working group III to the 4th assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK/New York

IPCC (2007b) Climate change 2007: climate Change 2007: the physical science basis, technical summary

IPCC (2007c) Climate change 2007. The physical science basis. Summary for policymakers

Janzen HH, Desjardins RL, Rochette P, Boehm M, Worth D (2008) Better farming, better air. Agriculture and Agri-food Canada, Ottawa

Jensen FH (1974) Geruchsminderung durch Umwälzlüftung (In German, Odor reduction by recirculating ventilation). KTBL-Script 186, The German association for technology and structures in agriculture (KTBL), Darmstadt-Kranichstein, Germany

Kaparaju P, Rintala J (2011) Mitigation of greenhouse gas emissions by adopting anaerobic digestion technology on dairy, sow and pig farms in Finland. Renew Energy 36:31–41

Key N, Tallard G (2012) Mitigating methane emissions from livestock: a global analysis of sectoral policies. Clim Change 112(2):387–414

Kroodsma W, Ogink NWM (1997) Volatile emissions from cow cubicle houses and its reduction by immersion of the slats with acidified slurry. In: Voormans JAM, Monteny GJ (eds) Proceedings of the international symposium on ammonia and odour control from animal production facilities, Vinkeloord, The Netherlands, 6–10 Oct, pp 475–483

Kuczynski T, Blanes-Vidal V, Li BM, Gates RS, Nääs IA, Moura DJ, Berckmans D, Banhazi TM (2011) Impact of global climate change on the health, welfare and productivity of intensively housed livestock. Int J Agric Biol Eng 4(2):1–22

Lay JJ, Li YY, Noike T (1997) Influences of pH and moisture content on the methane production in high-solids sludge digestion. Water Res 31(6):1518–1524

Li H, Xin H, Burns RT (2006) Reduction of ammonia emission from stored poultry manure using additives: zeolite, Al^+ clear, Ferix-3, and PLT. ASAE Paper No. 064188, 2006 ASABE Annual International Meeting, Portland, OR, USA

Martinez J, Jolivet J, Guiziou F, Langeoire G (1997) Ammonia emissions from pig slurries: evaluation of acidification and the use of additives in reducing losses. In: Voormans JAM, Monteny GJ (eds) Proceedings of the international symposium on ammonia and odour control from animal production facilities, Vinkeloord, The Netherlands, 6–10 Oct, pp 485–492

Merino P, Ramirez-Fanlo E, Arriaga H, del Hierro O, Artetxe A, Viguria M (2011) Regional inventory of methane and nitrous oxide emission from ruminant livestock in the Basque Country. Anim Feed Sci Technol 166–167:628–640

Monteny G-J, Bannink A, Chadwick D (2006) Greenhouse gas abatement strategies for animal husbandry. Agric Ecosyst Environ 112:163–170

Neufeldt H, Schaefer M (2008) Mitigation strategies for greenhouse gas emissions from agriculture using a regional economic-ecosystem model. Agric Ecosyst Environ 123:305–316

Ngwabie NM, Jeppsson K-H, Nimmermark S, Gustafsson G (2011) Effects of animal and climate parameters on gas emissions from a barn for fattening pigs. Appl Eng Agric 27(6):1027–1037

Novak SM, Fiorelli JL (2010) Greenhouse gases and ammonia emissions from organic mixed crop-dairy systems: a critical review of mitigation options. Agron Sustain Dev 30(2):215–236

Oenema O, Velthof GL (1993) Denitrification in nitric-acid-treated cattle slurry during storage. Neth J Agric Sci 41:63–80

Pain BF, Thompson RB, Rees YJ, Skinner JH (1990) Reducing gaseous losses of nitrogen from cattle slurry applied to grassland by the use of additives. J Sci Food Agric 50:141–153

Pedersen P (2003) Reduction of gaseous emissions from pig houses by adding sulphuric acid to the slurry. In: Proceedings of the international symposium on gaseous and odour emissions from animal production facilities, Horsens, Denmark, 1–4 June, pp 257–263

Petersen SO, Sommer SG (2011) Ammonia and nitrous oxide interactions: roles of manure organic matter management. Anim Feed Sci Technol 166–167:503–513

Petersen SO, Blanchard M, Chadwick D, Del Prado A, Edouard N, Mosquera J, Sommer SG (2013) Manure management for greenhouse gas mitigation. Animal 7(2):266–282

Powell JM, Russelle MP, Martin N (2010) Trends in the dairy industry and their implications for producers and the environment. In: Gerber P, Mooney HA, Kijkman J, Tarawali S, De Haan C (eds) Livestock in a changing landscape. Experiences and regional perspectives, vol 2. Island Press, Washington, DC, Chapter 7

Rahman S, DeSutter T, Zhang Q (2011) Efficacy of a microbial additive in reducing odor, ammonia, and hydrogen sulfide emissions from farrowing-gestation swine operation. Agric Eng Int: CIGR J 13(3):1–9

Reidy B, Rhim B, Menzi H (2008a) A new Swiss inventory of ammonia emissions from agriculture based on a survey on farm and manure management and farm-specific model calculations. Atmos Environ 42:3266–3276

Reidy B, Dammgen U, Dohler H, Eurich-Menden B, van Evert FK, Hutchings NJ, Luesink HH, Menzi H, Misselbrook TH, Monteny G-J, Webb J (2008b) Comparison of models used for national agricultural ammonia emission inventories in Europe: liquid manure systems. Atmos Environ 42:3452–3464

Reidy B, Webb J, Misselbrook TH, Menzi H, Luesink HH, Hutchings NJ, Eurich-Menden B, Dohler H, Dammgen U (2009) Comparison of models used for national agricultural ammonia emission inventories in Europe: litter-based manure systems. Atmos Environ 43:1632–1640

Reinhardt-Hanisch A (2008) Grundlagenuntersuchungen zur Wirkung neuartiger Ureaseinhibitoren in der Nutztierhaltung (Basic research on the effects of novel urease inhibitors in animal housing). Dissertation, University of Hohenheim, Stuttgart, Germany

Samer M (2010) A software program for planning and designing biogas plants. Trans ASABE 53(4):1277–1285

Samer M (2011a) How to construct manure storages and handling systems? IST Trans Biosyst Agric Eng 1(1):1–7

Samer M (2011b) Seasonal variations of gaseous emissions from a naturally ventilated dairy barn. Misr J Agric Eng 28(4):1162–1177

Samer M (2012a) Effect of airflow profile on reducing heat stress, enhancing air distribution and diluting gaseous concentrations in dairy barns. Misr J Agric Eng 29(2):837–856

Samer M (2012b) Biogas plant constructions. In: Kumar S (ed) Biogas. InTech, Rijeka, pp 343–368. doi:10.5772/31887. ISBN 978-953-51-0204-5

Samer M (2013a) Emissions inventory of greenhouse gases and ammonia from livestock housing and manure management. Agric Eng Int: CIGR J 15(3):29–54

Samer M (2013b) Towards the implementation of the Green Building concept in agricultural buildings: a literature review. Agric Eng Int: CIGR J 15(2):25–46

Samer M (2014) Implementation of nanotechnology and laser radiation to prototype a biological-chemical filter for reducing gas, odor and dust emissions from livestock buildings. Session: measurement and mitigation of pollutants from livestock and poultry housing. Proceedings of the 2014 American Society of Agricultural and Biological Engineers (ASABE) Annual International Meeting, a joint conference with the Canadian Society of Bioengineering (CSBE), 13-16.07.2014, Paper No. 141870677, Montreal, Quebec, Canada

Samer M, Abuarab ME (2014) Development of CO_2-balance for ventilation rate measurements in naturally cross ventilated dairy barns. Trans ASABE 57(4):1255–1264

Samer M, Grimm H, Hatem M, Doluschitz R, Jungbluth T (2008a) Mathematical modeling and spark mapping for construction of aerobic treatment systems and their manure handling system. Proceedings of international conference on agricultural engineering, Book of Abstracts, p 28, EurAgEng, 23–25 June, Hersonissos, Crete, Greece

Samer M, Grimm H, Hatem M, Doluschitz R, Jungbluth T (2008b) Mathematical modeling and spark mapping of dairy farmstead layout in hot climates. Misr J Agric Eng 25(3):1026–1040

Samer M, Loebsin C, von Bobrutzki K, Fiedler M, Ammon C, Berg W, Sanftleben P, Brunsch R (2011a) A computer program for monitoring and controlling ultrasonic anemometers for aerodynamic measurements in animal buildings. Comput Electron Agric 79(1):1–12

Samer M, Loebsin C, Fiedler M, Ammon C, Berg W, Sanftleben P, Brunsch R (2011b) Heat balance and tracer gas technique for airflow rates measurement and gaseous emissions quantification in naturally ventilated livestock buildings. Energy Build 43(12):3718–3728

Samer M, Ammon C, Loebsin C, Fiedler M, Berg W, Sanftleben P, Brunsch R (2012) Moisture balance and tracer gas technique for ventilation rates measurement and greenhouse gases and ammonia emissions quantification in naturally ventilated buildings. Build Environ 50(4):10–20

Samer M, Mostafa E, Hassan A M (2014a) Slurry treatment with food industry wastes for reducing methane, nitrous oxide and ammonia emissions. Misr J Agric Eng 31(4):1523–1548

Samer M, Müller H-J, Fiedler M, Berg W, Brunsch R (2014b) Measurement of ventilation rate in livestock buildings with radioactive tracer gas technique: theory and methodology. Indoor Built Environ 23(5):692–708

Schader C, Jud K, Meier M, Kuhn T, Oehen B, Gattinger A (2013) Quantification of the effectiveness of GHG mitigation measures in Swiss organic milk production using a life cycle assessment approach. J Clean Prod (in press). doi:http://dx.doi.org/10.1016/j.jclepro.2013.11.077

Schils RLM, Olesen JE, del Prado A, Soussana JF (2007) A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems. Livest Sci 112:240–251

Schuurkes J, Mosello R (1988) The role of external ammonium inputs in freshwater acidification. Aquat Sci – Res Across Bound 50(1):71–86

Shah SB, Kolar P (2012) Evaluation of additive for reducing gaseous emissions from swine waste. Agric Eng Int: CIGR J 14(2):10–20

Sheehan J, Camobreco V, Duffield J, Graboski M, Shapouri H (1998) Life cycle inventory of biodiesel and petroleum diesel for use in an urban bus. Final Report. National Renewable Energy Laboratory, US Department of Energy

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C, Scholes B, Sirotenko O (2007) Greenhouse gas mitigation in agriculture. In: Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA (eds) Climate change 2007: mitigation. Contribution of working group III to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, UK, Chapter 8

Sommer SG, Hutchings NJ (2001) Ammonia emission from field applied manure and its reduction – invited paper. Eur J Agron 15(1):1–15

Sommer SG, Christensen BT, Nielsen NE, Schjorring JK (1993) Ammonia volatilization during storage of cattle and pig slurry – effect of surface cover. J Agric Sci 121:63–71

Sommer SG, Pedersen SO, Sogaard HT (2000) Greenhouse gas emissions from stored livestock slurry. J Environ Qual 29:744–751

Sommer SG, Petersen SO, Møller HB (2004) Algorithms for calculating methane and nitrous oxide emissions from manure management. Nutr Cycl Agroecosyst 69(2):143–154

Sommer SG, Zhang GQ, Bannink A, Chadwick D, Misselbrook T, Harrison R, Hutchings NJ, Menzi H, Monteny GJ, Ni JQ, Oenema O, Webb J (2006) Algorithms determining ammonia emission from buildings housing cattle and pigs and from manure stores. Adv Agron 89:261–335

Sommer SG, Olesen J, Petersen SO, Weisbjerg M, Valli L, Rodhe L, Béline F (2009) Region-specific assessment of greenhouse gas mitigation with different manure management strategies in four agroecological zones. Glob Chang Biol 15(12):2825–2837

SRES (2000) In: Nakicenovic N, Swart R (eds) Special report on emissions scenarios (SRES). World Meteorological Organization, Geneva

Stevens RJ, Laughlin RJ, Frost JP (1989) Effect of acidification with sulphuric acid on the volatilization of ammonia from cow and pig slurries. Camb J Agric Sci 113:389–395

Tomasula PM, Nutter DW (2011) Mitigation of greenhouse gas emissions in the production of fluid milk. Adv Food Nutr Res 62:41–88

VanderZaag AC, Jayasundara S, Wagner-Riddle C (2011) Strategies to mitigate nitrous oxide emissions from land applied manure. Anim Feed Sci Technol 166–167:464–479

Vellinga TV, de Haan MHA, Schils RLM, Evers A, van den Pol–van Dasselaar A (2011) Implementation of GHG mitigation on intensive dairy farms: farmers' preferences and variation in cost effectiveness. Livest Sci 137:185–195

Vergé XPC, Dyer JA, Worth DE, Smith WN, Desjardins RL, McConkey BG (2012) A greenhouse gas and soil carbon model for estimating the carbon footprint of livestock production in Canada. Animals 2:437–454

Webb J, Menzi H, Pain BF, Misselbrook TH, Dammgen U, Hendriks H, Dohler H (2005) Managing ammonia emissions from livestock production in Europe. Environ Pollut 135(3):399–406

Weiske A, Vabitsch A, Olesen JE, Schelde K, Michel J, Friedrich R, Kaltschmitt M (2006) Mitigation of greenhouse gas emissions in European conventional and organic dairy farming. Agric Ecosyst Environ 112:221–232

Wheeler EF, Topper PA, Brandt RC, Brown NE, Adviento-Borbe A, Thomas RS, Varga GA (2011a) Multiple-chamber instrumentation development for comparing gas fluxes from biological materials. Appl Eng Agric 27(6):1049–1060

Wheeler EF, Adviento-Borbe MAA, Brandt RC, Topper PA, Topper DA, Elliott HA, Graves RE, Hristov AN, Ishler VA, Bruns MAV (2011b) Amendments for mitigation of dairy manure ammonia and greenhouse gas emissions: preliminary screening. Agric Eng Int: CIGR J 13(2):1–14

Wheeler EF, Adviento-Borbe MAA, Brandt RC, Topper PA, Topper DA, Elliott HA, Graves RE, Hristov AN, Ishler VA, Bruns MAV (2011c) Evaluation of odor emissions from amended dairy manure: preliminary screening. Agric Eng Int: CIGR J 13(2):15–29

Williams A (2003) Floating covers to reduce ammonia emissions from slurry. In: Proceedings of the international symposium on gaseous and odour emissions from animal production facilities, Horsens, Denmark, 1–4 June, pp 283–291

Wingsley P (2007) Biochar and bioenergy production for climate change mitigation. N Z Sci Rev 64:6–10

Yu L, Yaoqiu K, Ningsheng H, Wu Z, Xu L (2008) Popularizing household-scale biogas digesters for rural sustainable energy development and greenhouse gas mitigation. Renew Energy 33: 2027–2035

Zaks DPM, Winchester N, Kucharik CJ, Barford CC, Paltsev S, Reilly JM (2011) Contribution of anaerobic digesters to emissions mitigation and electricity generation under U.S. climate policy. Environ Sci Technol 45(16):6735–6742

Zervas G, Tsiplakou E (2012) An assessment of GHG emissions from small ruminants in comparison with GHG emissions from large ruminants and monogastric livestock. Atmos Environ 49:13–23

Zhang R, McGarvey JA, Ma Y, Mitloehner FM (2008) Effects of anaerobic digestion and aerobic treatment on the reduction of gaseous emissions from dairy manure storages. Int J Agric Biol Eng 1(2):15–20

21

Modelling of GHGs in Livestock Farms and Its Significance

Alicja Kolasa-Więcek

Abstract

The total global GHG emission from agriculture, considering all direct and indirect emissions, is between 17 % and 32 % of the total human-induced GHG emissions, including land use changes. It is estimated that livestock production is responsible for 15–24 % of GHG emissions. Cattle, pigs and poultry are the major world livestock, and European countries have one of the highest livestock densities in the world. The dairy cow and beef cattle sectors are the largest sources of agriculture GHG emissions, with CH_4 from enteric fermentation and N_2O from agricultural soils being the most important. However, agriculture could contribute significantly to GHG emission mitigation. In the EU, livestock farming contributes approximately 10 % of the total global GHG emissions. The European livestock sector is expected to remain dynamic in the forthcoming years. The possibility of predicting and modelling emissions from livestock farm GHGs is important due to the increasingly restrictive European standards. This chapter presents various modelling approaches to predict livestock's contribution to GHG emissions in the EU.

Keywords

DairyWise model • FarmGHG model • FarmSim model • IMAGE model • IMPACT model • LEITAP model • Livestock • MITERRA model • Modelling • SIMS-Dairy model

---

A. Kolasa-Więcek (✉)
Department of Economics, Finances and Regional Research, Faculty of Economy and Management,
Opole University of Technology,
Luboszycka 7, 45-036 Opole, Poland
e-mail: a.kolasa-wiecek@po.opole.pl

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_21,

21.1 Introduction

21.1.1 The Sources of Methane and Nitrous Oxide Emissions from Animal Production and Its Significance

The main greenhouse gas (GHG) emissions from agriculture are primarily direct emissions from crop and livestock production and those associated with land use changes. Indirect emissions from other sectors of the economy that are producing goods for agriculture are also significant. The main environmental pressures from agriculture are changes in land use and land cover, the CH_4 emission from ruminants and the emissions of reactive nitrogen (Stehfest et al. 2013).

The total global contribution of agriculture, considering all direct and indirect emissions, is between 8.5 and 16.5 Pg CO_2-eq., which represents between 17 % and 32 % of the global human-induced GHG emissions, including land use changes (Kolasa-Więcek 2012). It is estimated that livestock production is responsible for 15–24 % of greenhouse gas emissions – mainly methane (CH_4) and nitrous oxide (N_2O) (Steinfeld et al. 2006).

In the EU, livestock farming has an important effect on global warming by producing approximately 10 % of the total global GHG emissions (Lesschen et al. 2011). Digestive and excretion processes are responsible for the most relevant sources of GHG emission from livestock production. Animal manure is, apart from deforestation, the largest source of GHGs. Ruminant production of GHGs is considered in terms of both CH_4 and N_2O emissions and monogastric animals (pigs and poultry), mainly N_2O and NH_3 (Wall et al. 2008). Emissions from farms with ruminants are especially high due to CH_4 emissions from enteric fermentation and manure handling and because of the often intense nitrogen (N) cycling on such farms (Oenema et al. 1998; Olesen et al. 2006). Global livestock production accounts for about 80 % of global land use (Stehfest et al. 2013). Cattle are an important source of CH_4 because of their large population and high CH_4 emission rate due to their ruminant digestive system (Dong et al. 2006). Livestock production is responsible for 35–40 % of anthropogenic CH_4 emissions, mainly from ruminants (cows and goats) and to a lesser extent from monogastric animals. CH_4 is produced in a fermentation process by anaerobic methanogenic bacteria (Dong et al. 2006). Methane emissions also occur during decomposition of manure in open lagoons. In turn, approximately 29 % of emissions originate from manure management (Verburg et al. 2008). N_2O is an important pollutant because of the high global warming potential and its long retention in the stratosphere (Olivier et al 1998). In agriculture its emissions have intensified mainly due to the higher productivity of nitrification and denitrification processes in agricultural soils by escalating the use of nitrogen fertilisers. It is estimated that agriculture and rural areas are responsible for over 80 % of N_2O emissions.

Agricultural activity is a source of direct (use of nitrogen fertilisers, emissions of organic nitrogen in animal faeces, land management, sewage sludge storage) and indirect (evaporation of precipitation, surface runoff and nitrogen leaching into groundwater and surface water) emissions of N_2O. The main sources of N_2O are primarily emissions from chemical and natural fertilisers.

It has been estimated that 10–12 % of global greenhouse gas emissions caused by anthropogenic human activities comes from food production (International Trade Center 2007). However, the uncertainties in the emissions are large and so is the variation in time and space of fluxes from different sources. This makes the identification and implementation of effective measures to reduce emissions from agriculture difficult (Oenema et al. 1998).

GHG emissions from agriculture in the EU are presented in Fig. 21.1: (a) CH_4 emission from enteric fermentation and (b) CH_4 and N_2O emissions from manure management.

21.2 Animal Population in EU

The major populations of livestock in the EU over the last 50 years are presented in Fig. 21.2.

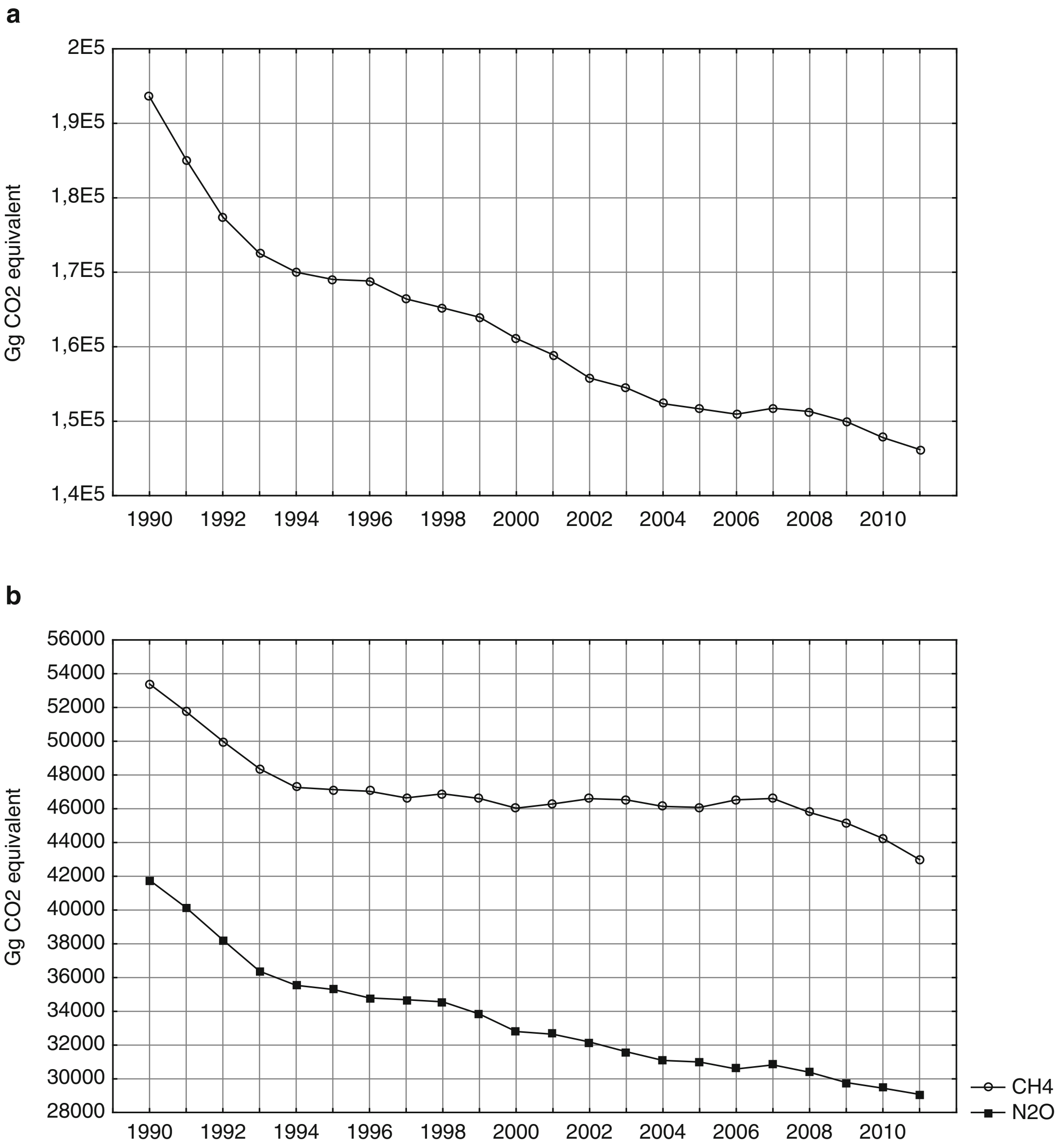


Fig. 21.1 GHG emissions from agriculture in the EU (Source: UNFCCC)

A particularly dynamic increase in livestock population is visible until the 1990s. Due to the number of policy instruments, mechanisms and regulations implemented in European agriculture, among others, through the European Common Agricultural Policy and the EU Nitrate and Water Framework Directives, livestock numbers have stabilised or reduced since the 1990s.

The downward trend in the population of ruminants – cattle and sheep – is noted. A dynamically rising cattle population significantly increased from 103 million animals in 1961 to 120 million animals in 1975 and reduced to 87 million by 2012. The sheep and goat population also dropped significantly from over 158 million animals in 1989 to around 111 million in 2012. During the observed years, the pig population increased

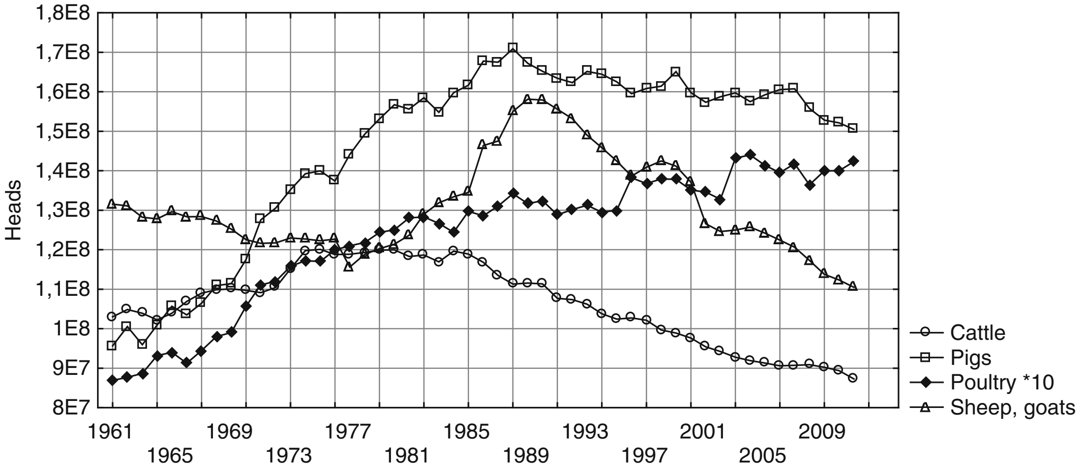


Fig. 21.2 Animal population in the EU between 1961 and 2012 (Source: FAO 2014)

rapidly – from 96 million in 1962 to 171 million in 1988, followed by a gradual reduction and stabilisation to 150 million in 2012. Poultry production has been growing steadily since 1961 and will overtake pig production by 2020.

The European livestock sector is expected to remain in flux in the forthcoming years, especially in regions that are currently characterised by high livestock densities. It is anticipated that there will be a decrease in livestock numbers within these regions over the coming years (Neumann et al. 2009).

Dynamic changes in animal management systems and the lack of systematic research into the percentage of livestock in particular areas (of high density) are common reasons for not including them in the calculation of GHG emissions. In many countries, the calculations of the variability of emissions resulting from the implementation of new technologies reducing GHG and ammonia emissions and intensification of animal husbandry are not taken into account.

On a global scale, CH_4 emissions from enteric fermentation are expected to increase 32 % by 2020, and the major sources will be China, Brazil, India, the USA and Pakistan (Rosegrant et al. 2008). A significant part of the released emissions arises from the natural life processes of animals. It is difficult to reduce these emissions other than by limiting the size of the population.

The possibility of predicting and modelling GHG emissions from livestock farms is important given the increasingly restrictive European standards. The importance is compounded by the increasing demand for animal products. This chapter presents various modelling approaches of livestock contributions to GHG emission in the EU.

The advantages of using prediction models among others are knowledge of the values of the explanatory variables in the forecast period, the simplicity of calculation, ease of extrapolation model for future periods and easiness of forecasting.

21.3 Modelling Approaches of GHGs on Livestock Farms in the EU

Potentially livestock production has negative effects on the environment by, among others, GHG emissions, expansion of agricultural land, deforestation and eutrophication of water. Studies conducted in the 27 member states of the EU (EU-27) indicate the existence of significant differences among farms in animal productivity and environmental performance and the associated GHG emissions.

Studies conducted with MITERRA-Europe model indicate the importance of livestock numbers. MITERRA-Europe model is an environmental assessment model calculating greenhouse gas emissions (CH_4, N_2O, CO_2) from agriculture in the EU-27. It takes into account emissions from enteric fermentation, manure management, direct and indirect N_2O soil emissions, fertiliser production and cultivation of organic soils, liming and fossil fuel use. The MITERRA-Europe model is partly based on the models GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) and CAPRI (Common Agricultural Policy Regionalised Impact), complemented with an N leaching module, a soil C module and a module for mitigation (Lesschen et al. 2011). The input data is obtained from databases from FAO and Eurostat, e.g. livestock numbers, crop areas, animal production and emission factors from IPCC and GAINS and spatial environmental data (e.g. soil and climate data). The highest GHG emissions in the EU come from dairy (195 Tg CO_2-eq.) and beef production (192 Tg CO_2-eq.). In the European livestock sector, the main source of GHG was enteric fermentation (36 %) followed by N_2O soil emissions (28 %). On a per kg product basis, beef had the highest GHG emission with 22.6 kg CO_2-eq./kg; dairy had 1.3 kg CO_2-eq./kg emission, pork production with 3.5 kg CO_2-eq./kg, poultry (meat) production with 1.6 kg CO_2-eq./kg and egg production with 1.7 kg CO_2-eq./kg. The modelling results indicated the existence of significant differences in greenhouse gas emissions per unit product in the EU countries. The reasons for this variation, inter alia, are differences in animal production systems, the type of feed used and nutrient use efficiencies. There is also a considerable uncertainty in the base data and methodology used, such as assumptions surrounding allocation of feedstuffs to livestock species (Lesschen et al. 2011).

As a result of the reforms of the European Common Agricultural Policy, the European livestock sector has changed quickly in recent years. Further changes are expected in the near future. Multi-scale modelling approach was used to determine spatial and temporal dynamics of livestock distribution by accounting for drivers at different spatial scales. The model can provide a basis for assessing the environmental impact of livestock farming in a wide spatial scale. The assessment was carried out for six types of animals. Four contrasting scenarios are presented: globalisation to regionalisation, low level of regulation and the dominance of market mechanisms to a higher degree of governmental regulation. The results indicate that in most of the old member states of the EU, a decrease in the number of livestock is expected. In the new EU member states, an increase in cattle, pigs and poultry and a decline in sheep and goats are projected. It is expected that there will be an increase in livestock density both within and outside the current livestock 'hotspot regions' in the absence of legislation.

Environmental pressure as a consequence of high livestock densities is also possible to stay in regulated scenarios where environmental policies are applied and income support continues to be stable over time on account of path dependencies in the livestock sector. But in opposition to the nonregulated scenario, it is less probable that new areas with high risk of negative environmental influences owing to livestock farming will make grow.

Another model simulating GHG emissions is IMAGE (Integrated Model to Assess the Global Environment). It is a global ecological-environmental model for the study of the long-term environmental effects of human activities. IMAGE imitates the GHG emissions based on regional production of food, animal products and timber and also takes into account local climatic conditions and terrain. IMAGE simulates the changes in land cover (Neumann et al. 2011; Kram and Stehfest 2006). The model simulates how many animals are needed to and how much feed they need. IMAGE output is based on regional conditions, such as livestock demand for feed and grass, and calculates the required area of grassland (Bouwman et al. 2005; Neumann et al. 2011).

Changes in the number of animals at the national level were determined using the LEITAP model. The LEITAP model is based on the GTAP model (Hertel 1997). It is a multiregional, multisectorial, static, applied general equilibrium model based on a neoclassical microeconomic theory. With the use of this model, the demand for livestock numbers and agricultural land was calculated for European countries for 2010, 2020 and 2030 (Neumann et al. 2011). LEITAP contains international and European agricultural policies in detail.

In view of the growing demand for meat and animal products, economic models were used in other studies which allowed testing various options for reducing the agriculture impact on the environment. Some of the options explored were changes in diet, increased production efficiency and limiting of food wastage. Two models (IMPACT and the mentioned LEITAP) were both used to integrate with model IMAGE. These are used in studies taking into account capabilities for the reduction of poverty and natural resources protection (Rosegrant et al. 1995). Model IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) enables researchers to define the relationships between the demand for food, food production, resource availability, commodity prices, trade and food safety in different spatial scales and time horizons.

The outputs from these models showed reductions in agricultural land use and greenhouse gas emissions, as well as in agricultural commodity prices (Stehfest et al. 2013). The model performance proves that for most alternatives fewer gains were obtained than the theoretical environmental gains owing to price feedbacks contributing to increased consumption and less intensive production. Furthermore, the effects were larger than expected because of decreased consumption in Europe.

Dairy cattle and beef are in terms of quantity of output and economic value extremely important to the EU (Neumann et al. 2011). Dairy farms are the largest sources of GHG emissions in EU-27 directly followed by the beef sector (Lesschen et al. 2011). For dairy farm systems in Europe, the models presented above simulate the internal and external flows of materials and nutrients and calculate the associated GHG emissions. The whole-farm approach, established in these models, guarantees that the interactions between the relevant themes are considered. The impact of changes in one component of the farm is not limited to a specific subsystem, but they are carried by the entire farm system (Schils et al. 2007a).

For estimating GHG emissions from dairy farms in the EU, a model (FarmGHG) was created. The model estimates CH_4 and N_2O emissions released during farm management and CO_2, CH_4 and N_2O emissions resulting from imported energy, feed, fertiliser, etc. It is commonly used to estimate N_2O emissions and is based on the more complex algorithms for CH_4 emissions from enteric fermentation and manure management. The model was proposed as a chance to reduce emissions of GHGs through the quantification of effects of management practices. Five European agro-ecological zones for both organic and conventional systems were considered. Studies indicate that reducing greenhouse gas emissions from agricultural production can be achieved by increasing the N use efficiency of agricultural sector (Olesen et al. 2006).

Other studies showed that the emission of CH_4 from fermentation is affected by diet composition and cannot be entirely eliminated without adverse effects on the production of ruminants (Moss et al. 2000) because CH_4 is the final product of fermentation in the rumen (Petersen et al. 2007). Modelling has shown that an increase in feed consumption reduced CH_4 emissions (Danfær and Weisbjerg 2006). Emissions were also lower when feed quality improved. It was also shown that the emission of CH_4 can be reduced by increasing the fat content and by increasing starch at the expense of sugar in the diet.

A model which simulates GHG emissions from dairy farms is DairyWise. This is an empirical model which integrates all major subsystems of a dairy farm into one whole-farm model. The model inputs include general farm management, herd type, cropping plan, soil characteristics, grass and feed management, buildings and equipment (Schils et al. 2007a). DairyWise calculates CH4 emission from enteric fermentation with emission factors expressed as on the basis of kg DM uptake. Emissions from manure management are calculated from stored manure and slurry excreted during grazing. DairyWise simulates direct and indirect N_2O emissions, connected with later denitrification of leached nitrate. Direct emissions are simulated with emission factors for N inputs through fertilisers, manure application, biological fixation, urine excreted during grazing, crop residues and peat oxidation.

The module calculates an additional N_2O emission when grassland is ploughed. The indirect N_2O emissions are calculated with emission factors from the modelled nitrate and ammonia emissions (Schils et al. 2007b).

The model of Sustainable and Integrated Management Systems for Dairy Production (SIMS-Dairy) simulates through 'score matrices' sustainability farm attributes of biodiversity, landscape, product quality, soil quality and animal welfare (del Prado et al. 2006). The model concentrates on the strategic and tactical levels of management and is able to optimise dairy management factors in order to find a more sustainable system (del Prado and Scholefield 2006). The model is capable among others to explore the possible impact of mitigation options on pollutants such as CH_4, N_2O, NH_3, NO_x, NO_3 and P. The simulation of farm GHG losses includes those emissions from the soil (as N_2O), those emissions from animal excreta as manure or urine and dung deposited during grazing (as N_2O and CH_4) and those emissions from the rumen (as CH4) (Schils et al. 2007b).

The FarmSim model (FARM SIMulation) simulates GHG emissions taking into account nine interacting modules (Saletes et al. 2004). FarmSim contains import, export and internal product flows between the various components of the farm system. The model includes the PASIM model (GHGs exchanged over the different grassland types on the farm) and integrates the IPCC methodology Tier 1 and Tier 2 (emissions from croplands and cattle housing). Many details are used as inputs: farm structure (area and type of crops and of grasslands, herd types), the herd (number of animals per type), the grasslands (grazing and cutting dates, stocking rates, organic and inorganic fertiliser applications), the crops and the feeding and waste management systems (Schils et al. 2007b). A general overview of above-mentioned models is presented in Table 21.1.

Table 21.1 Overview of models

Model	General characteristics
MITERRA-Europe	The MITERRA-Europe is a tool for integrated assessment of N emissions from agriculture on EU-27 level. The effects of N measures and policies can be quantitatively assessed and both ancillary benefits and trade-off of measures and policies can be identified
IMAGE	The model was designed to simulate the dynamics and interconnections between three major subsystems of the globe, namely, climate, biosphere and society
LEITAP	Computable general equilibrium model, covering all economic sectors, although at different levels of detail
IMPACT	The model was designed to examine alternative futures for global food supply, demand, trade, prices and food security. Model provides both fundamental, global baseline projections of agricultural commodity supply, demand, trade, prices and malnutrition outcomes along with cutting-edge research results on quickly evolving topics such as bioenergy, climate change, changing diet/food preferences and many other themes
FarmGHG	The FarmGHG is a model of carbon (C) and N flows on dairy farms. The model includes N balance and allows calculation of environmental effect balances for greenhouse gas emissions (CO_2, CH_4 and N_2O) and eutrophication (nitrate and NH_3)
DairyWise	The DairyWise is an existing empirical model integrating all major subsystems of a dairy farm into one whole-farm model. The central component is the FeedSupply model that balanced the herd requirements, as generated by the DairyHerd model, and the supply of homegrown feeds, as generated by the crop models for grassland and corn silage
SIMS-Dairy	The SIMS-Dairy modelling framework at the farm level, which integrates existing models for N and P and equations to simulate NH_3 losses from manure application and predict CH_3 losses and cows' nutrient requirements, uses 'score matrices' for measuring attributes of biodiversity, landscape aesthetics, product quality, soil quality and animal welfare and an economic model
FarmSim	The model was designed for projecting the probable economic and nutritional impacts of alternative technologies, farming systems, livestock management programmes, marketing arrangements, crop mixes, risk management schemes and environmental remediation programmes on a representative crop/livestock farm

21.4 Conclusion

Expansion of livestock production worldwide will continue to contribute GHG emissions. Cattle, pigs and poultry are the major world livestock, and the EU has one of the highest livestock densities in the world. In animal production, the dairy and beef sectors are the largest sources of GHG emissions due to CH_4 being produced from enteric fermentation and N_2O production from agricultural soils.

Especially important are the increasing environmental concerns and changing consumer awareness. In order to mitigate the agriculture impact particularly on livestock sector, many mechanisms and institutional policy instruments are able to be adopted.

Various models are used to assess the technical, environmental and financial implications of alternative farm management strategies, under changing external conditions. Based on model results, future development pathways towards more sustainable animal production are possible.

References

Bouwman AF, Hoek KW, Eickhout B, Soenario I (2005) Exploring changes in world ruminant production systems. Agr Syst 84:121–153. doi:10.1016/j.agsy2004.05.006

Danfær A, Weisbjerg MR (2006) Modelling methane emission from dairy cows. In: Petersen SO (ed) 12th Ramiran International Conference. Technology for recycling of manure and organic residues in a whole farm perspective, vol I. Danish Institute of Agricultural Sciences, pp 79–82 (DIAS Report No. 122)

del Prado A, Scholefield D (2006) Use of SIMS dairy model ling framework system to specify sustainable UK dairy farms. In: Delivering sustainability within profitable farming systems: is it possible? Aspects of applied biology, vol 80. Studley Castle, Warwickshire

del Prado A, Scholefield D, Chadwick D, Misselbrook T, Haygarth P, Hopkins A, Dewhurst R, Davison P, Lord E, Turner M, Aikman P, Schröder J (2006) A modelling framework to identify new integrated dairy production systems. EGF: 21st General Meeting on Sustainable Grassland Productivity, Badajoz

Dong H, Mangino J, McAllister TA, Hatfield JL, Johnson DE, Lassey KR, Aparecida de Lima M, Romanovskaya A (2006) IPCC guidelines for National greenhouse gas inventors, vol 4: Agriculture, forestry and other land use. Chapter 10: Emissions from livestock and manure management

Food and Agriculture Organization of the United Nations. http://faostat.fao.org/site/573/DesktopDefault.aspx?PageID=573#ancor. Accessed 11 Mar 2014

Hertel T (1997) Global trade analysis: modeling and applications. Cambridge University Press, Cambridge

International Trade Center UNCTAD/WTO (2007) Organic farming and climate change, research institute of organic agriculture (FiBL). ITC, Geneva, Doc No MDS-08-152.E, 27

Kolasa-Więcek A (2012) Forecasting CO_2 emissions from agriculture and relationship with some variables in OECD countries. Annu Set Environ Prot 14:202–213. http://old.ros.edu.pl/text/pp_2012_013.pdf. Accessed 21 Mar 2014

Kram T, Stehfest E (2006) The IMAGE model: history, current status and prospects. In: Bouwman AF, Kram T, Goldewijk KK (eds) Integrated modelling of global environmental change. Netherlands Environmental Agency, Bilthoven

Lesschen JP, van den Bergb M, Westhoekb HJ, Witzkec HP, Oenema O (2011) Greenhouse gas emission profiles of European livestock sectors. Anim Feed Sci Technol 166–167:16–28. doi:10.1016/j.scitotenv.2013.04.058

Moss A, Jouany JP, Newbold J (2000) Methane production by ruminants: its contribution to global warming. Ann Zootech 49:231–253. doi:10.1051/animres:2000119

Neumann K, Elbersen DS, Verburg PH, Staritsky I, Pérez-Soba M, de Vries W, Rienks WA (2009) Modelling the spatial distribution of livestock in Europe. Landsc Ecol 24:1207–1222. doi:10.1007/s10980-009-9357-5

Neumann K, Verburg PH, Elbersen B, Stehfest E, Woltjer GB (2011) Multi-scale scenarios of spatial-temporal dynamics in the European livestock sector. Agr Ecosyst Environ 140:88–101. doi:10.1016/j.agee.2010.11.01

Oenema O, Gebauer G, Rodriguez M, Sapek A, Jarvis SC, Corre WJ, Yamulki S (1998) Controlling nitrous oxide emissions from grassland livestock production systems. Nutr Cycl Agroecosyst 52:141–149. doi:10.1023/A:1009732226587

Olesen JE, Schelde K, Weiske A, Weisbjerg MR, Asman WAH, Djurhuus J (2006) Modelling greenhouse gas emissions from European conventional and organic dairy farms. Agr Ecosyst Environ 112:207–220. doi:10.1016/j.agee.2005.08.022

Olivier JGJ, Bouwman AF, Van der Hoek KW, Berdowski JJM (1998) Global air emission inventories for anthropogenic sources for NO_x, NH_3 and N_2O in 1990. In: Van der Hoek KW et al (eds) Nitrogen, the confer-N-s. First International Nitrogen Conference 1990. Elsevier, Amsterdam

Petersen SO, Sommer SG, Béline F, Burton C, Dach J, Dourmad JY, Leip A, Misselbrook T, Nicholson F, Poulsen HD, Provolo G, Sorensen P, Vinneras B, Weiske A, Bernal MP, Bohm R, Juhasz C, Mihelic R

(2007) Recycling of livestock manure in a whole-farm perspective. Livest Sci 112:180–191

Rosegrant MW, Agcaoili-Sombilla MC, Perez N (1995) Global food projections to 2020: implications investment, 2020 vision discussion paper. International Food Policy Research Institute, Washington, DC

Rosegrant MW, Ewing M, Yohe G, Burton I, Huq S, Valmonte-Santos R (2008) Climate change and agriculture, threats and opportunities. Deutsche Gesellschaft für Technische Zusammenarbeit GmbH Climate Protection Programme for Developing Countries, Eschborn

Saletes S, Fiorelli J, Vuichard N, Cambou J, Olesen JE, Hacala S, Sutton M, Fuhrer J, Soussana JF (2004) Greenhouse gas balance of cattle breeding farms and assessment of mitigation options. In: Kaltschmitt M, Weiske A (eds) Greenhouse gas emissions from agriculture. Mitigation options and strategies. Institute for Energy and Environment, Leipzig

Schils RLM, Olesen JE, del Prado A, Soussana JF (2007a) A review of farm level modelling approaches for mitigating greenhouse gas emissions from ruminant livestock systems. Livest Sci 112:240–251. doi:10.1016/j.livsci.2007.09.005

Schils RLM, de Haan MHA, Hemmer JGA, van den Pol-van Dasselaar A, de Boer JA, Evers AG, Holshof G, van Middelkoop JC, Zom RLG (2007b) DairyWise, a whole-farm dairy model. J Dairy Sci 90(11):5334–5346. doi:10.3168/jds.2006-842

Stehfest E, van den Berg M, Woltjer G, Msangi S, Westhoek H (2013) Options to reduce the environmental effects of livestock production – comparison of two economic models. Agr Syst 114:38–53. doi:10.1016/j.agsy.2012.07.002

Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (2006) Livestock's long shadow: environmental issues and options. FAO, Rome

United Nations Framework Convention on Climate Change. http://unfccc.int/di/DetailedByGas/Event.do?event=go. Accessed 11 Mar 2014

van Meijl H, van Rheenen T, Tabeau A, Eickhout B (2006) The impact of different policy environments on agricultural land use in Europe. Agric Ecosyst Environ 114:21–38. doi:10.1016/j. landusepol.2005.09.009

Verburg R, Woltjer G, Tabeau A, Eickhout B, Stehfest E (2008) Agricultural trade liberalisation and greenhouse gas emissions. A simulation study using the GTAP-IMAGE modelling Framework, Report 3.08.02 LEI. Hague

Wall E, Bell MJ, Simm G (2008) Developing breeding schemes to assist mitigation. In: Rowlinson P, Steele M, Nefzaoui A (eds) Livestock and global climate change, proceedings international conference. Cambridge University Press, Cambridge

Part V

Adaptation Strategies to Improve Livestock Production Under Changing Climate

22

Overview on Adaptation, Mitigation and Amelioration Strategies to Improve Livestock Production Under the Changing Climatic Scenario

Veerasamy Sejian, L. Samal, N. Haque, M. Bagath, Iqbal Hyder, V.P. Maurya, Raghavendra Bhatta, J.P. Ravindra, Cadaba S. Prasad, and Rattan Lal

Abstract

Livestock production is thought to be adversely affected by detrimental effects of extreme climatic conditions. Consequently, adaptation, mitigation and amelioration of detrimental effects of extreme climates have played a major role in combating the climatic impact in livestock production. While measures to reduce the growth of greenhouse gas emissions are an important response to the threat of climate change, adaptation to climate change will also form a necessary part of the response. The salient adaptation strategies are developing less sensitive breeds, improving water availability, improving animal health, promoting women empowerment, developing various policy issues, establishing early warning systems and developing suitable capacity building programmes for different stakeholders. Developing adaptation strategies is therefore an important part of ensuring that countries are

---

V. Sejian (✉) • J.P. Ravindra
Animal Physiology Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Hosur Road, Bangalore, Karnataka 560030, India
e-mail: drsejian@gmail.com

L. Samal
College of Agriculture, Odisha University of Agriculture and Technology, Arkabali Farm, Raipur Road, Bhawanipatna 766001, Odisha, India

N. Haque
Department of Physiology and Biochemistry, College of Veterinary and Animal Husbandary, Sardarkrushinagar Dantiwada Agriculture University, Dantiwada, Gujarat 385506, India

M. Bagath
Animal Nutrition Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Hosur Road, Bangalore, Karnataka 560030, India

I. Hyder
Department of Veterinary Physiology, NTR College of Veterinary Science, Gannavaram 521102, Andhra Pradesh, India

V.P. Maurya
Division of Physiology and Climatology, ICAR-Indian Veterinary Research Institute, Izatnagar, Bareilly 243122, Uttar Pradesh, India

R. Bhatta • C.S. Prasad
ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Hosur Road, Bangalore, Karnataka 560030, India

R. Lal
Carbon Management and Sequestration Center, School of Environment and Natural Resources, The Ohio State University, Columbus, OH 43210, USA

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_22, © Springer India 2015

well prepared to deal with any negative impacts that may occur as a result of climate change. The integration of new technologies into the research and technology transfer systems potentially offers many opportunities to further the development of climate change adaptation strategies. Adapting to climate change and reducing GHG emissions may require significant changes in production technology and farming systems that could affect productivity. Many viable opportunities exist for reducing CH_4 emissions from enteric fermentation in ruminant animals and from livestock manure management facilities. To be considered viable, these emission reduction strategies must be consistent with the continued economic viability of the producer and must accommodate cultural factors that affect livestock ownership and management. This chapter also elaborates on ameliorative strategies that should be given consideration to prevent economic losses incurred due to environmental stresses on livestock productivity. Reducing the impact of climatic stresses on livestock production requires multidisciplinary approaches which emphasise animal nutrition, housing and animal health. Therefore, emphasis should be given to all three aspects of adaptation, mitigation and amelioration strategies to sustain livestock production under the changing climate scenario.

Keywords
Adaptation • Amelioration • Climate change • Livestock and mitigation

22.1 Introduction

While there is still much uncertainty surrounding the potential magnitude and likely impacts of climate change (CC), there is consensus in the global scientific community that some CC is already occurring and that further change is inevitable (IPCC 2013; Quere et al. 2014). CC is evident in both a change in average temperature and rainfall and changes in the frequency and severity of extreme weather events, such as frosts, heatwaves, droughts and flood (IPCC 2001). It is considered likely that continued greenhouse gas emissions at or above current rates will result in further global warming in this century (WMO 2014). Moreover, even if the atmospheric concentrations of all greenhouse gases and aerosols are stabilised at 2,000 levels, global temperatures are projected to continue rising (IPCC 2007).

While measures to reduce the growth of greenhouse gas emissions are an important response to the threat of CC, adaptation to CC will also form a necessary part of the response (Gerber et al. 2013). In this context, adaptation refers to strategies that act to reduce the adverse impacts of CC. Developing adaptation strategies is therefore an important part of ensuring that countries are well prepared to deal with any negative impacts that may occur as a result of CC. Given limited resources, adaptation strategies must target those populations most vulnerable to global change and equip those unable to adapt—generally the poorest—with the tools and incentives that will enable them to do so. Adaptation to climate variability has been an ongoing necessity for the agricultural sector. Existing strategies to manage climate variability present opportunities for meeting the challenges of future CC. Reducing the impact of CC on livestock requires a multidisciplinary approach with emphasis on animal nutrition, housing and animal health. It is important to understand the livestock responses to environment and analyse them in order to design modifications of nutritional and environmental management thereby improving animal comfort and performance. So a range of technologies are needed to match the different economic and other needs of livestock farmers. It is therefore important that we gear up all efforts to enhance the resilience of the farms and livestock through dissemination—adoption of various coping strategies and mechanisms so that the production and productivity levels of the farm and livestock are maintained even in challenging climatic conditions. While efforts are on to prevent further CC through livestock sectors by developing suitable mitigation strategies, equally important is to reduce the impact of already occurred CC on livestock population by developing suitable amelioration strategies. These consorted efforts need to be implemented simultaneously if we intend to sustain livestock production under the changing climate scenario. This chapter will address the salient adaptation, mitigation and amelioration strategies available to improve livestock production under CC perspectives.

22.2 Climate Change Affecting Livestock Economy

Several studies have shown significant and alarming negative impacts of CC and adaptation of livestock farmers in different parts of the world (Deressa et al. 2005; Kabubo-Mariara 2007). Various research findings indicate that the damaging effects of global temperature are increasing, and most damages are predicted to occur in the region already faced average high temperatures and low precipitation, frequent droughts and scarcity of both ground and surface water (IPCC 2001). Previous studies on CC and adaptation of livestock farmers have shown that CC affects livestock farming directly and indirectly (Kabubo-Mariara 2008). Direct effects have been observed to include retardation of animal growth, low-quality animal products including hides and skins and animal production in general. Indirect effects include general decline in quantity and quality of feedstuffs, for example, pasture, forage, grain severity and distribution of different species of livestock, and other effects such as increase in livestock diseases and pests. In particular, extreme temperatures resulting in drought have had devastating effects on livestock farming, and the vulnerable rural poor have been left with marginal pasture and grazing lands (Kabubo-Mariara 2005). The impacts of CC not only influence natural systems, habitats and species but also human economy and society. Therefore, governments must act in time to adapt to these changes in order to reduce damage in both natural and social systems and in this way avoid unnecessary costs associated with late action.

22.3 Significance of Understanding the Impact of Climate Change on Livestock Production

Potential direct and indirect impacts of CC on livestock production have not been thoroughly explored. Changes in crop availability and quality, which have been the primary focus of previous studies, affect animal production through changes in feed supplies. Analyses of direct impacts of CC on livestock production are few. Changes in climate would directly lead to reductions in summer-season milk production and conception rates in dairy cows. Because voluntary feed intake (VFI) is the primary factor influencing the production capacity of livestock, accurate prediction of the feed consumption of livestock under heat stress is a precursor to accurate assessment of changes in production resulting from changes to a warmer climate. Quantification of potential impacts of CC on livestock production allows producers to gain a better understanding of the magnitude of the changes in production levels faced under CC. Projected economic losses resulting from temperature-induced reductions in production may justify mitigation of these temperature increases through changes in management practices, such as installation of shades or sprinklers in feedlots or evaporative cooling of barns.

CC represents one of the greatest environmental, social and economic threats facing the planet today. In developing countries, CC will have a significant impact on the livelihood and living conditions of the poor. Increasing temperatures and shifting rain patterns reduce access to food and create effects that impact regions, farming systems, households and individuals in varying ways. Additional global changes, including changed trade patterns and energy policies, have the potential to exacerbate the negative effects of CC on some of these systems and groups. Thus, analyses of the biophysical and socioeconomic factors that determine exposure, adaptation and the capacity to adapt to CC are urgently needed so that policymakers can make more informed decisions.

22.4 Salient Adaptation Strategies for Livestock to Cope Up to Changing Climate

Table 22.1 describes the various adaptation strategies for livestock sector to counter the impact of climate change. Effective adaptation to climate variability and climate change is dependent on access to climate information for the coming seasons and years, to enable communities to make decisions for now and the future. Flexible planning in the face of a continuously changing climate—a key element of adaptive capacity—needs to be informed by climate forecasts and the effects of uncertainties and risks on different vulnerable groups and socio-economic sectors, so as to identify a range of response options. Scenario development of how livelihoods and sectors would be affected by probable climate futures contributes to making livelihoods more climate resilient and can be a first step towards mitigating the effects of climate-related disasters on communities. Figure 22.1 describes the different adaptation, mitigation and amelioration strategies to sustain livestock production under the changing climate scenario.

Table 22.1 Livestock adaptation strategies under ensuing CC scenario

Parameters for livestock adaptation	Respective livestock adaptation strategies
Production adjustments	Change in quantity and timing of precipitation
Breeding strategies	1. Identifying and strengthening local breeds that have adapted to local climatic stress and feed sources
	2. Improving local genetics through cross-breeding with heat and disease-tolerant breeds
Market responses	1. For example, promotion of interregional trade and credit schemes
Institutional and policy changes	1. Removing or introducing subsidies, insurance systems
	2. Income diversification practices
	3. Livestock early warning systems
Science and technology development	1. Understanding of the impacts of CC on livestock
	2. Developing new breeds and genetic types
	3. Improving animal health
	4. Enhancing soil and water manage
Capacity building for livestock keepers	1. Understanding and awareness of CC
	2. Training in agroecological technologies and practices
Livestock management systems	1. Provision of shade and water to reduce heat stress from increased temperature
	2. Reduction of livestock numbers in some cases
	3. Changes in livestock/herd composition
	4. Improved management of water resources

22.4.1 Genetic Development of Less Sensitive Breeds

Genetic improvement is an evolutionary action; evolution should be defined as a continuous process of adaptation of the populations of organisms to the ever-changing geological, biological and climatic conditions. Because of the almost infinite number of combinations of environmental factors, organisms must have a great variety of genetic types that can deal with a range of climatic, nutritional or other conditions. In a word, any population must be genetically heterogeneous—i.e. with a great genetic diversity—in order to be able to survive under the challenge of the changing environment. This is the basis for the livestock genetic improvement. Genetic selection

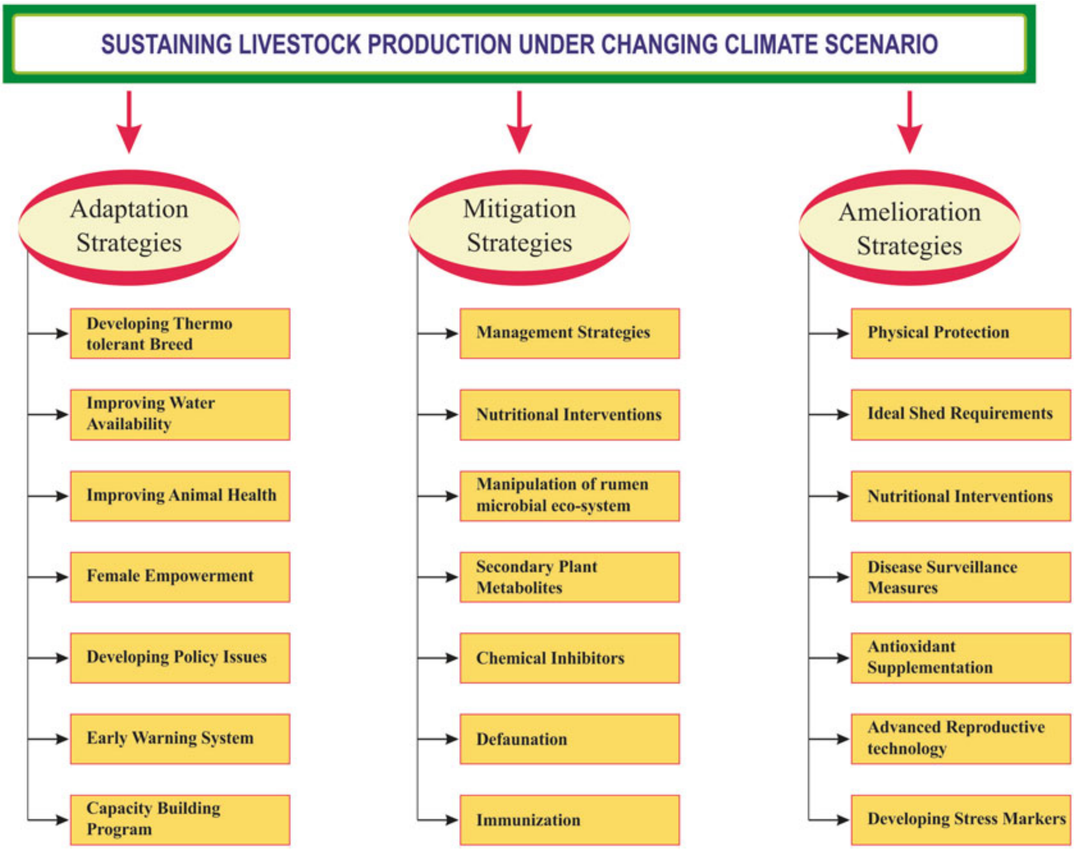


Fig. 22.1 Strategies to sustain livestock production under changing climate scenario

has been a traditional method to reduce effects of environment on livestock by development of animals that are genetically adapted to hot climates. There are additional possibilities for meeting this goal. Identification of specific genes that control traits related to thermotolerance makes it possible to select for thermal resistance without inadvertently selecting against milk yield. Possibly, there are also genes controlling cellular resistance to heat shock. Integration of marker-assisted selection into animal breeding systems should make selection for traits conferring thermotolerance more rapid. Functional genomics research is providing new knowledge about the impact of heat stress on livestock production and reproduction. Using functional genomics to identify genes that are up- or downregulated during a stressful event can lead to the identification of animals that are genetically superior for coping with stress and towards the creation of therapeutic drugs and treatments that target affected genes.

There is genetic variation among animals for cooling capability, which suggests that more heat-tolerant animals can be selected genetically. In spite of livestock being reared in tropical environment, there are local indigenous breeds of livestock which can effectively perform countering environmental extremes. These local breeds can perform well in adverse climatic condition like high temperature, drought and feed scarcity. Therefore, even under the changed climate scenario, the rich animal germplasm available may help to sustain the livestock productivity. Crossbreeding offers another opportunity. However, extensive cross-breeding studies have shown little heterosis for heat tolerance. Additional studies are needed to examine variability in heat tolerance of high yielding animals. Possibly improved herds could be developed when selected for milk yield and heat tolerance under local conditions.

In addition, there is a need to take up breeding programmes to develop CC-ready breed which performs better under stress due to climatic variability by using available rich germplasm. The recent advancement in global expression technologies (whole-genome arrays, RNA sequencing) is poised to be effectively utilised to identify those genes that are involved in key regulatory/metabolic pathway for thermal resistance and thermal sensitivity. Gene knockout technology will also allow better delineation of cellular metabolic mechanism required for acclimatisation to thermal stress in sheep and goat. By knowing the various genes responsible for thermotolerance, we can change the genetic structure of animal and drift towards superior thermotolerant ability.

22.4.2 Improving Water Availability

Water scarcity has become globally significant over the last 40 years or so and is an accelerating condition for one to two billion people worldwide (MEA 2005). Water and its availability and quality will be the main pressures on, and issues for, societies and the environment under CC (Wilk and Wittgren 2009). Nomadic people migrate seasonally to find water and grazing for their herds. Since ancient times, agricultural civilisations have invented techniques for water storage, transfer and irrigation (Wilk and Wittgren 2009). In general terms, the projected impacts of CC on water resources are a continuation of the impacts that have already been observed. At the same time, there are uncertainties of various magnitudes associated with the projections. The findings of several global models should be examined to reduce this uncertainty, especially in regard to regional or local effects (Wilk and Wittgren 2009; Thornton and Herrero 2010).

As more and more stresses are placed on our natural resources through effects of CC, a renewed use of water harvesting would have positive outcomes (Masike 2007). Water harvesting is a technique of developing surface water resources that can be used in dry regions to provide water for livestock, for domestic use, and for agroforestry and small-scale subsistence farming (Thames and Cluff 1982). Water harvesting offers a method of effectively developing the scarce water resources of arid regions. It is also a relatively inexpensive method of water supply that can be adapted to the resources and needs of the rural poor. A successful harvesting system must be (a) technically sound, properly designed and maintained, (b) economically feasible for the resources of the user and (c) capable of being integrated into the social traditions and abilities of the users.

The simplest technique is to use water-ponding dikes which slow down surface runoff, allow infiltration and increase soil moisture, and promote significant vegetation growth for habitat cover and forage. The advantages of water-ponding dikes are that they are simple to install and cost-effective and make use of water that would be lost to evaporation. The use of stock tanks as water sources on rangeland for cattle grazing is a traditional method that has one of the least expensive construction costs among a variety of possible methods. In arid regions, it places reliance on trapping surface runoff that will otherwise be lost back into the atmosphere through evaporation. By confining this surface runoff in a pond with small surface area and water depth of up to 2 m, evaporation and infiltration losses are both reduced over what would normally occur if the water was spread out and infiltrated into a stream bed.

The principles of integrated water resources management (IWRM) should be promoted and guide climate adaptation strategies. IWRM provides a useful framework for planning well-coordinated and targeted adaptation measures to CC. It is a systematic process to the sustainable development and equitable allocation of water resources through a holistic approach to water management. Successful IWRM strategies include, among others, capturing societal views, reshaping planning processes, coordinating land and water resources management, recognising water quantity and quality linkages, combining the use of surface water and groundwater, protecting and restoring natural systems, addressing impediments to the flow of information, and considering CC (Wilk and Wittgren 2009).

National adaptation programmes for action need to be integrated with other national development plans and adopt a river basin perspective, including transboundary cooperation in cases of multinational rivers. The local level is crucial in climate adaptation, and institutional reforms must be crafted accordingly. Mechanisms should be put in place to make sure that adaptation efforts respect, protect and promote fundamental human rights. Fresh and flexible funding should be found to speed up investment in water management of vulnerable developing countries, in particular the least developed countries, to meet both the present Millennium Development Goals and the consequences of observed and projected CC.

22.4.3 Improving Animal Health

As a result of globalisation and CC, the world is currently facing an unprecedented increase of emerging and re-emerging animal diseases and zoonoses (animal diseases transmissible to humans). A changing climate will cause changes in the patterns of endemic diseases in livestock. Indeed, a better understanding of the effect of CC on animal health and production is crucial and good for recommendations on how to lessen its potential impact. Unfortunately, the determinants of resilience and adaptation that already reduce this impact are often poorly understood even though they are not unique but are needed regardless. For example, adaptive capacity could be increased in the broader context of developing appropriate policy measures and institutional support to help the livestock owners to cope with all animal health problems. In fact, the development of an effective and sustainable animal health service, with associated surveillance and emergency preparedness systems and sustainable animal disease control and prevention programmes, is perhaps the most important and most needed adaptive strategy. This will safeguard livestock populations from the threats of CC and climate variability.

Improving the governance of animal health systems in both the public and private sector is the most effective response to this alarming situation. The recently experienced animal disease crises have provided a clearer understanding of the benefits to the international community of applying the appropriate animal health policies and programme in order to safeguard public health and ensure food safety.

The animal health service of FAO addresses four animal health-related issues: transboundary diseases, vectorial diseases, veterinary public health (including food safety) and veterinary services. The latter must join forces and encourage the more active participation of the private sector defining complementary roles for each with specific responsibilities in order to improve and/or maintain the overall sanitary status of a country. The following points are very valuable if one considers tackling disease outbreaks that arise as a result of CC:

(a) Improved monitoring and surveillance are required to detect changing patterns of diseases and to respond accordingly.
(b) Improved diagnosis, forecasting and effective vaccines to protect our livestock from this increasing threat of disease.
(c) Combine hazard maps with vulnerability maps for better prioritisation of areas/populations for interventions.
(d) Development of ideal decision support frameworks involving development of risk maps for targeted surveillance and development of prediction models for outbreaks.
(e) Institutional measures need to be sensitised for disease surveillance, and integration of experts of climate and health working groups needs to be prioritised for developing disease control technologies.
(f) Potential interventions are needed in developing livestock value chain involving

development of diversified livelihood options and safety nets comprising insurance schemes.

(g) Understanding in depth the epidemiology of important disease-causing pathogens and diagnostics should be interfaced with very sophisticated geographic information system technology and both statistically and process-based modelling approaches to produce risk maps for disease at an appropriate temporo-spatial scale (e.g. Bergquist and Rinaldi 2010; Fox et al. 2012).

(h) Validate models and quantify trends, through improved surveillance, ideally active rather than passive, of animal health disease issues, whether exotic or endemic. This places a requirement on improved diagnostic capabilities, with the potential to be rapid, high-throughput and cost-effective at an appropriate regional/national/international scale (Skuce et al. 2013).

(i) In the context of the endoparasites and ectoparasites specifically, vaccines to protect animals from infection, although not a complete solution, would be highly desirable. However, development of such vaccines has proven to be extremely technically demanding for a number of reasons (e.g. Vercruysse et al. 2007).

22.4.4 Female Empowerment

Division of rights and responsibilities affects incentives and ability to adopt new technologies and practices to increase production and productivity. We need to understand this better to develop appropriate technologies and design more effective interventions. In recent years, there have been increasing concerns about CC and its impacts on food security and on human lives. While much of the earlier discussions on CC centred on scientific and technical aspects such as greenhouse gas emissions, ozone depletion and environmental impacts of global warming, attention is now increasingly encompassing the economic and social aspects of CC. Women and the poor are likely to be most affected by CC. The constraints they face in crop-livestock systems are not being adequately addressed in research programmes due to the lack of a systematic approach and low capacities to integrate gender in a meaningful way.

Participatory research involving women in livestock sector should be increased. Women play important roles as producers of food, managers of natural resources, income earners and caretakers of household food and nutrition security. The control of assets including livestock and income derived from these assets by women has positive consequences for their decision-making within the household and for household well-being. Women play a much stronger role than men in the ecosystem management services and food security. Women are powerful agents of change and their leadership is critical. They have a significant role in dealing with issues such as energy consumption, deforestation, burning of vegetation, population growth, economic growth, developing scientific research and technologies and policy making, among others.

Women play a critical but often overlooked role in livestock production. Livestock are the most important asset for women. But unfortunately, most of the livestock are owned by men. With respect to livestock, women are heavily involved in small ruminant production, and it is easy for them to get into production. They need information on improved feeding practices, management practices and marketing. Hence, consorted efforts are needed in defining the complexities and changes associated with livestock ownership. This will ensure closing of gender asset gap. Considerable efforts are also needed to define the exact role of women in livestock keeping and encouraging women's participation in livestock markets. Further efforts are needed to integrate women, livestock, nutrition and health. Proper mechanisms should be put in place for securing women's access and control of livestock and other assets. This can be easily achieved by creating index-based livestock insurance for women and women-owned livestock as well as by developing a separate fund for both women and livestock. Promoting women's participation in both formal and informal livestock and livestock product markets can easily improve the confidence of women to take livestock as their primary livelihood activities.

22.4.5 Developing Policy Issues

The successful implementation of adaptation strategies to CC requires government support in terms of support by developing various policy issues. According to Antle (2010), there are two sets of policies that need to be developed. The first set of policies for designing adaptation strategies comprises (a) agriculture subsidy and trade policies, (b) production and income insurance policies and disaster assistance, (c) soil and water conservation policies and ecosystem services, (d) environmental policies and agricultural land use, (e) tax policies, (f) energy policies and (g) greenhouse gas mitigation policies. The second set of policies is concerned to facilitate adaptation. This comprises (a) estimating adaptation costs and reassessing impacts, (b) identifying adaptation strategies and related research needs, (c) identifying and estimating the vulnerability of ecosystem services to CC and adaptive responses, (d) providing public information about long-term climate trends and their economic implications and (e) implications of climate change and mitigation policies for agriculture and food sector.

22.4.6 Climate Change Communication and Early Warning System

Strengthening climate information and early warning systems (EWS) for climate-resilient development and adaptation to CC is to help farmers respond to both short-term/rapid-onset climatic hazards (e.g. cyclones, floods and storms) and long-term/slow-onset hazards (e.g. drought and long-term CC). To enhance the resilience of the population and the national economy, urgent action and measures needed to be taken to address the deficiencies and strengthen CC early warning system. The expected outcomes from the early warning systems are (a) enhanced capacity of hydrometeorological services and networks for predicting CC events and risk factors, (b) effective, efficient and targeted delivery of climate and CC information including early warnings and (c) improved and timely preparedness and responses of various stakeholders to forecast climate-linked risks and vulnerabilities. Further, the success of the early warning system depends on the following four elements: (1) risk knowledge, systematically collecting data and undertaking risk assessments; (2) monitoring and predicting, developing hazard monitoring and early warning services, including weather and hydrological monitoring equipment, improving forecast capabilities and the use of these technologies within agricultural advisories, flood-risk monitoring and supply chain management; (3) disseminating information, communicating risk information and reliable warnings to potentially affected locations through traditional and new media; and (4) responding to warnings, building national and community response capabilities to act effectively when warnings are received.

22.4.7 Capacity Building Programme

The success of adaptation strategies depends upon how effectively those strategies are being transferred to the ultimate target groups, the poor and marginal farmers. There is a need to improve the capacity of livestock producers and herders to understand and deal with climate change increasing their awareness of global changes. In addition, training in agroecological technologies and practices for the production and conservation of fodder improves the supply of animal feed and reduces malnutrition and mortality in herds. Developing suitable capacity building programme (CBP) is very crucial for successful implementation of adaptation strategies. CBP should address in detail the basic understanding of climate change science, climate change impacts on biodiversity and ecosystems and implication for conservation and sustaining eco-services and strategies for assessing vulnerability and adaptation. Figure 22.2 describes the various approaches and components of CBP. CBP (a) should be country driven and issue based, (b) should occur

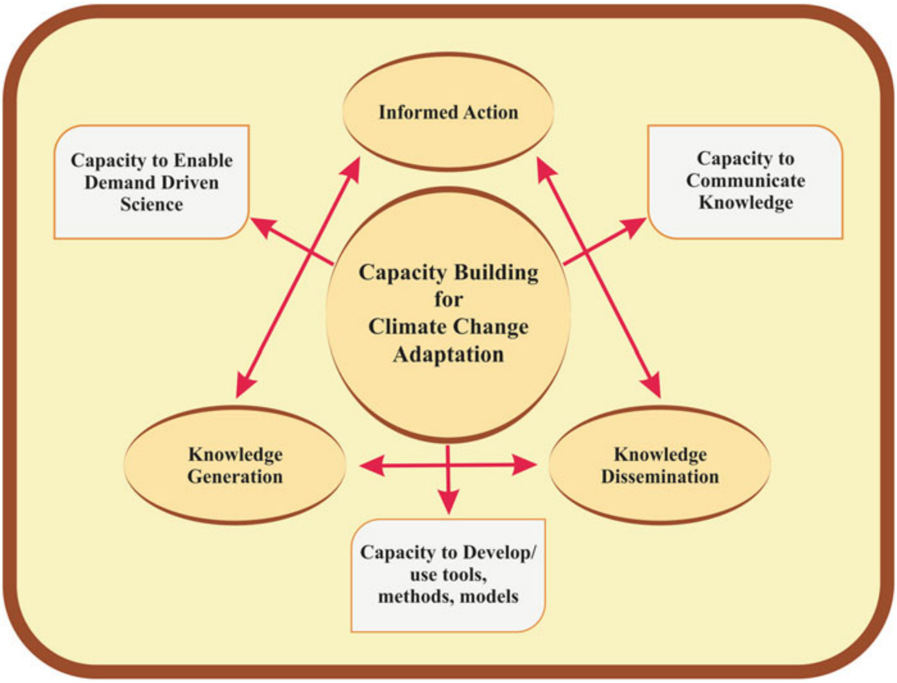


Fig. 22.2 Different approaches for capacity building programme

within a framework of integrated interdisciplinary problem solving, (c) is much more than training which requires institutional strengthening and human resource development and (d) should encourage potential for interaction and dialogues among diverse stakeholder groups. Building capacity of different stakeholders in parallel with the above adaptation strategies would help widen research and development communities to put climate, vulnerability and adaptation information into active use for pro-poor development.

22.5 Mitigation Strategies to Reduce Livestock-Contributed Climate Change

22.5.1 Management Strategies

Any methane reduction strategies must be confined to the following general framework, viz. development priority, product demand, infrastructure, livestock resource and local resources (Sejian et al. 2012a). The most attractive emission mitigation projects must balance the needs in all of these areas, so that no one factor creates a constraint on continued improvement in production efficiency and the resulting CH_4 emission reductions (Hristov et al. 2013). Within this framework, CH_4 emission mitigation options for enteric fermentation can encompass a wide range of activities across these areas. However, underlying these activities must be specific options for improving the production efficiency of the livestock. Without these options, CH_4 emissions cannot be reduced. Best management practices are defined as those that (a) minimise and mitigate impacts and risks to the environment by maintaining or improving quality of soil, water, air and biodiversity; (b) ensure the health and sustainability of natural resources used for agriculture production; and (c) support long-term economic and environmental viability of the agriculture industry. There are several management strategies that may be employed for livestock to reduce enteric methane emissions. Adoption of the basic livestock management principles offers the best opportunity of improving production efficiency while also reducing emissions. Within the context of these fundamental livestock management principles, specific techniques for improving production efficiency and reducing CH_4 emissions include the following (USEPA 1993): (1) enhanced nutrition through mechanical and chemical feed processing, (2) balanced nutrition through strategic supplementation, (3) intake of production-enhancing agents, (4) improved production through enhanced genetic characteristics, (5) increased production efficiency through improved reproduction and (6) improved grassland and rangeland management.

22.5.1.1 Animal Manipulation by Reducing Livestock Numbers

The countries which are committed to reduce the enteric methane emission from the livestock, reducing animal number is the best possible way, but it is totally unacceptable for those countries which rely heavily on livestock production for their national economy (Sejian et al. 2011a). Shifting of old-age cattle from heifers in the cattle herds can efficiently increase the productivity and decrease the enteric methane production due to high intake and passage rate of ingested feed materials that can lead to lower enteric emission. Hegarty (2001) points out that if animal numbers do not decrease in response to the improved productivity, then emissions from the sector will increase rather than decrease. Sheep population has been reduced from 57.9 million in 1990 to 45.2 million in 2000, while dairy cattle and beef cattle population has increased slightly. The net outcome was a decline in ruminant CH_4 emission from 1.45 to 1.31 Tg/year from 1990 to 2000 (Sejian et al. 2011a). The application of biotechnological aids can meet out the loss of reduced animal number, for example, the use of recombinant bST (bovine somatotropin) leads to an increase in milk production up to 10–20 %, and therefore, animal number can be reduced to lower the total enteric emission (Clemens and Ahlgrimm 2001). Kirchgessner et al. (1995) estimated that overall CH_4 emissions could be decreased by reducing animal numbers while maintaining milk production.

22.5.1.2 Animal Breeding with Low CH_4 Emissions

Genetic selection of animals that consume less feed or produce less CH_4 per unit of feed is a management strategy that may be used to reduce enteric CH_4 emissions. Pinares-Patino et al. (2007) established that there are differences between individual animals in the quantity of CH_4 they emit per unit of dry matter intake. This finding has resulted in the establishment of research programmes aimed at exploiting these differences. Animal effects on fermentation could be via the saliva, feed processing (e.g. comminution) or flow rate through the rumen. It is possible that the animal's impact on fermentation is genetically determined, and if this is the case, it may be possible to obtain markers that can be used to select low methane emitters.

22.5.1.3 Increasing the Efficiency of Livestock Production

Improving the efficiency of ruminant animal performance will generally lead to a reduction of CH_4 emitted per unit of animal product. There are two aspects of this: genetic improvement of the animals themselves to achieve more product per unit of feed intake, as has been achieved with pigs and poultry, and nutritional manipulation via increased feed intake and appropriate feed composition. This can be achieved in three ways: (a) increasing feed intake: increasing feed intake decreases the methane emission per unit of feed intake. Kirchgessner et al. (1995) reported that as milk yield increases, methane emitted per unit of milk yield decreases. By feeding animals ad libitum, it is possible to both maximise efficiency and reduce methane emission per unit of product. This is because as intake increases, the methane emission associated with the essential, but non-productive, requirements for maintenance is diluted. By improving animal production efficiency, emissions per unit product can be reduced by 25–75 % depending on animal management practices (Bowman et al. 1992). In addition, improved productivity can allow managers to reduce the size of the herd necessary to produce a certain quantity of product (O'Mara 2004); (b) nutritional manipulation: as described above, decreasing dietary fibre and increasing starch and lipid will reduce methane emission. Generally, diets of higher digestibility have these characteristics. Generally, dairy cows were given feeds of increasing digestibility to achieve the same level of milk production. The animals would have eaten less of the higher digestibility diets and thus produced less total methane and reduced methane emitted per unit of milk produced. Improving the nutritive value of the feed given to grazing animals by balancing the diet with concentrates, or by breeding-improved pasture plants, should result in reduced methane emission; and (c) metabolic efficiency by production-enhancing agents: production-enhancing agents are available for use to increase production efficiency in cattle. Bovine somatotropin (bST) for dairy cows is a naturally occurring growth hormone produced by the pituitary gland. Recombinant bST, an identical molecule, is produced biotechnologically and has been shown to increase milk production in US dairy cows. In general, the use of bST leads to an increase in milk production of 10–20 %, and therefore, animal numbers can be reduced to lower total enteric emissions (Clemens and Ahlgrimm 2001). Johnson et al. (1996) estimated that the use of bST to improve US dairy cattle productivity could result in decreased CH_4 emissions (% of GEI) by about 9 %.

22.5.1.4 Grazing Management

Implementing proper grazing management practices to improve the quality of pastures will increase animal productivity and lower CH_4 per unit of product. McCaughey et al. (1997) observed that CH_4 production was greatest for steers continuously grazing at low stocking rates (1.1 steer ha–1; 306.7 L d–1) and least for steers grazing continuously at high stocking rates (2.2 steers ha–1; 242.2 L d–1). At higher stocking rates, forage availability and intake are low. When pastures were rotationally grazed, stocking rates had no effect on CH_4 production (L d–1) (McCaughey et al. 1997). At low stocking rates (1.1 steer ha–1), CH_4 production (L ha–1 d–1) was 9 % lower on rotational grazing than continuous grazing (McCaughey et al. 1997). Measurements of CH_4 production from grazing beef cows indicated a 25 % reduction in CH_4 losses with alfalfa-grass pastures (7.1 % of GEI) compared to grass-only pastures (9.5 % of GEI) (McCaughey et al. 1999). Early grazing of alfalfa-grass pastures reduced CH_4 production (% GEI) by 29–45 % in steers compared to grazing at mid and late seasons (Boadi et al. 2004). In most productive husbandry systems, the herbage digestibility tends to be maximised by agricultural practices such as frequent grazing and use of highly digestible forage cultivars. Consequently, in these systems, the primary factor which modifies the C flux returned to the soil by excreta is the grazing pressure, which varies with the annual stocking rate, i.e. mean number of livestock units per unit area (Soussana et al. 2004). Secondary effects of grazing on the C cycle of a pasture include: (1) the role of excretal returns which, at a moderate rate of grazing intensity, could favour nutrient cycling and increase primary production, especially in nutrient-poor grasslands (De Mazancourt et al. 1998) and (2) the role of defoliation intensity and frequency and of treading by animals, which both reduce the leaf area and then the atmospheric CO_2 capture.

22.5.1.5 Improving Nutrition

Methane production was reduced (−7 % and −40 %) by increasing DMI and the proportion of concentrate in the diet (Rowlinson et al. 2008; Kingeston-Smith et al. 2010). The use of more digestible forage (less mature and processed forage) resulted in a reduction of methane production (−15 % and −21 %). Methane production was lower with legume than with grass forage (−28 %). Legumes generally have higher dry matter intakes and produce more milk solids. This reduces methane emissions per unit of milk or meat production. Methane emissions are also commonly lower with higher proportions of forage legumes in the diet, partly because of the lower fibre content, the faster rate of passage, and in some cases, the presence of condensed tannins (CTs) (Beauchemin et al. 2008). Forage quality has a significant impact on enteric CH_4 emissions (Ulyatt et al. 2002; Sejian et al. 2011b). There is also evidence that using clovers and grasses with high water-soluble carbohydrates (WSC) in animal diets can directly reduce methane emissions (Lovett et al. 2004). It has been demonstrated that increasing the WSC content in perennial ryegrass by 33 g/kg reduces methane production in vitro by 9 % (Rowlinson et al. 2008). Also, increasing the proportion of concentrate in the diet will generally reduce rumen pH and as methanogens are pH sensitive; this will also tend to reduce methane emission. The proportion of concentrate within the diet has been reported to be negatively correlated with methane emissions (Lovett et al. 2005; McAllister and Newbold 2008). An increase in feeding level also was reported to induce lower CH_4 losses. This is caused mainly by the rapid passage of feed out of the rumen (Mathison et al. 1998; Hegarty 2001). Grinding or pelleting of forages to improve the utilisation by ruminants has been shown to decrease CH_4 losses per unit of feed intake by 20–40 % when fed at high intakes (Johnson et al. 1996). The lowered fibre digestibility, decreased ruminally available organic matter and faster rate of passage associated with ground or pelleted forages can explain the decline in CH_4 production (Le-Liboux and Peyraud 1999). In summary, there are several promising strategies to reduce methane emissions through forage selection, but these need further investigation, particularly at a whole-farm level.

22.5.1.6 Improved Grassland and Rangeland Management

Increasing the digestibility of cell walls in forages has been suggested as a means to lower CH_4 losses, but in fresh grass and grass silage, the scope of this approach appears to be rather limited. There is evidence that fresh grass results in lower CH_4 losses than grass silage, but no direct comparisons exist between fresh grass and grass silage. Mainly forage diets are often supplemented with sugar-based concentrates to provide a rapidly available source of energy for the rumen microbes or to increase the palatability of the diet DM and hence stimulate the digestibility (Mills et al. 2001). CH_4 production in ruminants tends to increase with maturity of forage fed, and CH_4 yield from the ruminal fermentation of legume forages is generally lower than the yield from grass forages (McAllister et al. 1996; Moss et al. 2000). Shifting the animals from grass to legume plant species tends to decrease the enteric emission due to lower proportion structural carbohydrates and faster rate of passage which shifts the fermentation pattern towards higher propionate production (Johnson and Johnson 1995). Continuous grazing of improved pasture managed with a high stocking rate (2.2 steers ha-1) resulted in 21 % lower daily CH_4 emissions as compared to the low stocking rate (1.1 steers ha-1) when measured as emissions per animal per day, but these differences were not evident when measured as emissions per unit gain or as % GEI (McCaughey et al. 1997).

22.5.1.7 Longevity/Extended Lactation

Extended lactation can reduce the energy demand of cows and methane by approximately 10 %. Extended lactation has other benefits, such as reducing peak workload; cow health problems (due to less calving) and less heifer replacements are required. Milk in the extended lactation phase is higher in milk solids, making the milk more valuable per litre and there may be price incentives for milk produced outside peak supply months. Extended lactation is always considered as an option for herd, and selected breeds suited for extended lactation. The longer the cows stay in a herd, the lower the number of replacements required, and thus, the lower the total farm methane emissions. An example of a 100-cow farm is where the average number of lactations varies from 2.5 to 5. It is assumed that dairy cow emissions are 118 kg/year, while the rearing of a replacement heifer to calve at 2 years old results in methane emissions of 100 kg. This shows that total farm emissions of CH_4 from enteric fermentation decline from 15,800 to 13,800 kg/year (0.127 less) as the average number of lactations increases from 2.5 to 5. This does not factor in the higher yield of the older cows which would further reduce emissions per kg of milk. Thus, any measures which reduce involuntary culling should be encouraged.

22.5.2 Nutritional Interventions

Methanogenesis is essential for an optimal performance of the rumen because it avoids hydrogen accumulation, which would lead to inhibition of dehydrogenase activity involved in the oxidation of reduced cofactors. Fermentation is an oxidative process, during which reduced cofactors (NADH, NADPH, FADH) are reoxidised (NAD1, NADP1, FAD1) through dehydrogenation reactions releasing hydrogen in the rumen. As soon as produced, hydrogen is used by methanogenic archaea, a microbial group distinct from *Eubacteria*, to reduce CO_2 into CH_4 according to the depicted equation. Acetate and butyrate production results in a net release of hydrogen and favours CH_4 production, while the propionate formation is a competitive pathway for hydrogen use in the rumen. It was established that CH_4 production can be calculated from stoichiometry of the main volatile fatty acid (VFA) formed during fermentation (Demeyer and Fievez 2000). The metabolic pathways involved in hydrogen production and utilisation as well as the methanogenic community are important factors that should be considered when developing strategies to control CH_4 emissions by ruminants. Any given strategy has to address one or more of the following goals: (1) reduction of hydrogen production that should be achieved without impairing feed digestion and (2) stimulation of hydrogen utilisation towards pathways producing alternative end products beneficial for the animal and/or an inhibition of the methanogenic archaea (numbers and/or activity). Table 22.2 describes the potential mitigation strategies to reduce enteric methane emission.

22.5.2.1 Feeding Management

Feeding management is one of the most important strategies for CH_4 mitigation in ruminants. An integrated approach that considers the rumen microbiota, the animal and the diet seems the best approach to find a long-term solution for reducing enteric CH_4 production by ruminants. Both the amount of digestible nutrients ingested and the composition of the diet were found to be major factors governing methane production (Blaxter and Clapperton 1965). The developed equations (Yates et al. 2000), demonstrate that increasing the energy density of the diet (e.g. by increasing ratio of concentrates to forage) decreases methane production per unit of digestible energy ingested. Increasing energy density also increases productivity, thereby also contributing to decreased carbon per unit of product.

22.5.2.2 Inducing Acetogenesis and Feeding Probiotics

Reductive acetogenesis is a natural mechanism of hydrogen utilisation that coexists with methanogenesis in the gastrointestinal tract of many animals. This pathway is also the dominant one in several hindgut-fermenting mammals (human, rabbit, hamster, rat) but also in foregut fermenting such as kangaroos (Klieve and Joblin 2007). The final product of the reaction, acetate, has the additional advantage of being a source of energy for the animal. However, in the rumen environment, acetogens are less numerous and less efficient than methanogens in the competition for reducing equivalents. This is probably because acetogens need a higher concentration of hydrogen in the medium to reduce CO_2 into acetate than that required for methanogens to reduce CO_2 into CH_4. In addition, the former reaction is thermodynamically less favourable (Weimer 1998). Attempts to increase the natural rumen population of acetogens have been assayed but without success (Van Nevel and Demeyer 1996). The use of acetogens as probiotics has also been tested by several authors with and without the addition of methanogen inhibitors to favour competition (Nollet et al. 1998; Lopez et al. 1999). Live yeast, the most commonly used probiotic in ruminant production, has not been extensively tested for their effect on CH_4 production (Chaucheyras-Durand et al. 2008). The few reports available used strains selected for effects other than CH_4 reduction, and the results are contradictory (Doreau and Jouany 1998; Chaucheyras-Durand et al. 2008).

22.5.2.3 Defaunation

Defaunation is the complete removal of protozoa from the rumen ecology and consequently

Table 22.2 Potential mitigation strategies to reduce enteric CH_4 emission

Variables	Mitigation strategies	Mechanism of action	References
Management strategies			
Animal manipulation	Reducing livestock numbers	Efficiently increase the productivity due to high intake and passage rate of ingested feed materials leading to lower CH_4 emission	Kirchgessner et al. (1995) and Sejian et al. (2011a)
	Shifting of old-age cattle from heifers in the herd		
	Recombinant bST	Increase in milk production so animal numbers can be reduced to lower CH_4 emission	Clemens and Ahlgrimm (2001)
	Animal breeding with low CH_4 emissions	Genetic selection of animals that consume less feed or produce less CH_4 per unit of feed	Pinares-Patiño et al. (2007)
Grazing management	Frequent grazing and use of highly digestible forage cultivars	Herbage digestibility tends to be maximised	Soussana et al. (2004)
Nutritional interventions			
Improving nutrition	Increasing the proportion of concentrate, more digestible forage, legumes or clovers and grasses with high WSC	Reduce rumen pH and methanogens are pH sensitive, fermentation pattern shifts towards higher propionate production	Beauchemin et al. (2008), McAllister and Newbold (2008), Rowlinson et al. (2008) and Kingeston-Smith et al. (2010)
	Increasing feeding level	Rapid passage of feed out of the rumen	Mathison et al. (1998) and Hegarty (2001)
	Grinding or pelleting of forages to improve utilisation	Lower fibre digestibility, decrease ruminally available organic matter and faster rate of passage	Johnson et al. (1996) and Le-Liboux and Peyraud (1999)
Inducing acetogenesis	Acetogens as probiotics	Reduce CO_2 into acetate than CH_4	Nollet et al. (1998) and Lopez et al. (1999)
Defaunation	Lauric acid, coconut oil, linseed FAs	Remove protozoa-associated methanogens; less H_2 for methanogenesis	Doreau and Ferlay (1995), Morgavi et al. (2010), Hristov et al. (2011) and Hollmann and Beede (2012)

(continued)

Table 22.2 (continued)

Variables	Mitigation strategies	Mechanism of action	References
Chemical inhibitors	Nitrates	Act as terminal electron acceptors and alternate hydrogen sinks	Nolan et al. (2010), Van Zijderveld et al. (2011) and Hulshof et al. (2012)
	Sulphate	Sulphate-reducing bacteria outcompete methanogenic bacteria and reduce CH_4 production	Van Zijderveld et al. (2010)
	Organic acids like fumarate, malate, aspartate, acrylate, oxaloacetate or their sodium salts	Act as alternative hydrogen sinks in the rumen shifting rumen fermentation towards propionate	Ungerfeld et al. (2007), Molano et al. (2008), Foley et al. (2009), Wood et al. (2009) and Van Zijderveld et al. (2011)
	Ionophores like monensin, lasalocid, salinomycin, nigericin and gramicidin	Inhibit protozoa and Gram-positive bacteria, reduce the amount of H_2 available for methanogens, decrease acetate: propionate ratio	Odongo et al. (2007) and Appuhamy et al. (2013)
	Halogenated methane analogues like bromochloromethane (BCM), chloral hydrate, amichloral, 2-bromoethane sulphonate, chloroform and cyclodextrin	BCM reacts with coenzyme B which functions at the last step of the methanogenic pathway	Tomkins et al. (2009) and Abecia et al. (2012)
	Prebiotics like GOS	Increase propionate production	Santoso et al. (2004)
	Nitro compounds like nitroethane, 3-nitropropanol, 3-nitropropionate, 2-nitropropanol, nitroethanol, 3-nitrooxypropanol, ethyl-3-nitrooxypropanol	Act as alternate electron acceptors	Anderson et al. (2003), Gutierrez-Banuelos et al. (2007), Brown et al. (2011), Haisan et al. (2013) and Martinez-Fernandez et al. (2013)
Feeding forages	Forage preservation and processing	Methanogenesis is lower when forages are ensiled than when they are dried, and when they are finely ground or pelleted than when coarsely chopped	Beauchemin et al. (2008)
Dietary lipids	Soya oil, coconut oil, canola oil, linseed oil, rapeseed oil, sunflower oil, copra meal, lauric acid, myristic acid and linoleic acid	Reduce fibre digestion, inhibit methanogens and protozoa, more propionate production than acetate; biohydrogenation of USFAs	Beauchemin et al. (2008), Hristov et al. (2009), Eckard et al. (2010), Sejian et al. (2011b), Ding et al. (2012), Brask et al. (2013) and Zhou et al. (2013)
Manipulation of rumen microbial ecosystem			
Direct-fed microbials	Yeast culture, i.e. *Saccharomyces cerevisiae* and *Aspergillus oryzae*	Reduce protozoa numbers, increase butyrate or propionate production, stimulate acetogens which compete with methanogens	Mwenya et al. (2004) and Chaucheyras et al. (2008)
	CH_4 oxidisers or methanotrophs	Utilise CH_4 as carbon and energy source	Hanson and Hanson (1996)

Bacteriocins	Nisin, bovicin HC5, PRA-1, pediocin, enterocin	Inhibit methanogens and some Gram-positive bacteria, redirect H_2 to propionate producers or acetogens, decrease acetate to propionate ratio	Callaway et al. (1997), Lee et al. (2002), Sang et al. (2002) and Asa et al. (2010)
Fungi	Fungal metabolites from *Monascus* spp.	Decrease acetate: propionate ratio, reduce methanogen numbers	Morgavi et al. (2013)
CH_4 reducer	*Mitsuokella jalaludinii*	Compete with methanogens for H_2	Mamuad et al. (2012)
Phage therapy	*Methanobacterium* phage psi M1, M2 and M100, *Methanothermobacter* phage psi M100, siphophages	Infect methanogens	Pfister et al. (1998), Luo et al. (2001), McAllister and Newbold (2008) and Leahy et al. (2010)
Secondary plant metabolites			
Tannins	*Terminalia belerica*, *T. chebula*, sulla, Kobe lespedeza, *Bergenia crassifolia*, *Peltiphyllum peltatum*, *Vaccinium vitis-idaea*, *Rheum undulatum*, *Ficus benghalensis*, *Rhus typhina*, *Artocarpus integrifolia* and *Azadirachta indica*	Inhibit methanogens and ciliate protozoa, decrease fibre digestion, increase propionate production	Zhou et al. (2011), Staerfl et al. (2012), Jayanegara et al. (2012) and Bhatta et al. (2013a)
Saponins	Tea plant, *Yucca schidigera*, alfalfa, *Quillaja saponaria*, *Acacia auriculiformis*, *Sapindus saponaria*, fenugreek	Bind with cholesterol present on the protozoal cell membrane leading to its lysis, limit H_2 availability to methanogens and rechannel H_2 from CH_4 to propionate production	Francis et al. (2002), Wina et al. (2005), Goel et al. (2008) and McAllister and Newbold (2008)
Immunisation			
Vaccines	VF3 and VF7 vaccines	Trigger immune system to produce antibodies against methanogens	Wright et al. (2004), Williams et al. (2009) and Wedlock et al. (2010)
	Entodinial or mixed protozoa antigens	Release IgG antibodies against protozoa	Williams et al. (2008)
	Subcellular fractions (cytoplasmic and cell wall-derived protein) of *M. ruminantium* M1	Target against *M. ruminantium*	Wedlock et al. (2010)

reduces methane release by 20–30 % (Kreuzer et al. 1986). Association and cross-feeding between ruminal protozoa and archaea have been established and are the basis for suggesting defaunation as a CH_4 mitigation strategy. Defaunation also markedly increases the total bacterial number, whereas it reduces the number of methanogens which may be due to the loss of preferable colonisation sites for them at which they associated ecto- and endosymbiotically with protozoa. Ruminal protozoa may also play an important role in methane production, particularly when cattle are fed high-concentrate diets. Ruminal methanogens have been observed attached to protozoal species suggesting possible interspecies hydrogen transfer. However, the response in CH_4 production to partial or complete defaunation has been variable. Morgavi et al. (2010) calculated 10 % decrease in CH_4 production due to defaunation, but the data from that study were extremely variable. Research with beef cattle reported no effect on rumen methanogen abundance despite a 65 % difference in protozoal numbers between a high-forage and a high-starch, lipid-supplemented diet (Popova et al. 2011). Similarly, a 96 % reduction in ruminal protozoa had no effect on methanogenic archaea in dairy cows treated with lauric acid (Hristov et al. 2011). Apart from lauric acid and coconut oil (Hristov et al. 2009, 2011; Hollmann and Beede 2012), and some vegetable oils with a high proportion of unsaturated fatty acids such as linseed (Doreau and Ferlay 1995), there have been no effective and practical defaunating agents tested comprehensively in vivo. Defaunation of the rumen of cattle fed a barley diet decreased methane production by approximately one half (Whitelaw et al. 1984). However, defaunation of animals receiving high-forage diets (Itabashi et al. 1984) did not reduce methane losses.

22.5.2.4 Mitigation Through Chemical Inhibitors

22.5.2.4.1 Nitrates

Leng (2008) provided a comprehensive review of the earlier literature on nitrates. Recent research with sheep (Nolan et al. 2010; Van Zijderveld et al. 2010) and cattle (Van Zijderveld et al. 2011; Hulshof et al. 2012) has shown promising results with nitrates decreasing CH_4 production by up to 50 %. Nitrate persistently decreased CH_4 production from lactating dairy cows during 4 successive 24-day periods (Van Zijderveld et al. 2011). In a short-term study, addition of 22 g nitrate/kg DM in the diet reduced methane emission by 32 % in Nellore×Guzera beef steers fed with sugarcane-based diets. However, in practice, the use of nitrate should be limited to diets naturally low in protein, in which addition of an NPN source is favourable (Hulshof et al. 2012). Nitrates may serve as a terminal electron acceptor and therefore may behave as alternate hydrogen sink and can be converted to ammonia and used in the rumen as a source of nitrogen. Nitrates (NO_3) themselves are not very toxic, but nitrites (NO_2), which they are converted to, are toxic. The nitrate and nitrite along with CO_2 are the hydrogen acceptors in the rumen. Microorganisms are able to increase nitrate reductase activity in the rumen three to five times the normal values, with 3–5 day acclimatisation period, but toxicity at larger dose limits its application. The harmful effect is due to the oxidising properties of nitrite, whereby blood haemoglobin is converted into methaemoglobin, which is a poor oxygen carrier, resulting in anoxia in the animals. This methaemoglobin can be decreased by the β 1-4 galacto-oligosaccharides which are also proved to be methane inhibitors (Sar et al. 2004).

22.5.2.4.2 Sulphates

In the rumen, sulphate is reduced to sulphide. As hypothesised for marine sediments, sulphate-dependent methane oxidation with the use of methane and/or acetate is thermodynamically more favourable in anaerobic conditions like rumen. Sulphate-reducing bacteria (SRB) in the large intestine of human and pig outcompete those of methanogenic bacteria (MB) and thus reduce methane production. As free sulphate levels in digesta appear to affect the relationship between MB and SRB, sulphate levels in the rumen are likely to be insufficient for SRB to outcompete MB. Stoichiometric calculations show that reducing methane emissions in a sheep by

50 % would require ingestion of 0.75 moles of sulphate or nitrate per day. Adding sulphate to the diet of sheep also reduced CH_4 production, and when both nitrate and sulphate were added, the effect on CH_4 production was additive (Van Zijderveld et al. 2010).

22.5.2.4.3 Organic Acids

Fumaric and malic acids, the direct metabolic precursors of propionate, have also been studied as alternative hydrogen sinks in the rumen (Molano et al. 2008; Foley et al. 2009; Van Zijderveld et al. 2011). Inclusion of malic and fumaric acids or their sodium salts or the intermediates of carbohydrate degradation in diets results in shifting rumen fermentation towards propionate and hence less methane production (Castillo et al. 2004). Addition of sodium fumarate consistently decreased methane production in vitro by 2.3–41 % (Ungerfeld et al. 2007). Similarly, malate, which is converted to fumarate in rumen, stimulated propionate formation and also inhibited methanogenesis in some in vitro studies (Carro and Ranilla 2003; Tejido et al. 2005), although other studies have failed to find clear reductions of methanogenesis in vitro (Gómez et al. 2005; Ungerfeld and Forster 2011). In vivo effects of adding organic acids such as fumarate, aspartate and malate or oxaloacetate to the diet on methane mitigation are quite variable (Ungerfeld et al. 2003; McGinn et al. 2004). Wood et al. (2009) noted 60–76 % reductions in methane emissions by supplementing fumarate at 100 g/kg to growing lambs, while Foley et al. (2009) observed the reductions of only 6 % and 16 %, when the diet of beef heifers was supplemented with malic acid at 37.5 and 75 g/kg, respectively. In contrast, no effects of fumaric or malic acid on methane emissions were observed in other studies (Beauchemin and McGinn 2006; Foley et al. 2009). The effect of organic acid supplementation on methane reduction appears to be influenced by the roughage to concentrate ratio and the type of cereal grain being fed in diet (Carro and Ranilla 2003; Gómez et al. 2005; Tejido et al. 2005). Newbold and Rode (2005) tested 15 potential precursors of propionate, including pyruvate, lactate, fumarate, acrylate, malate and citrate in short-term batch cultures. Sodium acrylate and sodium fumarate produced the most consistent effect decreasing CH_4 production by 8–17 %. Free acids rather than salts were more effective in reducing CH_4.

22.5.2.4.4 Ionophores

Among ionophore antibiotics, monensin is the most studied in ruminants, besides lasalocid, salinomycin, nigericin and gramicidin. Monensin specifically targets bacteria producing H_2 and formate. It reduces the amount of H_2 available for methanogenic bacteria and attaches to the cell membrane of ruminal bacteria and protozoa, resulting in a decrease in the proportion of acetate relative to propionate in the rumen and thereby effectively lowering CH_4 production by up to 76 % in vitro and to an average of 18 % in vivo (Van Nevel and Demeyer 1996; Hristov et al. 2003). However, the inhibitory effect on methane production appears to be dose dependent. Odongo et al. (2007) reported that feeding monensin to dairy cows (24 mg/kg diet) caused 7 % reduction in methane compared to control animals and the reductions sustained for 6 months with no adaptation detected. In a meta-analysis of 22 controlled studies, monensin (given at 32 mg/kg DM) reduced CH_4 emissions by 19 ± 4 g/animal/day ($P < 0.001$) in beef steers (Appuhamy et al. 2013). The corresponding reductions in dairy cows were 6 ± 3 g/animal/day ($P = 0.065$) for monensin given at 21 mg/kg DM. Overall, the conclusion of that analysis was that monensin had stronger antimethanogenic effect in beef steers than in dairy cows (mostly fed forage-based diets), but the effects in dairy cows can be improved by dietary modifications and increasing monensin dose. Another meta-analysis has shown a consistent decrease in acetate: propionate ratio with monensin addition in high grain diets fed to beef cattle (Ellis et al. 2012), which may lead to a reduction in CH_4 emission per unit of feed. Hook et al. (2009) observed that long-term (up to 6 months) monensin supplementation did not affect either the number or diversity of methanogens in the rumen of dairy cows, confirming that monensin is able to suppress methanogenesis through an indirect effect on methanogens which may be due to inhibition of protozoa, which produce hydrogen and are colonised by methanogens. Ionophores inhibit Gram-positive microorganisms responsible for supplying methanogens with substrate for methanogenesis and reduce protozoal numbers (Hook et al. 2009). There can be a risk that ionophores get absorbed from rumen and reach animal products (i.e. meat or milk). So, it has been banned in the European Union since January 2006 and it is being currently strongly questioned in many countries.

22.5.2.4.5 Halogenated Compounds

Halogenated methane analogues such as BCM, chloral hydrate, amichloral, 2-bromoethane sulphonate, chloroform and cyclodextrin are highly effective at reducing methane production, though methanogen species differ in their responsiveness (McAllister and Newbold 2008; Mitsumori et al. 2011; Knight et al. 2011). Though these compounds can be highly effective, the effect of these chemicals is transitory with no significant long-term reduction in methane production (McAllister and Newbold 2008). The BCM can inhibit methanogenesis by reacting with coenzyme B, which functions at the last step of the methanogenic pathway. Recently, Abecia et al. (2012) confirmed the methane-reducing effects of BCM in lactating dairy goats and reported a 33 % reduction with no effect on rumen bacteria, protozoa and methanogens. Some compounds such as bromine analogue of coenzyme M were potent methane inhibitors in vitro, but the inhibition was not persistent in vivo, suggesting adaptation of methanogenic populations (van Nevel and Demeyer 1995). An adaptation of methanogens to quaternary ammonium compounds has also been demonstrated (Tezel et al. 2006). Data by Knight et al. (2011) showed an immediate and dramatic drop in CH_4 production in dry cows administered with chloroform; however, CH_4 production gradually increased to about 62 % of the pretreatment levels by day 42, suggesting adaptation to chloroform by the rumen ecosystem, but in contrast, the effect of BCM appeared to persist in the studies by Tomkins et al. (2009) and Abecia et al. (2012). However, a banned compound, such as BCM (an ozone-depleting agent), cannot be recommended as a CH_4 mitigating agent, but compounds with similar mode of action could be developed.

22.5.2.4.6 Prebiotics

In ruminants, the role of prebiotics has not yet been quantified, but they are used in rumen manipulation along with nitrate and probiotics and had potential to reduce methane production. They are speculated to enhance the propionate production by stimulating *Selenomonas*, *Succinomonas* and *Megasphaera* with simultaneous inhibition of acetate producers such as *Ruminococcus* and *Butyrivibrio* (Mwenya et al. 2004). Administration of galacto-oligosaccharide (GOS) supplementation decreased nitrite accumulation in rumen and plasma and nitrate-induced methaemoglobin while retaining low methane production. Eleven percent reduction in methane emission (litres/day) in GOS-supplemented diet compared to control diet has been reported (Zhou et al. 2004). Inclusion of GOS increased propionate production and decreased CH_4 (Santoso et al. 2004).

22.5.2.4.7 Nitro compounds

Growth of nitro-metabolising bacterium *Denitrobacterium detoxificans* was supported by the electron acceptors such as 3-nitropropanol, 3-nitropropionate, nitrate, 2-nitropropanol, nitroethane, nitroethanol or 3-nitro-1-propyl-β-D-glucopyranoside (miserotoxin). These less toxic nitro compounds may have the potential to be used as an alternative to decrease CH_4 production in ruminants (Gutierrez-Banuelos et al. 2007; Brown et al. 2011). In the presence of the appropriate nitro compound, formate, lactate and H_2 served as electron donors of *D. detoxificans*. Nitroethane is a potent anti-methanogenic compound on three gastrointestinal microbial sources (i.e. chicken ceca, bovine rumen and ovine rumen). Nitroethane has been safely administered to cattle and has the potential to serve as an alternative electron acceptor within the rumen (Anderson et al. 2003). More recently, the effect of 3-nitrooxypropanol (3NP) and ethyl-3-nitrooxypropanol on rumen fermentation and methane emission has been studied using Rusitec fermenters and in in vivo trials (Haisan et al.

2013; Martinez-Fernandez et al. 2013). The 3NP compound decreased CH_4 production per unit of DMI in sheep in respiration chambers (24 % reduction; Martinez-Fernandez et al. 2013) and dairy cows using the SF_6 technique (a dramatic 60 % decrease; Haisan et al. 2013).

22.5.2.5 Mitigation Through Forage Feeding

Lucerne hay decreases CH_4 emissions by 21 % (Benchaar et al. 2001) when expressed as % of digestible energy. McCaughey et al. (1999) observed that beef cattle reared on grazing decrease 10 % CH_4 production by unit of product when grasses were replaced by a mixture of lucerne and grasses (70: 30). The authors concluded that this was due to the higher intake observed for lucerne-fed animals, which was related with a higher digestibility rate and an increased passage of feed particles out of the rumen. This effect on methanogenesis is not a characteristic of all legumes; for instance, clover (white and/or red) did not differ from ryegrass on CH_4 emissions of growing cattle (Beever et al. 1989) or dairy cows (Van Dorland et al. 2007). Several authors have shown that including tannin-rich legumes (sainfoin, lotus, sulla) and shrubs in the diet contributes to a decrease in methanogenesis due to the presence of condensed tannins (Waghorn et al. 2002). Forage preservation and processing also affect enteric CH_4 production, but limited information with regard to these effects is available in the literature. Methanogenesis tends to be lower when forages are ensiled than when they are dried and when they are finely ground or pelleted than when coarsely chopped (Beauchemin et al. 2008).

22.5.2.6 Dietary Lipids

Vegetable and animal lipids are also considered useful in terms of reduced rumen methanogenesis (Beauchemin et al. 2007; Brask et al. 2013). Ten to 25 % reduction of methane may be achievable through the addition of dietary oils to the diets of ruminants (Beauchemin et al. 2008). Possible mechanisms by which added lipid can reduce methane production include: (a) by reducing fibre digestion (mainly in long-chain fatty acids), (b) by lowering dry matter intake (if total dietary fat exceeds 6–7 %), (c) through direct inhibition of activities of different microbes including methanogens, (d) through suppression of rumen protozoa and (e) to a limited extent, through biohydrogenation of unsaturated fatty acids (Beauchemin et al. 2008; Eckard et al. 2010). The addition of different oils (soya, coconut, canola, linseed, rapeseed, sunflower, etc.) to ruminant diets has been shown to reduce methane production between 18 % and 62 % in Rusitec fermenters (Dohme et al. 2000), sheep (Ding et al. 2012), beef cattle (O'Mara 2004; McGinn et al. 2004; Beauchemin and McGinn 2006) and dairy cows (Hristov et al. 2009; Sejian et al. 2011b; Brask et al. 2013). Copra meal gives comparable decreases in CH_4 to refined coconut oil (Jordan et al. 2006).

Comparison of the effects of different fatty acids revealed that lauric, myristic and linoleic acids were the most potent reducers of methanogenesis (Jordan et al. 2006; Ding et al. 2012), and the ability of lauric acid to decrease cell viability of *Methanobrevibacter ruminantium* has been recently reported by Zhou et al. (2013). A wide range of essential oils (derived from garlic, thyme, oregano, cinnamon, rhubarb, frangula, etc.) has been shown to decrease methane production in vitro in a dose-dependent manner, but at high doses, the decrease in methanogenesis was accompanied by adverse effects on fermentation such as reduction in VFA production and feed digestibility (Busquet et al. 2005; Patra and Yu 2012). The lack of response in vivo is partly attributed to the adaptation of microbes (Bodas et al. 2012) but also to the use of lower doses compared to those in the in vitro experiments. Ohene-Adjei et al. (2008) also do not exclude the possibility of influence of essential oils in the activity of methane-producing genes.

22.5.2.7 Concentrate Supplementation

Increasing the level of concentrate in the diet leads to a reduction in CH_4 emissions as a proportion of energy intake or expressed by unit of animal product (milk and meat). Methane losses appear relatively constant for diets containing up to 30–40 % concentrate (6–7 % of GE intake) and then decrease rapidly to low values (2–3 % of GE intake) for diets containing 80–90 % concentrate (Lovett et al. 2005; Martin et al. 2007). Replacing structural carbohydrates from forages (cellulose, hemicellulose) in the diet with nonstructural carbohydrates (starch and sugars) contained in most energy-rich concentrates is associated with increases in feed intake, higher rates of ruminal fermentation and accelerated feed turnover, which results in large modifications of rumen physio-chemical conditions and microbial populations. This results in a lower CH_4 production because the relative proportion of ruminal hydrogen sources declines whereas that of hydrogen sinks increases. Concerning the effect of the nature of concentrate on methanogenesis, few direct comparisons have been carried out. Concentrates rich in starch (wheat, barley, maize) have a more negative effect on CH_4 production than fibrous concentrates (beet pulp).

22.5.2.8 Propionate Enhancers

Within the rumen, hydrogen produced by the fermentation process may react to produce either methane or propionate. By increasing the presence of propionate precursors (e.g. pyruvate, oxaloacetate, malate, fumarate, citrate, succinate, etc.), more of the hydrogen is used to produce propionate and methane production is reduced (O'Mara 2004). Moreover, the stoichiometric balance of VFA, CO_2 and CH_4 indicates that acetate and butyrate promote CH_4 production whereas propionate formation conserves H_2. Therefore, when CH_4 production is decreased, propionate production is increased. Propionate precursors can be introduced as a feed additive for livestock receiving concentrates. The propionate precursor malate also occurs naturally in grasses, and research is being conducted to identify affordable natural sources, e.g. alfalfa and engineered feedstocks with high concentrations of propionate precursors. As propionate precursors naturally occur in the rumen, they are likely to be more readily acceptable than antibiotic or chemical additives.

22.5.3 Manipulation of Rumen Microbial Ecosystem

22.5.3.1 Direct-Fed Microbials

Direct-fed microbials (DFM) used in ruminant nutrition are yeast-based products (YP). The notion of using YP to mitigate CH_4 production has been discussed (Newbold and Rode 2006), but with the exception of some exciting and unconfirmed in vitro results (Chaucheyras et al. 1995), convincing animal data to support this concept are lacking. There have also been other attempts to inoculate the rumen with fungi (*Candida kefyr*) and lactic acid bacteria (*Lactococcus lactis*) along with nitrate supplementation to both control methanogenesis and possibly prevent nitrite formation, but no consistent animal data have been reported (Takahashi 2011).

22.5.3.1.1 Yeast Culture

Yeast cultures reduce methane production in three ways: (1) by reducing protozoa numbers, (2) by increasing butyrate or propionate production and (3) by stimulating acetogens to compete with methanogens or to co-metabolise hydrogen, thereby decreasing methane formation (Mwenya et al. 2004; Chaucheyras et al. 2008). However, only limited information is available on the effects of yeasts (i.e. *Saccharomyces cerevisiae* and *Aspergillus oryzae*) on methane production, and most of the studies were conducted in vitro. Carro et al. (1992) reported that supplementing Rusitec fermenters with *S. cerevisiae* reduced methane production and protozoa numbers with a 50:50 forage-concentrate diet, but no effects were observed with a 70:30 forage-concentrate diet, which would indicate that effects of probiotics may be diet dependent.

22.5.3.1.2 Methane Oxidisers

Methane-oxidising bacteria (methanotrophs) could also be introduced as direct-fed microbial preparations. The oxidation reaction would compete with the production of methane, which is a strictly anaerobic process. Methanotrophs are a unique group of methylotrophic bacteria, which utilise methane as their sole carbon and energy source (Hanson and Hanson 1996). Methane oxidisers from gut and non-gut sources could be screened for their activity in rumen.

22.5.3.2 Use of Bacteriocins

Bacteriocins are antimicrobial proteinaceous polymeric substances that are ubiquitous in nature and produced by a variety of Gram-negative and Gram-positive bacteria. They are typically narrow-spectrum antibacterial substances under the control of plasmid and play a role in competition among microbial species for niches within the rumen system. McAllister and Newbold (2008) reported that bacteriocins could prove effective in directly inhibiting methanogens and redirecting H_2 to other reductive bacteria, such as propionate producers or acetogens. The most well-known bacteriocin is nisin. Nisin obtained from *Lactobacillus lactis* ssp. *lactis* has also been shown to decrease methane production in vitro. It is nearly as potent a methane inhibitor as monensin, and it was just as effective in decreasing the acetate to propionate ratio and has been reported that 36 % methanogenesis was reduced by the use of nisin (Callaway et al. 1997). A combination of nisin and nitrate, an alternative electron receptor, has been reported to reduce methane emissions in sheep (Sar et al. 2005). Bovicin HC5, the semi-purified bacteriocin produced by *Streptococcus bovis* HC5 from the rumen, has been reported to suppress methane production by 50 % in vitro (Lee et al. 2002; Sang et al. 2002), and even low concentration of bovicin HC5 (128 activity units ml^{-1}) may be equally as useful as monensin in limiting methane production in the rumen (Lee et al. 2002). Mantovani and Russell (2002) suggested that bovicin HC5 inhibited a variety of Gram-positive bacteria and the spectrum of activity was similar to monensin. Recently, highly specific antibacterial activity of PRA-1 produced by *Lactobacillus plantarum* TUA1490L against methanogens was reported by Asa et al. (2010). The methane content was observed to decline with pediocin, enterocin and combinations of both after 24 h incubation. Some bacteriocins produced by lactic acid bacteria have been identified as an alternative group of antimicrobials for manipulation of the rumen microbial ecosystem and characterised biochemically and genetically (Chen and Hoocver 2003).

22.5.3.3 Fungal Metabolites

Secondary fungal metabolites from *Monascus* spp. reduced enteric methane emissions in sheep by 30 % in a short-term trial. Reduction of methane was accompanied, both in vitro and in vivo, by a shift in VFA pathways, decreasing the acetate to propionate ratio. The main microbial modifications observed were reduction in methanogen numbers, suggesting a specific and toxic effect on this microbial group. Methane emissions and the acetate to propionate ratio remained numerically less in the 2 weeks post-treatment as compared with measures before treatment (Morgavi et al. 2013).

22.5.3.4 Methane-Reducing Species

Mitsuokella jalaludinii has been demonstrated as an efficient methane-reducing agent in the rumen by competing with methanogens for hydrogen, necessary for growth by both (Mamuad et al. 2012). Moreover, *Mitsuokella jalaludinii* may not only decrease gas production in livestock but also improve ruminal fermentation and, in turn, improve feed efficiency. This may suggest that the favourable relationship between better feed efficiency and lower methane production may be due to an increased ability to reduce methane in the rumen as opposed to lower abundance of actual methanogenic species.

22.5.4 Phage Therapy

The lytic potential of phages and their genes make them an important tool for methane mitigation strategies. In contrast to nearly 300 phage genomes, only six archaeal phages are sequenced and described, and just four of them are from methanogens: *Methanobacterium* phage psi M1, M2 and M100 (Pfister et al. 1998) and also *Methanothermobacter* phage psi M100 (Luo et al. 2001). Little information is currently available on the genetic blueprint and gene functionality of archaeal, particularly methanogenic, phages, but more are being discovered using electron microscopy and in vitro techniques. McAllister and Newbold (2008) reported siphophages that can infect methanogens (*Methanobacter*, *Methanobrevibacter* and *Methanococcus* spp.), although these phages have not been isolated from rumen. Metagenomic surveys are expected to reveal the presence of embedded prophages and phage-like elements that would have otherwise remain unnoticed. An unanticipated outcome from sequencing the *M. ruminantium* genome was the discovery of prophage φ-mru having 69 phage-related proteins (Leahy et al. 2010). A gene encoding a putative lytic enzyme was identified, expressed and shown to lyse *M. ruminantium*. Such lytic enzyme is a potentially useful bio-controlling agent for manipulating rumen methanogenic populations (Leahy et al. 2010). Phages are host- and even strain-specific, so phage-based methane mitigation strategies could be developed without affecting other phylogenetically distinct microbes in the rumen. However, hosts and phages are also known to be involved in a rapid evolutionary race as the host changes to avoid infection and the phage changes to maintain infectivity. In combination with the application of other phage enzymes and structural components, a rotation system can be envisioned that may overcome the rapid adaptation mechanisms of microbes to phage challenges. More methanogenic phages need to be identified, sequenced and characterised to identify and employ such phage-based methane mitigation strategies.

22.5.5 Secondary Plant Metabolites

This category includes a variety of plant secondary metabolites (PSM), specifically tannins and saponins, which have been extensively studied for their CH_4 mitigating potential (Staerfl et al. 2012; Bhatta et al. 2012, 2013a). As a separate chapter addresses the role of PSM in this book, only the salient features of PSM are being discussed in this chapter.

22.5.5.1 Tannins

Tannins are plant polyphenols of varying molecular size and exist in two forms in plants: hydrolysable and condensed tannins (CT). Tannins as feed supplements or as tanniferous plants have often, but not always (Beauchemin et al. 2007), shown potential for reducing CH_4 emission by up to 20 % (Zhou et al. 2011; Staerfl et al. 2012). A meta-analysis of in vivo experiments with tannins by Jayanegara et al. (2012) reported a relatively close relationship between dietary tannin concentration and CH_4 production per unit of digestible organic matter. According to Goel and Makkar (2012), the anti-methanogenic effect of tannins depends on the dietary concentration and is positively related to the number of hydroxyl groups in their structure. These authors concluded that hydrolysable tannins tend to act by directly inhibiting rumen methanogens, whereas the effect of condensed tannins on CH_4 production is more through inhibition of fibre digestion. The mechanism to decrease methanogenesis seems to vary with the nature of CT, as Bhatta et al. (2013b) observed that *Ficus benghalensis* and *Artocarpus integrifolia* reduced methane production due to defaunation, but *Azadirachta indica* reduced methanogenesis by a direct effect on methanogens, whereas feeding up to 2 % of the dietary DM as quebracho tannin extract failed to reduce enteric methane emissions from growing cattle (Beauchemin et al. 2007).

22.5.5.2 Saponins

Saponins are naturally occurring surface-active glycosides with foaming characteristics, occurring in many plant species. They usually consist of a sugar moiety linked to a hydrophobic compound, either triterpenoid or steroid in nature (Francis et al. 2002). Saponins reduce methane production via inhibition of either protozoa or methanogens or both. These inhibited protozoa at relatively low concentrations, whereas higher concentrations were required to kill or suppress methanogenic archaea (Wina et al. 2005; Goel et al. 2008). Saponins are considered to have detrimental effects on protozoa through their binding with cholesterol present on the protozoal cell membrane leading to its disruption, breakdown, lysis and finally cell death (Francis et al. 2002). Because of their anti-protozoal activity, saponins might have the potential to reduce CH_4 as protozoa have both an ecto- and endosymbiotic relationship with methanogens, and methanogens associated with protozoa are estimated to be responsible for 9–37 % of the total CH_4 production in the rumen (McAllister and Newbold 2008). Anti-methanogenic activity of saponins is believed to occur by limiting hydrogen availability to methanogens and rechannelling of metabolic hydrogen from methane to propionate production in the rumen (Wina et al. 2005). In addition, saponins, due to their chemical structure, may display antibacterial properties by reducing the number of bacteria producing H_2 thus resulting in the inhibition of H_2 production—a substrate for methane formation (Wang et al. 2009).

22.5.6 Immunisation for Reducing Enteric Methane Mitigation

Host immunisation offers a diverse and eco-friendly solution to the problems associated with animal health. Therefore, developing vaccines against methanogens appears to be an alternative and attractive approach for extensive production systems. Vaccines against rumen archaea are based on the concept of a continuous supply of antibodies to the rumen through saliva. The vaccine also works by triggering an animal's immune system to produce antibodies against methanogenic bacteria that live in the rumen of the animal. Wright et al. (2004) developed two vaccines, VF3 (based on three methanogenic strains 1Y, AK-87 and ZA-10) and VF7 (based on seven methanogens), that produced a 7.7 % reduction in methane emissions from sheep, despite targeting only a minority (20 %) of methanogens present within these host animals. Moreover, in Europe up to 23 % ruminal methane emission reduction was reported (Wedlock et al. 2010). They also created a vaccine based on five methanogens (*Methanobrevibacter* spp. strains 1Y, AK-87, *M. millerae* ZA-10, *Methanomicrobium* mobile BP and *M. stadtmanae* MCB-3) that was administered in three vaccinations to sheep (Williams et al. 2009). Surprisingly, immunisation with this second vaccine caused methane output to increase by 18 %, despite the fact that a larger proportion of the methanogenic population (52 %) was targeted. Vaccines against archaea have been successful in vitro (Wedlock et al. 2010) but not in vivo (Wright et al. 2004; Williams et al. 2009). Vaccines prepared from New Zealand and Australian methanogen strains proved unsuccessful in reducing CH_4 production in ewe lambs (Clark et al. 2004). Thus, further work is needed to optimise the individual components of these vaccines such that the most potent methanogens are specifically targeted. Researchers believe that anti-methanogenic vaccines will only yield the short-term reductions in methanogens and/or methanogenesis, due to the possible proteolytic degradation and low persistence of host antibodies in rumen (Cook et al. 2008; Lascano and Cárdenas 2010). Vaccination of sheep with entodinial or mixed protozoa antigens reduced protozoa, and the released IgG antibodies against rumen protozoa remained active and continued to bind the target cells up to 8 h (Williams et al. 2008). Vaccines targeting single surface antigens may not be effective, as methanogenic archaea differ largely based on their host, diet as well as geographical regions. A new vaccine has been developed using subcellular fractions (cytoplasmic and cell wall-derived protein) of *M. ruminantium* M1 (Wedlock et al. 2010). Twenty sheep were vaccinated, then booster doses were given after 3 weeks and the antisera were found to agglutinate and decrease the growth of archaeal methanogens and methane production in vitro. The in vivo efficacy of the vaccine on methanogens is yet to be evaluated. New approaches have involved identification of genes encoding specific membrane-located proteins from *M. ruminantium* and using purified proteins (produced in *Escherichia coli*) as antigens to vaccinate sheep (Buddle et al. 2011).

In another approach, antisera were generated in sheep against subcellular fractions from *M. ruminantium*, which reduced microbial growth and CH_4 production in vitro (Wedlock et al. 2010). Sequencing the genome of *M. ruminantium* has opened new opportunities for inhibition of rumen methanogens and the potential to mitigate ruminant CH_4 emissions (Leahy et al. 2010). Based on liquid chromatography mass spectrometer, it was reported that most of the proteins were intracellular enzymes, particularly methyl-coenzyme M reductase, and these intracellular proteins would not be suitable as vaccine antigens owing to their inaccessibility for antibody binding. Since there is growing database for the genome sequences of rumen methanogens, the possibility of finding new target antigens/proteins using comparative and pangenomics analysis has increased. Furthermore, extensive research is needed to identify adjuvants that stimulate high titre of antibody and are suitable for formulating with protein antigens to produce a low-cost and effective vaccine. However, the vaccine-based inhibition method will have to pass the regulatory systems to guarantee animal health.

A team of researchers at Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Australia have made an application for a worldwide patent for a method of improving the productivity of a ruminant animal by administering to the animal an immunogenic preparation effective to invoke an immune response to at least one rumen protozoan. The removal of one species of protozoan from the rumen will invoke the improvements in productivity associated with defaunation. It is also believed that by modifying the activity of the rumen protozoan, there will be an indirect effect on the activity of methanogens, due to their commensal relationship with rumen protozoa. Data from this work are not yet published, but it is anticipated that methane production could be reduced by as much as 70 %. The anti-methanogen vaccine is under development by CSIRO in Australia. A number of experimental vaccine preparations were given to sheep. The studies have shown that up to a 20 % reduction in methane production is possible, but the observed reductions are dependent on diet, climate and time of year. To date, sheep have been used as the experimental animal because of the ease of use and availability. Methane production was reduced by 11–23 % in vaccinated animals. CSIRO's next task is to develop a vaccine and test its effectiveness in cattle.

22.5.7 Modelling of GHG in Livestock Farm

Livestock undoubtedly need to be a priority focus of attention as the global community seeks to address the challenge of CC. The magnitude of the discrepancy between estimates illustrates the need to provide the CC community and policymakers with accurate emission estimates and information about the link between agriculture and climate. Improving the global estimates of GHG attributed to livestock systems is of paramount importance. This is not only because we need to define the magnitude of the impact of livestock on CC but also because we need to understand their contribution relative to other sources. Estimates of GHG emission through experiments under different production system is practically impossible and with growing awareness of global warming and its continuous negative impact on agricultural production system demands immediate mitigation strategies to curtail such emissions. In this context, simulation models offer a great scope to predict accurately the GHG emission in farm as a whole (Sejian et al. 2011c). Such information will enable effective mitigation options to be designed to reduce emissions and improve the sustainability of the livestock sector while continuing to provide livelihoods and food for a wide range of people. A synthesis of the available literature suggests that the mechanistic models are superior to empirical models in accurately predicting the CH_4 emission from dairy farms (Sejian and Naqvi 2012). The latest development in prediction model is the integrated farm system model which is a process-based whole-farm simulation technique (Chianese et al. 2009; Rotz et al. 2009).

22.6 Amelioration Strategies to Improve Livestock Production Under Changing Climate Scenario

Livestock producers have traditionally adapted to various environmental and climatic changes by building on their in-depth knowledge of the environment in which they live. However, the expanding human population, urbanisation, environmental degradation and increased consumption of animal source foods have rendered some of those coping mechanisms ineffective (Sidahmed 2008). Since CC could result in an increase of heat stress, all methods to help animals cope with or, at least, alleviate the impacts of heat stress could be useful to mitigate the impacts of global change on animal responses and performance (Sejian et al. 2012b).

22.6.1 Physical Protection

Physical protection with artificial or natural shade presently offers the most immediate and cost-effective approach for enhancing the productive and reproductive efficiency of animals (Sejian 2013). Evaporative cooling also can be effective. Various shade management systems have been evaluated extensively and generally result in improved feed intake and productivity. Sprinkling animal in the morning is more effective than sprinkling in the afternoon. Certainly, it is recommended to start cooling strategies prior to animal showing signs of heat stress (panting). Sprinkling of pen surfaces may be as much or more beneficial than sprinkling the animal. Cooling the surface would appear to provide a heat sink for animal to dissipate body heat, thus allowing animal to better adapt to environmental conditions than adapting to being wetted. In handling studies, moving animal through working facilities requires an expenditure of energy causing an elevation of average body temperature between 0.5 and 1.0 °C (0.9 and 1.8 °F), depending on the ambient conditions. So during hot days, minimal handling of animal is recommended for promoting animal comfort. Bedded barn facilities appear to be useful for buffering animal against the adverse effects of the environment under hot and cold conditions even though 2–4 °C higher temperature as well as THI level is maintained within the barn when compared to outside conditions, possibly by the decreased airflow through the building. The use of bedded barns does not reduce heat stress, as measured by the THI, but act as a shade to decrease the solar heat load on the animal.

22.6.2 Ideal Shed Requirements

Careful management which can alleviate heat stress is the best way to maintain high production levels in lactating cows in a hot environment. Cattle will produce milk and reproduce more efficiently if they are protected from extreme heat and particularly from direct sunshine. Good management includes the modification of the surrounding environment to reduce the impact of the environment and/or to promote heat loss from the animals (Shibata 1996). Thus, in tropical and subtropical climates, providing shade becomes an important factor. In many cases, the provision of shade may be the most economical solution of reducing high heat load. It is suggested that a well-designed shade structure should reduce the total heat load by 30–50 %. Although the benefits of providing shade to cattle will vary depending on factors such as breed, coat colour, weight, health and lactation status, producers may be able to increase production and improve pasture use and water quality by providing it. The amount of shade needed depends on the type and age of the cattle. Shade is a must for pasture-based grazing systems. It curtails heat stress, which is detrimental to cattle. Besides, if cattle are kept in a confined area, it should be free from mud and manure in order to reduce hoof infection to a minimum. Concrete floors or pavements are ideal where the area per cow is limited. However, where ample space is available, an earth yard, properly sloped for good drainage, is adequate. The size of this paved area depends on the orientation of the shade structure. If the longitudinal axis is east to west, then part of the floor under the roof should be in shade all day. Extending the floor by approximately one-third of its length on the east and on the west results in a paved surface being provided for the shaded area at all times. If the longitudinal axis is north to south, the paved area must be three times the roof area, i.e. one-third to the east, one-third to the west and one-third underneath. In regions where temperatures average 30 °C or more for up to 5 h per day during some period of the year, the east-west orientation is the most beneficial.

Shade cloth is typically used as the roof covering to allow air movement. Shade cloth patterns come in various weaves providing 30–90 % shade. One of the more common types is a woven polypropylene fabric which provides 80 % shade. While longevity is considerably less than that expected of permanent structures, shade cloth if properly maintained (kept tight) can last 5 years or longer. Shade cloth is commonly available in black, though lighter colours reflect more heat. The gable roof is more wind resistant than a single pitch roof and allows for a centre vent. A woven mat of local materials can be installed between the rafters and the corrugated iron roof to reduce radiation from the steel and to reduce temperatures just below the roof by 10 °C or more.

Cattle generally prefer shade from trees rather than constructed structures. Trees are effective at blocking incoming solar radiation, and moisture evaporating from their leaves helps cool surrounding air (Hahn 1981). Planting shade trees on the west side of pastures will provide protection from the afternoon sun. Feed and water can be located close to the existing or planned natural shade. Permanent shade can be provided by constructing barns or sheds. It is most often provided for dry lots and bull lots. Often in a grazing system, permanent shade is not located where it is needed, and it can be costly. The size of shade structures varies according to climatic conditions. Researchers worldwide generally recommend 19–27 ft^2 of floor space per cow. However, for environments that are particularly hot and humid, floor space equivalent to 60–65 ft^2 per cow is recommended. Space requirements are essentially doubled in hot and humid climates to provide additional open area for improved air movement.

Air movement increases the rate of heat loss from a cow's body surface, as long as the air temperature is lower than the animal's skin temperature. Fans should be tilted downward at a 20–30° angle (from vertical) to direct the flow of air onto the cows, and preferably they should be kept above the sprinklers to remove the moisture. Another cooling device that might be useful is using mist and fan system. In this cooling system, mist particles are sprayed onto the animal's body to wet the hair. A fan is then used to evaporate the moisture, as a way of cooling the cows. The single use of a sprinkling and fan system, for 30 min before milkings, has proved to be useful to relieve dairy cows' heat stress, in terms of efficiency to reduce the impact of heatwaves under a grazing system (Valtorta et al. 2002).

22.6.3 Nutritional Interventions

There is a growing interest in strategically altering the diet in an attempt to improve the production of livestock in changing climatic stress (Sejian 2013; Shinde and Sejian 2013). A common strategy is to increase the energy and nutrient density (reduced fibre, increased concentrates and supplemental fat) of the diet as feed intake is markedly decreased during heat stress. In addition to the energy balance concern, reducing the fibre content of the diet is thought to improve the cow's thermal balance and may reduce body temperature (FAO 2012). Because there is greater heat production associated with metabolism of acetate compared with propionate, there is a logical rationale for the practice of feeding low fibre rations during hot weather. Feeding more concentrate at the expense of fibrous ingredients increases ration energy density and reduces heat increment (Sejian et al. 2012b). Due to reduced feed intake, dietary protein levels may need to be increased during heat stress (West 1999). However, recent recommendations suggest that addition of dietary crude protein, more specifically rumen undegradable protein, is not helpful (Arieli et al. 2006). Increasing the amount of dietary fat has been a widely accepted strategy within the industry in order to reduce basal metabolic heat production. The heat increment of fat is over 50 % less than typical forages, so it is seemingly a rational decision to supplement additional lipid and reduce fibre content of the diet.

Water intake is vital for milk production (milk is ~87 % water) and also essential for thermal homeostasis. This stresses the importance of water availability. Keeping water tanks clear of feed debris and algae is a simple and cheap strategy to help cows remain cool and improve production (Baumgard and Rhoads 2007). Further, dietary supplementation with either lipoic or dihydrolipoic acid may improve heat tolerance and animal performance during heat stress by enhancing insulin action. However, the effectiveness of lipoic acid supplementation to alter glucose availability may be dependent on the magnitude and duration of heat stress events (Hamano 2012).

22.6.3.1 Mineral Supplementation

Unlike humans, bovines utilise potassium (K^+) as their primary osmotic regulator of water secretion from sweat glands. As a consequence, K^+ requirements are increased (1.4–1.6 % of DM) during the heat stress, and this should be adjusted for in the diet. In addition, dietary levels of sodium (Na^+) and magnesium (Mg^+) should be increased as they compete with K^+ for intestinal absorption (West 2002). Among micronutrients, zinc is one of the most important in the body (Stefanidou et al. 2006). At the cellular level, zinc is essential for cell proliferation and survival and contributes to genomic stability and antioxidant defence. Zinc is a potent inducer of Hsp70 in cell culture (Hatayama et al. 1993), which is indispensable for adaptation (Voellmy 2004). Besides, chromium has proved its importance during thermal stress. Chromium facilitates insulin action on glucose, lipid and protein metabolism. Because glucose use predominates during heat stress, chromium supplementation may improve thermal tolerance or production in heat-stressed animals (Spears et al. 2012).

22.6.3.2 Antioxidant Supplementation

Nutritional tools such as antioxidant feeding (vit. A, selenium, zinc, etc.) and ruminant-specific live yeast can help. Studies have shown that addition of antioxidant in diets of sheep is able to reduce heat stress and is a good strategy to prevent mastitis, optimise feed intake and reduce the negative impact of heat stress on milk production. Moreover, the use of antioxidant such as vit. E, vit. A, selenium and selenium-enriched yeast helps in reducing the impact of heat stress on the oxidant balance, resulting in improved reproductive efficiency (Sejian et al. 2014). Both vitamin C and vitamin E protect the biological membranes against the damage of reactive oxygen species (ROS). The role of vitamin E as an inhibitor—“chain blocker”—of lipid peroxidation has been well established (Seyrek et al. 2004). Vitamin C along with electrolyte supplementation has also been reported to ameliorate the heat stress in buffaloes (Sunil Kumar et al. 2010).

22.6.4 Disease Surveillance Measures

Adaptation assessments are designed to identify options to reduce the current and projected health risks attributable to CC by preventing exposures to weather and climate hazards, reducing the consequences of exposure and/or reducing vulnerabilities. Assessing the potential infectious disease risks of CC also requires considering the non-climatic factors that drive their incidence and distribution, including demographics, socio-economic development, land use, urbanisation, technology and the political and health-care context (Weiss and McMichael 2004; Suk and Semenza 2011). There is an urgent need for public health and health care to develop adaptation strategies for the impacts of CC on infectious diseases (Zhang et al. 2008; Paaijmans et al. 2010).

One of the most critical obstacles to improving our understanding of climate-disease linkages is the lack of high-quality epidemiological data on disease incidence for many locations. Greater attention should be focused on areas where climate-sensitive diseases are often found or where outbreaks that appear to be weather related are more severe and more difficult to predict. Increased understanding of disease-climate linkages should permit public health workers to begin to shift focus from “surveillance and response” to a more proactive approach of “prediction and prevention”. Adaptive capacity can be improved through better surveillance if the resulting data are made available in a timely fashion and appropriate manner.

Age- and cause-specific mortality surveillance offers a baseline for recognising what is considered "normal" and allows recognition of unusual mortality periods or locations. Such death data have served as the basis for analysis of extreme weather events that occur over days to weeks. Floods, heatwaves and "cold snaps" are examples. Historical surveillance data permit evaluation of how these extreme weather periods may have resulted in deaths above what would have been expected for that time and place. Modern computing power is also being used to improve surveillance through geographical information systems (GIS) and spatial statistical analyses. More and more countries are using simple, low-cost GIS for management and mapping of their data. The health map programme of the World Health Organization (WHO) helps countries use GIS systems with standardised indicators to enhance comparability. These computer programs allow data entry and analysis at the local level and can be transmitted electronically to higher levels without loss of detail. When available, such data may be relevant to understanding the pattern of various diseases, depending on their transmission pattern and other relationships. Other kinds of surveillance data, derived from satellite images (remote sensing data), are often included in GIS and spatial statistical analyses that contribute to disease surveillance and pattern analysis. Another important contemporary surveillance method involves use of acute-care networks that employ innovative software for detecting known risks and unexpected events. These measures will ensure timely intervention of sudden disease outbreaks of livestock that might occur as a result of CC.

22.6.5 Advanced Reproductive Technologies

Infertility in the male caused by heat stress can be eliminated through the utilisation of artificial insemination (AI) with semen collected and frozen from males in cool environments. In females, the situation is more complicated; embryo transfer (ET) represents a method analogous to AI in that embryos can be collected from nonstressed cows and transferred to heat-stressed recipients (Rutledge 2001). ET can be an effective fertility-enhancing strategy for the heat-stressed cow because most of the effects of heat stress to reduce fertility occur before the blastocyst stage of development when embryos are typically transferred. It may also be possible to remove damaged follicles from the ovary by transvaginal aspiration to hasten the recovery period after heat stress. Estrus induction techniques offer the opportunity to induce fertile estrus in noncyclic animals to increase fertility. Different treatments have been utilised to induce estrus, such as prostaglandin, gonadorelin and progestagen. Better results have been obtained using progesterone-impregnated intravaginal device (PRID) plus pregnant mare serum gonadotropin (PMSG) and prostaglandin. Stem cell research in livestock is still in its infancy, and a number of technical hurdles need to be overcome before the full potential of research and therapeutic use can be realised. Induced differentiation of stem cells towards male and female gametes can be exploited for combating infertility problems. The embryo production and transfer technique is immensely useful in the production of embryonic stem cells and transgenic animals. It shall be highly useful to improve efficiency of this technology and study basic mechanisms involved in it using modern molecular and proteomics approaches.

Administrations of hormonal preparations have found to be more beneficial for improving reproductive efficiency in livestock. Pregnancy rate can also be improved in the summer and autumn in primiparous cows by the use of gonadotropin-releasing hormone and prostaglandin F2α to generate three consecutive 9-day follicular waves beginning at 50–60 days in milk (Friedman et al. 2011). The gonadotropin-releasing hormone (GnRH) administered at estrus onset is found more effective in primiparous cows and during the summer in increasing conception rate in cows with low body condition scores at AI (Kaim et al. 2003). In particular, administration of either follicle-stimulating hormone (FSH) or somatotropin during one estrous cycle in the autumn improves oocyte quality in the subsequent cycle (Roth et al. 2002). Among its many actions, insulin-like growth factor-1

(IGF-1) can protect cells from various forms of stress including elevated temperature. In particular, administration of IGF-1 to bovine embryos produced in vitro reduced the magnitude of effects of elevated temperature on inhibition of development and apoptosis (Jousan and Hansen 2004, 2007). Probably the easiest way to increase IGF-1 concentrations in lactating cows is to administer bovine somatotropin (bST). Sakatani et al. (2004) indicated that treatment of cows with bST can increase pregnancy rates of cows bred via timed AI, increase the survivability of embryos recovered from donors and increase the pregnancy rate of recipients treated with bST. ET offers the opportunity to expose embryos directly to IGF-1. Transfer of in vitro-produced embryos that were cultured with IGF-1 into heat-stressed, lactating recipients resulted in increased pregnancy and calving rates as compared to transfer of in vitro-produced embryos cultured without IGF-1 (Block and Hansen 2007).

22.6.6 Thermal Tolerance Genes in Livestock

Given the complexity of the traits related to adaptation to tropical environments, the discovery of genes controlling these traits is a very difficult task. One obvious approach of identifying genes associated with acclimation to thermal stress is to utilise gene expression microarrays in models of thermal acclimation to identify changes in gene expression during acute and chronic thermal stress. Another approach will be with single gene deletions exposed to a defined thermal environment. This permits the identification of those genes that are involved in key regulatory pathways for thermal resistance and thermal sensitivity. Finally, gene knockout models in single cells will also allow better delineation of the cellular metabolic machinery required to acclimate to thermal stress. Those genes identified as key to the process of thermal acclimation will then need to be mapped to their chromosomal location, and the sequences of these genes will need to be determined in order to see if there are single-nucleotide polymorphisms (SNPs) that are associated with changes in the coding for gene expression or protein function. Identification of SNPs that are associated with variation in animal resistance or sensitivity to thermal stress will permit screening of animal's presence or absence of desirable or undesirable alleles. However, further research is needed to quantify the genetic antagonism between adaptation and production traits to evaluate the potential selection response.

Studies evaluating genes identified as participating in the cellular acclimation response from microarray analyses or genome-wide association studies have indicated that heat-shock proteins are playing a major role in adaptation to thermal stress. In mammalian cells, nonlethal heat shock produces increased thermotolerance through enhanced expression of heat-shock genes. Additional genes of interest which two or more studies have identified are the genes for fibroblast growth factor, solute carrier proteins, interleukins and tick-resistance genes. Genes which have only been identified by microarray analysis but not by genome-wide association studies include genes associated with cellular metabolism (phosphofructokinase, isocitrate dehydrogenase, NADH dehydrogenase, glycosyltransferase, transcription factor and mitochondrial inositol protein). Other genes of importance were thyroid hormone receptor, insulin-like growth factor II and annexin. Genes repressed in response to the environmental stress are mostly concerned with translation of genes for cytoplasmic ribosomal protein, DNA polymerase I, II and III, transcription, t-RNA synthetases, proteins required for processing ribosomal RNA and a subset of translation initiation factors. The identification of the variety of CER genes involved in stress responses suggests that these responses are aimed at production of additional energy (ATP), maintenance of environment as well as the repression of protein synthesis to ensure energy conservation and minimise unnecessary burden on the part of the cell. Marker-assisted selection (MAS) programme may be clubbed with appropriate breeding programme involving these thermotolerant genes to produce animals which have superior adaptive capability to environmental extremes.

22.7 Conclusion

Climate change is seen as a major threat to the survival of many species, ecosystems and the sustainability of livestock production systems in many parts of the world. Livestock production is thought to be adversely affected by detrimental effects of extreme climatic conditions. Consequently, adaptation and mitigation of detrimental effects of extreme climates have played a major role in combating the climatic impact in livestock production. In fact, the animals can adapt to the hot climate; nevertheless, the response mechanisms are helpful for survival but are detrimental to performance. Hence, formulating mitigation strategies incorporating all requirements of livestock is the hour of need to optimise productivity in livestock farms. This chapter also elaborates on different adaptive strategies that need to be given due consideration to prevent huge economic losses incurred due to climate change impact on livestock productivity. Further, this chapter details the issues of less-than-perfect information on climate impacts and vulnerabilities and need for better informed decisions on "resilient adaptation" by merging adaptation, mitigation and amelioration strategies. It offers new perspectives for policymakers, institutions, societies and individuals on improved ways of identifying most at-risk communities and "best practices" of coping with current climate variability and extreme climate events. With the development of molecular biotechnologies, new opportunities are available to characterise gene expression and identify key cellular responses to environmental stresses that arise due to climate change. These new tools will enable to improve the accuracy and the efficiency of selection for heat tolerance in livestock.

22.8 Future Perspectives

Adaptation to CC is an integral part of agricultural production now and will become more important in the future as the impacts of CC become more evident. In developing a strategy for adapting to CC, one key challenge is dealing with uncertainty. Significant uncertainty relates to the nature and extent of regional CC impacts, impacts across agricultural industries and impacts over time. The challenge for governments and agricultural industry stakeholders is to deal with these uncertainties through further research and the development of policies and farm management approaches that are flexible enough to deal effectively with a range of potential CC outcomes.

Responding to the challenges of global warming necessitates a paradigm shift in the practice of agriculture and in the role of livestock within the farming system. Science and technology are lacking in thematic issues, including those related to climatic adaptation, dissemination of new understandings in rangeland ecology, and a holistic understanding of pastoral resource management. The key thematic issues on environment stress and livestock production includes: early warning system, multiple stress research, simultaneous simulation models, water experiments, exploitation of genetic potential of native breeds, suitable breeding programme and nutritional intervention research. Livestock farmers should have key roles in determining what adaptation and mitigation strategies they support if these have to sustain livestock production in changing climate. The integration of new technologies into the research and technology transfer systems potentially offers many opportunities to further the development of CC adaptation strategies.

With the development of molecular biotechnologies, new opportunities are available to characterise gene expression and identify key cellular responses to environmental stresses that arise due to CC. These new tools will enable to improve the accuracy and the efficiency of selection for heat tolerance in livestock. Substantial efforts are also needed to identify specific genes associated with tolerance and sensitivity to heat stress. Continued research evaluating genomic and proteomic approaches to improve reproductive performance and nutritional status of heat stress animals is also warranted. Also, further researches are required to quantify the genetic antagonism between adaptation and production traits to evaluate the potential selection response. Epigenetic regulation of gene expression and thermal imprinting of the genome could also be an efficient method to improve thermal tolerance.

References

Abecia L, Toral PG, Martín-García AI, Martínez G, Tomkins NW, Molina-Alcaide E, Newbold CJ, Yaňez-Ruiz DR (2012) Effect of bromochloromethane on methane emission, rumen fermentation pattern, milk yield, and fatty acid profile in lactating dairy goats. J Dairy Sci 95:2027–2036

Anderson RC, Callaway TR, Van Kessel JA, Jung YS, Edrington TS, Nisbet DJ (2003) Effect of select nitrocompounds on ruminal fermentation; an initial look at their potential to reduce economic and environmental costs associated with ruminal methanogenesis. Bioresour Technol 90:59–63

Antle JM (2010) Asymmetry, partial moments, and production risk. Am J Agric Econ 92(5):1294–1309

Appuhamy JADRN, Strathe AB, Jayasundara S, Wagner-Riddle C, Dijkstra J, France J, Kebreab E (2013) Antimethanogenic effects of monensin in dairy and beef cattle: a meta-analysis. J Dairy Sci 96:5161–5173

Arieli A, Adin G, Bruckental I (2006) The effect of protein intake on performance of cows in hot environmental temperatures. J Dairy Sci 87:620–629

Asa R, Tanaka A, Uehara A, Shinzato I, Toride Y, Usui N, Hirakawa K, Takahashi J (2010) Effects of protease-resistant antimicrobial substances produced by lactic acid bacteria on rumen methanogenesis. Asian Aust J Anim Sci 23:700–707

Baumgard LH, Rhoads RP (2007) The effects of hyperthermia on nutrient partitioning. Proc Cornell Nutr Conf 93–104

Beauchemin KA, McGinn SM (2006) Methane emissions from beef cattle: effects of fumaric acid, essential oil, and canola oil. J Anim Sci 84:1489–1496

Beauchemin KA, McGinn SM, Martinez TF, McAllister TA (2007) Use of condensed tannin extract from quebracho trees to reduce methane emissions from cattle. J Anim Sci 85:1990–1996

Beauchemin KA, Kreuzer M, O'Mara F, McAllister TA (2008) Nutritional management for enteric methane abatement: a review. Aust J Exp Agric 48:21–27

Beever DE, Cammell SB, Sutto JD, Spooner MC, Haines MJ, Harland JI (1989) Effects of concentrate type on energy utilization in lactating dairy cows. In: Van der Honing Y, Close WH (eds) Energy metabolism of farm animals, EAAP Publication no. 43. Pudoc, Wageningen, pp 33–36

Benchaar C, Pomar C, Chiquette J (2001) Evaluation of dietary strategies to reduce methane production in ruminants: a modelling approach. Can J Anim Sci 81:563–574

Bergquist R, Rinaldi L (2010) Health research based on geospatial tools: a timely approach in a changing environment. J Helminthol 84:1–11

Bhatta R, Saravanan M, Baruah L, Sampath KT (2012) Nutrient content, in vitro ruminal fermentation characteristics and methane reduction potential of tropical tannin-containing leaves. J Sci Food Agric 92:2929–2935

Bhatta R, Enishi O, Yabumoto Y, Nonaka I, Takusari N, Higuchi K, Tajima K, Takenaka A, Kurihara M (2013a) Methane reduction and energy partitioning in goats fed two concentrations of tannin from Mimosa spp. J Agric Sci (Cambridge) 151:119–128

Bhatta R, Saravanan M, Baruah L, Dhali A, Kolte A, Prasad CS (2013b) Effect of graded levels of tropical leaves containing-secondary metabolites on rumen fermentation pattern protozoa population and methanogenesis in vitro. Adv Anim Biosci 4(2):307

Blaxter KL, Clapperton JL (1965) Prediction of the amount of methane produced by ruminants. Br J Nutr 19:511–522

Block J, Hansen PJ (2007) Interaction between season and culture with insulin-like growth factor-1 on survival of in vitro produced embryos following transfer to lactating dairy cows. Theriogenology 67:1518–1529

Boadi D, Wittenburg KM, Scott SL, Burton D, Buckley K, Small JA, Ominski KH (2004) Effect of low and high forage diets on enteric and manure pack GHG emissions from a feedlot. Can J Anim Sci 84:445

Bodas R, Prieto N, García-González R, Andrés S, Giráldez FJ, López S (2012) Manipulation of rumen fermentation and methane production with plant secondary metabolites. Anim Feed Sci Technol 176:78–93

Bowman RL, Croucher JC, Picard MT (1992) Assessment of the prefeasibility of strategic supplementation as an opportunity for reducing methane emissions in Gujarat, India, A.T, International, prepared for the Global change Division, U.S. Environmental protection agency, Washington, DC

Brask M, Lund P, Weisbjerg MR, Hellwing AL, Poulsen M, Larsen MK, Hvelplund T (2013) Methane production and digestion of different physical forms of rapeseed as fat supplement in dairy cows. J Dairy Sci 96:2356–2365

Brown EG, Anderson RC, Carstens GE, Gutierrez-Baňuelos H, McReynolds JL, Slay LJ, Callaway TR, Nisbet DJ (2011) Effects of oral nitroethane administration on enteric methane emissions and ruminal fermentation in cattle. Anim Feed Sci Technol 166–167:275–281

Buddle BM, Denis M, Attwood GT, Altermann E, Janssen PH, Ronimus RS, Pinares-Patiño CS, Muetzel S, Wedlock DN (2011) Strategies to reduce methane emissions from farmed ruminants grazing on pasture. Vet J 188:11–17

Busquet M, Calsamiglia S, Ferret S, Kamel C (2005) Screening for the effects of natural plant extracts and secondary plant metabolites on rumen microbial fermentation in continuous culture. Anim Feed Sci Technol 123:597–613

Callaway TR, Alexandra MS, Carneiro De Melo, Russell JB (1997) The effect of nisin and monensin on ruminal fermentations in vitro. Curr Microbiol 35:90–96

Carro MD, Ranilla MJ (2003) Effect of the addition of malate on in vitro rumen fermentation of cereal grains. Br J Nutr 89:181–188

Carro MD, Lebzien P, Rohr K (1992) Influence of yeast culture on the in vitro fermentation (Rusitec) of diets containing variable portions of concentrates. Anim Feed Sci Technol 37:209–220

Castillo C, Benedito JL, Méndez J, Pereira V, López-Alonso M, Miranda M, Hernández J (2004) Organic acids as a substitute for monensin in diets for beef cattle. Anim Feed Sci Technol 115:101–116

Chaucheyras F, Fonty G, Bertin G, Gouet P (1995) In vitro H_2 utilization by a ruminal acetogenic bacterium cultivated alone or in association with an archaea methanogen is stimulated by a probiotic strain of Saccharomyces cerevisiae. Appl Environ Microbiol 61:3466–3469

Chaucheyras F, Walker ND, Bach A (2008) Effects of active dry yeasts on the rumen microbial ecosystem: past, present and future. Anim Feed Sci Technol 145:5–26

Chaucheyras-Durand F, Walker ND, Bach A (2008) Effects of active dry yeasts on the rumen microbial ecosystem: past, present and future. Anim Feed Sci Technol 145:5–26

Chen H, Hoocver DG (2003) Bacteriocins and their food applications. CRFSFS 12:82–99

Chianese DS, Rotz CA, Richard TL (2009) Whole farm greenhouse gas emissions. A review with application to a Pennsylvania dairy farm. Appl Eng Agric 25(3):431–442

Clark H, Wright AD, Joblin K, Molano G, Chavanagh A, Peters J (2004) Field testing and Australian developed antimethanogen vaccine in growing ewe lambs. In: Proceedings of the workshop on the science of atmospheric trace gases, Wellington, 18–19 Mar 2004, pp 107–108

Clemens J, Ahlgrimm HJ (2001) Greenhouse gases from animal husbandry and mitigation options. Nutr Cycl Agroecosyst 60:287–300

Cook SR, Maiti PK, Chaves AV, Benchaar C, Beauchemin KA, McAllister TA (2008) Avian (IgY) anti-methanogen antibodies for reducing ruminal methane production: in vitro assessment of their effects. Aust J Exp Agric 48:260–264

De Mazancourt C, Loreau M, Abbadie L (1998) Grazing optimization and nutrient cycling: when do herbivores enhance plant production? Ecology 79:2242–2252

Demeyer D, Fievez V (2000) Ruminants et environment: la méthanogénèse. Ann Zootech 49:95–112

Deressa T, Hassan R, Poonyth D (2005) Measuring the economic impact of climate change on South Africa's sugarcane growing regions. Agrekon 44(4):524–542

Ding X, Long R, Zhang Q, Huang X, Guo X, Mi J (2012) Reducing methane emissions and the methanogen population in the rumen of Tibetan sheep by dietary supplementation with coconut oil. Trop Anim Health Prod 44:1541–1545

Dohme F, Machmüller A, Wasserfallen A, Kreuzer M (2000) Comparative efficiency of various fats rich in medium-chain fatty acids to suppress ruminal methanogenesis as measured with RUSITEC. Can J Anim Sci 80:473–484

Doreau M, Ferlay A (1995) Effect of dietary lipids on nitrogen metabolism in the lumen: a review. Livest Prod Sci 43:97–110

Doreau M, Jouany JP (1998) Effect of a Saccharomyces cerevisiae culture on nutrient digestion in lactating dairy cows. J Dairy Sci 81:3214–3221

Eckard RJ, Grainger C, De Klein CAM (2010) Options for the abatement of methane and nitrous oxide from ruminant production – a review. Livest Sci 130:47–56

Ellis JL, Dijkstra J, Bannink A, Kebreab E, Hook SE, Archibeque S, France J (2012) Quantifying the effect of monensin dose on the rumen volatile fatty acid profile in high-grain fed beef cattle. J Anim Sci 90:2717–2726

FAO (2012) Balanced feeding for improving livestock productivity – increase in milk production and nutrient use efficiency and decrease in methane emission. In: Garg MR (ed) FAO Anim Prod Health Pap No. 173. Rome. 1080/00330124.2014.921017 (2014)

Foley PA, Kenny DA, Callan JJ, Boland TM, O'Mara FP (2009) Effect of dl-malic acid supplementation on feed intake, methane emission, and rumen fermentation in beef cattle. J Anim Sci 87:1048–1057

Fox NJ, Marion G, Davidson RS, White PCL, Hutchings MR (2012) Livestock helminths in a changing climate: approaches and restrictions to meaningful predictions (review). Animals 2:93–107

Francis G, Kerem Z, Makkar HSP, Becker K (2002) The biological action of saponins in animal systems: a review. Br J Nutr 88:687–695

Friedman E, Voet H, Reznikov D, Dagoni I, Roth Z (2011) Induction of successive follicular waves by gonadotropin-releasing hormone and prostaglandin F2α to improve fertility of high-producing cows during the summer and autumn. J Dairy Sci 94:2393–2402

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A, Tempio G (2013) Tackling climate change through livestock – a global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of the United Nations (FAO), Rome

Goel G, Makkar HPS (2012) Methane mitigation from ruminants using tannins and saponins. Trop Anim Health Prod 44:729–739

Goel G, Makkar HPS, Becker K (2008) Changes in microbial community, structure, methanogenesis and rumen fermentation in response to saponin-rich fractions from different plant materials. J Appl Microbiol 105:770–777

Gómez JA, Tejido ML, Carro MD (2005) Mixed rumen microorganisms growth and rumen fermentation of two diets in RUSITEC fermenters: influence of disodium malate supplementation. Br J Nutr 93:479–484

Gutierrez-Banuelos H, Anderson RC, Carstens GE, Slay LJ, Ramlachan N, Horrocks SM, Callaway TR, Edrington TS, Nisbet DJ (2007) Zoonotic bacterial populations, gut fermentation characteristics and methane production in feedlot steers during oral nitroethane treatment and after the feeding of an experimental chlorate product. Anaerobe 13:21–31

Hahn GL (1981) Housing and management to reduce climatic impacts on livestock. J Anim Sci 52:175–186

Haisan J, Sun Y, Beauchemin K, Guan L, Duval S, Barreda DR, Oba M (2013) Effect of feeding 3-nitrooxypropanol on methane emissions and productivity of lactating dairy cows. Adv Anim Biosci 4(2):260

Hamano Y (2012) Alleviative effects of a-lipoic acid supplementation on acute heat stress-induced thermal panting and the level of plasma nonesterified fatty acids in hypothyroid broiler chickens. Br Poult Sci 53:125–133

Hanson RS, Hanson TE (1996) Methanotropic bacteria. Microbiol Rev 60(2):439–471

Hatayama T, Asai Y, Wakatsuki T, Kitamura T, Imahara H (1993) Regulation of hsp70 synthesis induced by cupric sulfate and zinc sulfate in thermotolerant HeLa cells. J Biochem (Tokyo) 114:592–597

Hegarty RS (2001) Strategies for mitigating methane emissions from livestock – Australian options and opportunities. In: 1st international conference on GHGes and animal agriculture, Obihiro, pp 31–34

Hollmann M, Beede DK (2012) Comparison of effects of dietary coconut oil and animal fat blend on lactational performance of Holstein cows fed a high-starch diet. J Dairy Sci 95:1484–1499

Hook SE, Northwood KS, Wright AD, McBride BW (2009) Long-term monensin supplementation does not significantly affect the quantity or diversity of methanogens in the rumen of the lactating dairy cow. Appl Environ Microbiol 75:374–380

Hristov AN, Ivan M, Neill L, McAllister TA (2003) A survey of potential bioactive agents for reducing protozoal activity in vitro. Anim Feed Sci Technol 105:163–184

Hristov AN, Vander Pol M, Agle M, Zaman S, Schneider C, Ndegwa P, Vaddella VK, Johnson K, Shingfield KJ, Karnati SKR (2009) Effect of lauric acid and coconut oil on ruminal fermentation, digestion, ammonia losses from manure, and milk fatty acid composition in lactating cows. J Dairy Sci 92:5561–5582

Hristov AN, Lee C, Cassidy T, Long M, Heyler K, Corl B, Forster R (2011) Effects of lauric and myristic acids on ruminal fermentation, production, and milk fatty acid composition in lactating dairy cows. J Dairy Sci 94:382–395

Hristov AN, Oh J, Lee C, Meinen R, Montes F, Ott T, Firkins J, Rotz CA, Dell C, Adesogan A, Yang WZ, Tricarico J, Kebreab E, Waghorn G, Dijkstra J, Oosting S (2013) Mitigation of greenhouse gas emissions in livestock production – a review of technical options for non-CO_2 emissions. In: Gerber P, Henderson B, Makkar H (eds) FAO animal production and health. FAO, Rome, p 177

Hulshof RBA, Berndt A, Gerrits WJJ, Dijkstra J, van Zijderveld SM, Newbold JR, Perdok HB (2012) Dietary nitrate supplementation reduces methane emission in beef cattle fed sugarcane-based diets. J Anim Sci 90:2317–2323

IPCC (2001) Technical summary: contribution of Working Group I to the Third Assessment Report. Inter governmental panel on climate change, Jan 2001

IPCC (2007) Climate change 2007: the physical science basis, summary for policy makers. Contribution of working group I to the fourth assessment report of intergovernmental panel on climate change. http://www.ipcc.ch

IPCC (Intergovernmental Panel on Climate Change) (2013) Impacts, adaptation and vulnerability. http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-TS_FGDall.pdf

Itabashi H, Kobayashi T, Matsumoto M (1984) The effects of rumen ciliate protozoa on energy metabolism in some constituents in rumen fluid and blood plasma of goats. Jpn J Zoo Tech Sci 55:248

Jayanegara A, Leiber F, Kreuzer M (2012) Meta-analysis of the relationship between dietary tannin level and methane formation in ruminants from in vivo and in vitro experiments. J Anim Physiol Anim Nutr 96:356–375

Johnson KA, Johnson DE (1995b) Methane emissions from cattle methane emissions from cattle. J Anim Sci 73:2483–2492

Johnson DE, Ward GW, Ramsey JJ (1996) Livestock methane: current emissions and mitigation potential. In: Kornegay ET (ed) Nutrient management of food animals to enhance and protect the environment. Lewis Publishers, New York, pp 219–234

Jordan E, Lovett DK, Monahan FJ, Callan J, Flynn B, O'Mara FP (2006) Effect of refined coconut oil or copra meal on methane output and on intake and performance of beef heifers. J Anim Sci 84:162–170

Jousan FD, Hansen PJ (2004) Insulin-like growth factor-I as a survival factor for the bovine preimplantation embryo exposed to heat shock. Biol Reprod 71:1665–1670

Jousan FD, Hansen PJ (2007) Insulin-like growth factor-I promotes resistance of bovine preimplantation embryos to heat shock through actions independent of its anti-apoptotic actions requiring PI3K signaling. Mol Reprod Dev 74:189–196

Kabubo-Mariara J (2005) Herders response to acute land pressure under changing property rights: some insights from Kenya. Environ Dev Econ 10(1):67–85

Kabubo-Mariara J (2007) Poverty and rural livelihoods in Kenya: evidence from a semi-arid region. In: Tisdell C (ed) Poverty, poverty alleviation and social disadvantage: analysis, case studies and policies. Serials Publications, Vol III, Part VII, Chapter 56

Kabubo-Mariara J (2008) Climate change adaptation and livestock activity choices in Kenya: an economic analysis. Nat Res Forum 32:131–141

Kaim M, Bloch A, Wolfenson D, Braw-Tal R, Rosenberg M, Voet H, Folman Y (2003) Effects of GnRH administered to cows at the onset of estrus on timing of ovulation, endocrine responses and conception rates. J Dairy Sci 86:2012–2021

Kingeston-Smith AH, Edwards JE, Huws SA, Kim EJ, Abberton M (2010) Plant based strategies towards minimizing live stocks long shadow. Proc Nutr Soc 69:613–620

Kirchgessner M, Windisch W, Muller HL (1995) Nutritional factors for quantification of methane production. Ruminant physiology, digestion metabolism growth and reproduction. In: Proceedings of the 8th international symposium on ruminant physiology. Ferdinand Enke Verlag, Stuttgart, pp 333–348

Klieve AV, Joblin K (2007) Comparison in hydrogen utilisation of ruminal and marsupial reductive acetogens. In: Kennedy R (ed) 5 year research progress report 2002–2007. The pastoral greenhouse gas research consortium, Wellington, pp 34–35

Knight T, Ronimus RS, Dey D, Tootill C, Naylor G, Evans P, Molano G, Smith A, Tavendale M, Pinares-Patino CS, Clark H (2011) Chloroform decreases rumen methanogenesis and methanogen populations without altering rumen function in cattle. Anim Feed Sci Technol 166:101–112

Kreuzer M, Kirchgessner M, Müller HL (1986) Effect of defaunation on the loss of energy in wethers fed different quantities of cellulose and normal or steam-flaked maize starch. Anim Feed Sci Technol 16:233–241

Lascano CE, Cárdenas E (2010) Alternatives for methane emission mitigation in livestock systems. Rev Bras Zootec 39:175–182

Le-Liboux S, Peyraud JL (1999) Effect of forage particle size and feeding frequency on fermentation patterns and sites and extent of digestion in dairy cows fed mixed diets. Anim Feed Sci Technol 76:297–319

Leahy SC, Kelly WJ, Altermann E, Ronimus RS, Yeoman CJ, Pacheco M, Li D, Kong Z, McTavish S, Sang C, Lambie SC, Janssen PH, Dey D, Attwood GT (2010) The genome sequence of the rumen Methanogen Methanobrevibacter reveals new possibilities for controlling ruminant methane emissions. PLoS ONE 5:e8926

Lee SS, Hsu JT, Mantovani HC, Russell JB (2002) The effect of bovicin HC5, a bacteriocin from Streptococcus bovis HC5, on ruminal methane production in vitro. FEMS Microbiol Lett 217:51–55

Leng RA (2008) The potential of feeding nitrate to reduce enteric methane production in ruminants. http://www.penambulbooks.com/Papers%20&%20Presentations.htm

Lopez S, McIntosh FM, Wallace RJ, Newbold CJ (1999) Effect of adding acetogenic bacteria on methane production by mixed rumen microorganisms. Anim Feed Sci Technol 78:1–9

Lovett D, Bortolozzo A, Conaghan P, O'Kiely P, O'Mara FP (2004) In vitro total and methane gas production as influenced by rate of nitrogen application, season of harvest and perennial ryegrass cultivar. Grass Forage Sci 59:227–232

Lovett DK, Stack LJ, Lovell S, Callan J, Flynn B, Hawkins M, O'Mara FP (2005) Manipulating enteric methane emissions and animal performance of late-lactation dairy cows through concentrate supplementation at pasture. J Dairy Sci 88:2836–2842

Luo Y, Pfister P, Leisinger T, Wasserfallen A (2001) The genome of archaeal prophage ψm100 encodes the lytic enzyme responsible for autolysis of Methanothermobacter wolfeii. J Bacteriol 183:5788–5792

Mamuad LL, Kim SH, Lee SS, Cho KK, Jeon CO, Lee SS (2012) Characterization, metabolites and gas formation of fumarate reducing bacteria isolated from Korean native goat (Capra hircus coreanae). J Microbiol 50:925–931

Mantovani HC, Russell JB (2002) The ability of a bacteriocin of streptococcus bovis HC5 (bovicin HC5) to inhibit clostridium aminophilum, an obligate amino acid fermenting bacterium from the rumen. Anaerobe 8:247–252

Martin C, Dubroeucq H, Micol D, Agabriel J, Doreau M (2007) Methane output from beef cattle fed different high-concentrate diets. In: Proceedings of the British Society of Animal Science, Southport, 2–4 Apr 2007, p 46

Martinez-Fernandez G, Arco A, Abecia L, Cantalapiedra-Hijar G, Molina-Alcaide E, Martin-Garcia AI, Kindermann M, Duval S, Yanez-Ruiz DR (2013) The addition of ethyl-3-nitrooxy propionate and 3-nitrooxypropanol in the diet of sheep sustainably reduces methane emissions and the effect persists over a month. Adv Anim Biosci 4(2):368

Masike S (2007) The impacts of CC on cattle water demand and supply in Khurutshe, Botswana. PhD thesis, University of Waikato, New Zealand

Mathison GW, Okine EK, McAllister TA, Dong Y, Galbraith J, Dmytruk OIN (1998) Reducing methane emissions from ruminant animals. J Appl Anim Res 14:1–28

McAllister TA, Newbold CJ (2008) Redirecting rumen fermentation to reduce methanogenesis. Aust J Exper Agri 48:7–13

McAllister TA, Okine EK, Mathison GW, Cheng KJ (1996) Dietary, environmental and microbiological aspects of methane production in ruminants. Can J Anim Sci 76:231–243

McCaughey WP, Wittenberg KM, Corrigan D (1997) Methane production by steers on pasture. Can J Anim Sci 77:519–524

McCaughey WP, Wittenberg K, Corrigan D (1999) Impact of pasture type on methane production by lactating cows. Can J Anim Sci 79:221–226

McGinn SM, Beauchemin KA, Coates T, Colombatto D (2004) Methane emissions from beef cattle: effects of monensin, sunflower oil, enzymes, yeast and fumaric acid. J Anim Sci 82:3346–3356

MEA (2005) Ecosystems and human well-being: our human planet. Summary for decision makers. The Millennium Ecosystem Assessment, online at http://www.millenniumassessment.org

Mills JA, Dijkstra J, Bannink A, Cammel SB, Kebreab E, France J (2001) A mechanistic model of whole-tract digestion and methanogenesis in the lactating dairy cow: model development, evaluation, and application. J Anim Sci 79:1584–1597

Mitsumori M, Shinkai T, Takenaka A, Enishi O, Higuchi K, Kobayashi Y, Nonaka I, Asanuma N, Denman SE, McSweeney CS (2011) Responses in digestion, rumen fermentation and microbial populations to inhibition of methane formation by a halogenated methane analogue. Br J Nutr 8:1–10

Molano G, Knight TW, Clark H (2008) Fumaric acid supplements have no effect on methane emissions per unit of feed intake in wether lambs. Aust J Exp Agric 48:165–168

Morgavi DP, Forano E, Martin C, Newbold CJ (2010) Microbial ecosystem and methanogenesis in ruminants. Animal 4:1024–1036

Morgavi DP, Martin C, Boudra H (2013) Fungal secondary metabolites from Monascus spp. reduce rumen methane production in vitro and in vivo. J Anim Sci 91:848–860

Moss AR, Jouany JP, Newbold J (2000) Methane production by ruminants: its contribution to global warming. Ann Zootech 49:231–253

Mwenya B, Santoso B, Sar C, Gamo Y, Kobayashi T, Arai I, Takahashi J (2004) Effects of including β1-4 galacto-oligosaccharides lactic acid bacteria or yeast culture on methanogenesis as well as energy and nitrogen metabolism in sheep. Anim Feed Sci Technol 115:313–326

Newbold CJ, Rode LM (2005) Dietary additives to control methanogenesis in the rumen. In: Soliva CR, Takahashi J, Kreuzer M (eds) Second international conference on greenhouse gases and animal agriculture, Working Papers, ETH, Zurich, pp 60–70

Newbold CJ, Rode LM (2006) Dietary additives to control methanogenesis in the rumen. In: Soliva CR, Takahashi J, Kreuzer M (eds) Greenhouse gases and animal agriculture: an update, vol 1293, Elsevier International Congress Series. Elsevier, Amsterdam, pp 138–147

Nolan JV, Hegarty RS, Hegarty J, Godwin I, Woodgate R (2010) Effects of dietary nitrate on rumen fermentation, methane production and water kinetics in sheep. Anim Prod Sci 50:801–806

Nollet L, Mbanzamihigo L, Demeyer D, Verstraete W (1998) Effect of the addition of Peptostreptococcus productus ATCC 35244 on reductive acetogenesis in the ruminal ecosystem after inhibition of methanogenesis by cell-free supernatant of Lactobacillus plantarum 80. Anim Feed Sci Technol 71:49–66

O'Mara F (2004) GHG production from dairying: reducing methane production. Adv Dairy Technol 16:295–309

Odongo NE, Bagg R, Vessie G, Dick P, Or-Rashid MM, Hook SE, Gray JT, Kebreab E, France J, McBride BW (2007) Long-term effects of feeding monensin on methane production in lactating dairy cows. J Dairy Sci 90:1781–1788

Ohene-Adjei S, Chaves AV, McAllister TA, Benchaar C, Teather RM, Forster RJ (2008) Evidence of increased diversity of methanogenic archaea with plant extract supplementation. Microbial Ecol 56:234–242

Paaijmans KP, Blanford S, Bell AS, Blanford JI, Read AF, Thomas MB (2010) Influence of climate on malaria transmission depends on daily temperature variation. Proc Natl Acad Sci U S A 107:15135–15139

Patra AK, Yu Z (2012) Effects of essential oils on methane production and fermentation by and abundance and diversity of rumen microbial populations. Appl Environ Microbiol 78:4271–4280

Pfister P, Wasserfallen A, Stettler R, Leisinger T (1998) Molecular analysis of Methanobacterium phage ΨM2. Mol Microbiol 30:233–244

Pinares-Patiño CS, Hour PD, Jouany JP, Martin C (2007) Effects of stocking rate on methane and carbon dioxide emissions from grazing cattle. Agric Ecosyst Environ 121:30–46

Popova M, Martin C, Eugène M, Mialon MM, Doreau M, Morgavi DP (2011) Effect of fibre- and starch-rich finishing diets on methanogenic Archaea diversity and activity in the rumen of feedlot bulls. Anim Feed Sci Technol 166:113–121

Quere CL, Peters GP, Andrew RM, Boden TA, Ciais P, Friedlingstein P, Houghton RA et al (2014) Global carbon budget 2013. Earth Syst Sci Data 6:235–263

Roth Z, Arav A, Braw-Tal R, Bor A, Wolfenson D (2002) Effect of treatment with follicle-stimulating hormone or bovine somatotropin on the quality of oocytes aspirated in the autumn from previously heat-stressed cows. J Dairy Sci 85:1398–1405

Rotz CA, Corson MS, Chianese DS, Coiner CU (2009) The integrated farm system model: reference manual. University Park, Pa: USDAARS Pasture Systems and Watershed Management research unit: www.ars.usda.gov/SP2UserFiles/Place/19020000/ifsmreference

Rowlinson P, Steele M, Nefzaoui A (2008) Livestock and global climate change. Proceedings of the international conference in Hammamet. Cambridge University Press, pp 216–216

Rutledge JJ (2001) Use of embryo transfer and IVF to bypass effects of heat stress. Theriogenology 55:105–111

Sakatani M, Kobayashi S, Takahashi M (2004) Effects of heat shock on in vitro development and intracellular oxidative state of bovine preimplantation embryos. Mol Reprod Dev 67:77–82

Sang SL, Mantovani HC, Russell JB (2002) The binding and degradation of nisin by mixed ruminal bacteria. FEMS Microbiol Ecol 42:339–345

Santoso B, Mwenyaa B, Sara C, Gamoa Y, Kobayashia T, Morikawaa R, Kimurab K, Mizukoshib H, Takahashi J (2004) Effects of supplementing galacto-oligosaccharides, Yucca schidigera or nisin on rumen methanogenesis, nitrogen and energy metabolism in sheep. Livest Prod Sci 91:209–217

Sar C, Santoso B, Gamo Y, Kobayashi T, Shiozaki S, Kimura K, Mizukoshi H, Arai I, Takahashi J (2004) Effects of combination of nitrate with β1-4 galacto-oligosaccharides and yeast (Candida kefyr) on methane emission from sheep. Asian Austr J Anim Sci 17(1):73–79

Sar C, Mwenya B, Santoso B, Takaura K, Morikawa R, Isogai N, Asakura Y, Toride Y, Takahashi J (2005) Effect of Escherichia coli wild type or its derivative with high nitrite reductase activity on in vitro ruminal methanogenesis and nitrate/nitrite reduction. J Anim Sci 83:644–652

Sejian V (2013) Climate change: impact on production and reproduction, adaptation mechanisms and mitigation strategies in small ruminants: a review. Indian J Small Rumin 19(1):1–21

Sejian V, Naqvi SMK (2012) Livestock and climate change: mitigation strategies to reduce methane production. In: Liu G (ed) Greenhouse gases – capturing, utilization and reduction. Intech Publisher, Croatia, pp 254–276

Sejian V, Lal R, Lakritz J, Ezeji T (2011a) Measurement and prediction of enteric methane emission. Int J Biometeorol 55:1–16

Sejian V, Lakritz J, Ezeji T, Lal R (2011b) Forage and flax seed impact on enteric methane emission in dairy cows. Res J Vet Sci 4:1–8

Sejian V, Rotz A, Lakritz J, Ezeji T, Lal R (2011c) Modeling of green house gas emissions in dairy farms. J Anim Sci Adv 1(1):12–20

Sejian V, Indu S, Ujor V, Ezeji T, Lakritz J, Lal R (2012a) Global climate change: enteric methane reduction strategies in livestock. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GMbH Publisher, Germany, pp 469–502

Sejian V, Valtorta S, Gallardo M, Singh AK (2012b) Ameliorative measures to counteract environmental stresses. In: Sejian V, Naqvi SMK, Ezeji T, Lakritz J, Lal R (eds) Environmental stress and amelioration in livestock production. Springer-Verlag GMbH Publisher, Germany, pp 153–180

Sejian V, Singh AK, Sahoo A, Naqvi SMK (2014) Effect of mineral mixture and antioxidant supplementation on growth, reproductive performance and adaptive capability of Malpura ewes subjected to heat stress. J Anim Physiol Anim Nutr 98:72–83

Seyrek K, Kargin KF, Bildik A (2004) Chronic ethanol induced oxidative alterations in the rat tissues and protective effect of vitamin E. Ind Vet J 81:1102–1104

Shibata M (1996) Factors affecting thermal balance and production of ruminants in a hot environment – a review. Memories of National Institute of Animal Industry No. 10. 60 pp

Shinde AK, Sejian V (2013) Sheep husbandry under changing climate scenario in India: an overview. Indian J Anim Sci 83(10):998–1008

Sidahmed A (2008) Livestock and CC: coping and risk management strategies for a sustainable future. In: Livestock and global CC conference proceeding, May 2008, Tunisia

Skuce PJ, Morgan ER, van Dijk J, Mitchell M (2013) Animal health aspects of adaptation to CC: beating the heat and parasites in a warming Europe. Animal 7(2):333–345

Soussana JF, Loiseau P, Vuichard N, Ceschia E, Balesdent J, Chevallier T, Arrouays D (2004) Carbon cycling and sequestration opportunities in temperate grasslands. Soil Use Manag 20:219–230

Spears JW, Whisnant CS, Huntington GB, Lloyd KE, Fry RS, Krafka K, Lamptey A, Hyda J (2012) Chromium propionate enhances insulin sensitivity in growing cattle. J Dairy Sci 95:2037–2045

Staerfl SM, Amelchanka SL, Kälber T, Soliva CR, Kreuzer M, Zeitz JO (2012) Effect of feeding dried high-sugar ryegrass ('AberMagic') on methane and urinary nitrogen emissions of primiparous cows. Livest Sci 150:293–301

Stefanidou M, Maravelias C, Dona A, Spiliopoulou C (2006) Zinc: a multipurpose trace element. Arch Toxicol 80:1–9

Suk JE, Semenza JC (2011) Future infectious disease threats to Europe. Am J Public Health 101:2068–2079

Sunil Kumar BV, Singh G, Meur SK (2010) Effects of addition of electrolyte and ascorbic acid in feed during heat stress in buffaloes. Asian Aust J Anim Sci 23(7):880–888

Takahashi J (2011) Some prophylactic options to mitigate methane emission from animal agriculture in Japan. Asian Aust J Anim Sci 24:285–294

Tejido ML, Ranilla MJ, García-Martínez R, Carro MD (2005) In vitro microbial growth and rumen fermentation of different diets as affected by the addition of disodium malate. Anim Sci 81:31–38

Tezel U, Pierson JA, Pavlostathis SG (2006) Fate and effect of quaternary ammonium compounds on a mixed methanogenic culture. Water Res 40(19):3660–3668

Thames JL, Cluff CB (1982) Water harvesting on surface mine spoils. Paper presented at the Wisconsin mined-land rehabilitation research workshop, Ft. Collins, Colorado, 1–11 June 1982, 4 pages

Thornton PK, Herrero M (2010) The inter-linkages between rapid growth in livestock production, CC, and the impacts on water resources, land use, and deforestation. Policy research working paper 5178, pp 1–82

Tomkins WW, Colegate SM, Hunter RA (2009) A bromochloromethane formulation reduces enteric methanogenesis in cattle fed grain-based diets. Anim Prod 49(12):1053–1058

Ulyatt MJ, Lassey KR, Shelton ID, Walker CF (2002) Seasonal variation in methane emission from dairy cows and breeding ewes grazing ryegrass/white clover pasture in New Zealand. N Z J Agric Res 45:217–226

Ungerfeld E, Forster RJ (2011) A meta-analysis of malate effects on methanogenesis in ruminal batch cultures. Anim Feed Sci Technol 166–167:282–290

Ungerfeld EM, Rust SR, Burnett R (2003) Use of some novel alternative electron sinks to inhibit ruminal methanogenesis. Reprod Nutr Dev 43:189–202

Ungerfeld EM, Kohn RA, Wallace RJ, Newbold CJ (2007) A meta-analysis of fumarate effects on methane production in ruminal batch cultures. J Anim Sci 85:2556–2563

USEPA (1993) Anthropogenic methane emissions in the United States. Estimates for 1990: report to congress. Atmospheric PolluStatestion Prevention Division, Office of Air and Radiation, US, Washington, DC

Valtorta SE, Leva PE, Gallardo MR, Scarpati OE (2002) Milk production responses during heat waves events in Argentina. In: 15th conference on biometeorology and aerobiology – 16th international congress on biometeorology. Kansas City, MO. American Meteorological Society, Boston p 98–101

Van Dorland HA, Wettstein HR, Leuenberger H, Kreuzer M (2007) Effect of supplementation of fresh and ensiled clovers to ryegrass on nitrogen loss and methane emissions of dairy cows. Livest Sci 111:57–69

van Nevel CJ, Demeyer DI (1995) Feed additives and other interventions for decreasing methane emissions. Biotechnol Anim Feeds Feed 17:329–349

Van Nevel C, Demeyer D (1996) Control of rumen methanogenesis. Environ Monit Assess 42:73–97

Van Zijderveld SM, Gerrits WJJ, Apajalahti JA, Newbold JR, Dijkstra J, Leng RA, Perdok HB (2010) Nitrate and sulfate: effective alternative hydrogen sinks for mitigation of ruminal methane production in sheep. J Dairy Sci 93:5856–5866

Van Zijderveld SM, Gerrits WJJ, Dijkstra J, Newbold JR, Hulshof RBA, Perdok HB (2011) Persistency of methane mitigation by dietary nitrate supplementation in dairy cows. J Dairy Sci 94:4028–4038

Vercruysse J, Schetters T, Knox DP, Willadsen P, Claerebout E (2007) Control of parasitic disease by vaccination – an answer to drug resistance? Rev Sci Technol 26:105–115

Voellmy R (2004) On mechanisms that control heat shock transcription factor activity in metazoan cells. Cell Stress Chaperones 9:122–133

Waghorn GC, Tavendale MH, Woodfield DR (2002) Methanogenesis from forages fed to sheep. Proc N Z Grassl Assoc 64:167–171

Wang CJ, Wang SP, Zhou H (2009) Influences of flavomycin, ropadiar, and saponin on nutrient digestibility, rumen fermentation, and methane emission from sheep. Anim Feed Sci Technol 148:157–166

Wedlock DN, Pedersen G, Denis M, Dey D, Janssen PH, Buddle BM (2010) Development of a vaccine to mitigate greenhouse gas emissions in agriculture; vaccination of sheep with methanogen fractions induces antibodies that block methane production in vitro. N Z Vet J 58:29–36

Weimer PJ (1998) Manipulating ruminal fermentation: a microbial ecological perspective. J Anim Sci 76:3114–3122

Weiss RA, McMichael AJ (2004) Social and environmental risk factors in the emergence of infectious diseases. Nat Med 10:S70–S76

West JW (1999) Nutritional strategies for managing the heat stressed dairy cow. J Anim Sci 77(2):21–35

West JW (2002) Physiological effects of heat stress on production and reproduction. Proc Tri-State Nutr Conf 1–9

Whitelaw FG, Eadie WJ, Bruce LA, Shand WA (1984) Methane formation in faunated and ciliate-free cattle and its relationship with rumen volatile fatty acid proportions. Br J Nutr 52:261

Wilk J, Wittgren HB (eds) Adapting water management to CC. Swedish Water House Policy Brief Nr. 7. SIWI 2009

Williams YJ, Rea SM, Popovski S, Pimm CL, Williams AJ, Toovey AF, Skillman LC, Wright ADG (2008) Responses of sheep to a vaccination of entodinial or mixed rumen protozoal antigens to reduce rumen protozoal numbers. Br J Nutr 99:100–109

Williams YJ, Popovski S, Rea SM, Skillman LC, Toovey AF, Northwood KS, Wright ADG (2009) A vaccine against rumen methanogens can alter the composition of archaeal populations. Appl Environ Microbiol 75:1860–1866

Wina E, Muetzel S, Hoffmann E, Makkar HPS, Becker K (2005) Saponins containing methanol extract of Sapindus rarak affect microbial fermentation, microbial activity and microbial community structure in vitro. Anim Feed Sci Technol 121:159–174

Wood TA, Wallace RJ, Rowe A, Price J, Yáñez-Ruiz DR, Murray P, Newbold CJ (2009) Encapsulated fumaric acid as a feed ingredient to decrease ruminal methane emissions. Anim Feed Sci Technol 152:62–71

World Meteorological Organization (2014) Weather and climate: engaging youth. WMO Bull 63(1):1–44

Wright AD, Kennedy P, O'Neill CJ, Toovey AF, Popovski S, Rea SM, Pimm CL, Klein L (2004) Reducing methane emissions in sheep by immunization against rumen methanogens. Vaccine 22:3976–3985

Yates CM, Cammell SB, France J, Beever DE (2000) Predictions of methane emissions from dairy cows using multiple regression analysis. In: Proceedings of the British Society of Animal Science, Scarborough, UK, March 2000, pp 94

Zhang Y, Bi P, Hiller JE (2008) CC and the transmission of vector-borne diseases: a review. Asia Pac J Public Health 20:64–76

Zhou X, Sar C, Kobayashi T, Takahashi J, Santoso B, Gamo Y, Mwenya B (2004) Effects of probiotic vitacogen and ß1-4 galacto-oligosaccharides supplementation on methanogenesis and energy and nitrogen utilization in dairy cows. Asian Aust J Anim Sci 17(3):349–354

Zhou M, Chung YH, Beauchemin KA, Holtshausen L, Oba M, McAllister TA, Guan LL (2011) Relationship between rumen methanogens and methane production in dairy cows fed diets supplemented with a feed enzyme additive. J Appl Microbiol 111:1148–1158

Zhou X, Meile L, Kreuzer M, Zeitz JO (2013) The effect of lauric acid on methane production and cell viability of Methanobrevibacter ruminantium. Adv Anim Biosci 4(2):458

Shelter Design for Different Livestock from a Climate Change Perspective

23

Prasad Ambazamkandi, Giggin Thyagarajan,
Smitha Sambasivan, Justin Davis,
Sankaralingam Shanmugam, and Biya Ann Joseph

Abstract

Shelter design of different livestock needs suitable modifications to prevail climate change infliction. Thermal stress alleviation, methane mitigation and optimisation of space requirements are major shelter design considerations for livestock in the climate change scenario. In this perspective, the chapter deals with considerations and some suggested modifications in flooring, roofing, heat stress alleviation and waste management and disease prevention aspects of housing of different livestock. In cattle barns, the thermal conductivity of floor, ventilation aspects and other thermal properties of different roofs and roofing materials, temperature humidity index (THI)-based wetting and other important thermal stress alleviation techniques and measures to reduce methane emission through proper waste management are relevant in the context. In pigsties, flooring, roof, thermal stress aspect, disease prevention and waste management aspects need careful considerations. Proper designing of goat units not only averts production loss but also optimises space utilisation and prevents diseases ensuring maximum production. Rabbit and poultry are highly susceptible to stress, especially due to climatic variations, and the success of rabbit and poultry farming mostly depends on congenial macro- and micro-environments and the effectiveness of the ameliorating measures taken to reduce the stress factors. The integration of different livestock through suitable designs will ensure food security, reduce stress and help in carbon recycling. Innovative, integrated and self-sufficient shelter designs for climate change adaption of animal agriculture can be achieved through multidisciplinary approach.

P. Ambazamkandi (✉) • S. Sambasivan • J. Davis
B.A. Joseph
Department of Livestock Production Management,
College of Veterinary and Animal Sciences,
Mannuthy, Thrissur, Kerala, India
e-mail: prasad@kvasu.ac.in

G. Thyagarajan
KrishiVigyan Kendra, Kannur, Kerala, India

S. Shanmugam
Department of Poultry Science, College of Veterinary
and Animal Sciences, Mannuthy, Thrissur, Kerala, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_23, © Springer India 2015

Keywords
Climate change adaptation • Livestock shelter design • Thermal stress alleviation • Methane mitigation • Integrated livestock shelter

23.1 Introduction

Climate change is projected to be a major threat for survival of many species and ecosystems and for the viability and sustainability of livestock production (Frankham 2005). All productive traits of livestock will be affected by climate (Nardone et al. 2006). One of the biggest challenges faced by researchers today is to increase the livestock production in the context of climate change (Collier et al. 2006). Livestock production is already compromised in tropical belt due to thermal stress, and the risk is further expected to increase in the climate change scenario due to detrimental effects of environmental heat stress on animal welfare and production (Bernabucci and Lacetera 2010). The perils of thermal stress on animal productivity are a matter of concern in other agro-ecological zones of the world also due to the projected global climate change scenario. Developing appropriate cost-effective technologies for climate change mitigation, and sustaining the livestock productivity are very important in the current context.

Proper housing design is of paramount importance in reducing stress in livestock. Environmental aspect of housing the farm animals is necessarily multidisciplinary. An understanding of the housing needs of the animals can be derived from physiological, physical and behavioural studies, and this needs to be overlapped with meteorological data and economic considerations for arriving at proper designs. The design of suitable ameliorative interventions draws on information and principles from the applied physical disciplines such as engineering (Clark 1981).

The livestock, especially the ruminants, are incriminated for the increasing greenhouse gas (GHG) levels in the atmosphere, so the designs should also consider efforts to mitigate methane. So apart from stress reduction, design consideration to mitigate methane through proper waste management is also important. Another major consideration in futuristic livestock housing design is the fact that human population continues to increase especially in tropical areas of the globe causing shrinkage of availability of arable land. Consequently, animal agriculture in these areas needs to expand (Renaudeau et al. 2008). But the crux of the problem is that, as there is space constraint, we need to innovate to produce more in the limited space available without causing stress to animal.

The climate change-related modifications needed in the housing design differ between different livestock, but the general considerations are the same. This chapter is therefore aimed at providing the essentials of shelter design considerations which reduce stress in different livestock species, optimise space and look at wastes as unutilised wealth to mitigate methane and help in carbon recycling (Fig. 23.1). The economic levels of millions of farmers of tropical world have been taken into consideration while suggesting these designs.

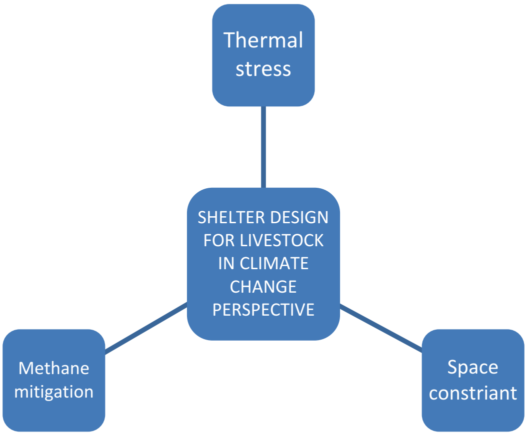


Fig. 23.1 Thematic representation of shelter design considerations for livestock

23.2 Shelter Design for Cattle in a Climate Change Perspective

Dairy sector is the most important subsidiary of livestock sector. Imperfect modelling and wrong choice of materials in housing design had resulted in cumulative loss in production as evident from change in total milk yield in different climatic conditions. Hence considering the climate change trend, dairy housing system needed scientific design considerations to improve comfort level for optimising production (Suraj 2011).

23.2.1 Flooring Design Modifications

Flooring is one of the most important components of animal housing as far as animal health and welfare are concerned. Different flooring materials are being used for different types of livestock over the world. In dairy animals, the most common flooring material used is cement concrete. Though concrete flooring has many advantages like durability, thermal conductivity and strength, there are some obvious disadvantages like slippery nature, hardness which reduces animal comfort, conformational defects and injuries on hoof leading to increased incidence of laminitis. Cows on concrete have greater odds of developing or exacerbating existing heel erosion than cows on rubber flooring, and the odds of becoming lame are greater for concrete-exposed cows than those on rubber (Vanegas et al. 2006).

Proper flooring management and design is critical for the effective control of production parameters, cow health, longevity and comfort. Many studies have investigated the bedding preferences of dairy cows by comparing different types of floor structures (Lendelova and Pogran 2003). Results of similar experiments indicate that cows prefer stalls with softer, elastic, dry and slip resistant floors.

The long-term effect of the use of rubber mat as flooring material in animal sheds in the hot humid tropical climate has not been scientifically proven. The lying cow is in direct body contact with the floor for 12–14 h per day (Lendelova and Pogran 2003). Gupta et al. (2004) compared three types of housing systems, viz. loose house having asbestos roof and cemented floor, loose house with mud blaster roof and village-type closed barn with kuchha floor for buffalo heifers during winter, and found that the morning rectal temperature was higher in village-type closed barn with kuchha floor than cemented floor.

An animal lying on a cool wet surface will have greater conductive heat transfer depending on the thermal conductance of the substrate as well as the temperature gradient and magnitude of the area of contact relative to the total surface area. In a study conducted in Kerala, a tropical humid state in India, by Prasad et al. (2013), it was inferred that the rubber mat floor had significantly higher temperature than concrete floor during the daytime (Fig. 23.2). Though rubber

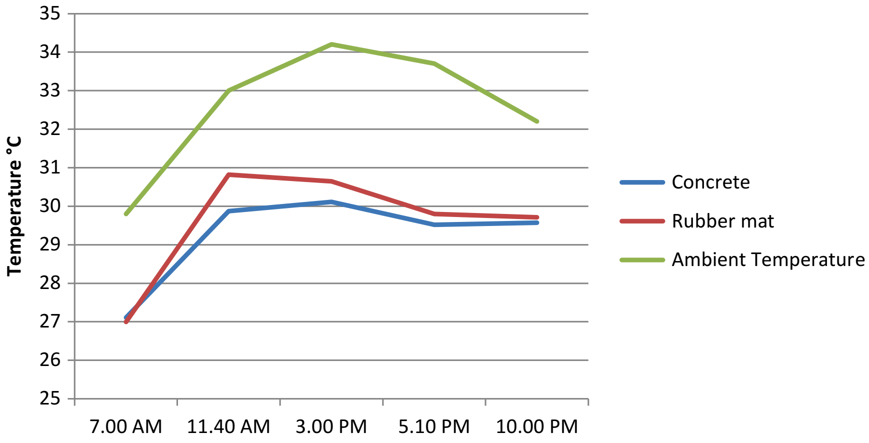


Fig. 23.2 Ambient temperature and ground temperature at different times of the day

mat flooring has many obvious advantages, its effect on thermolysis, animal comfort and physiological significance in hot humid conditions has to be explored by further research.

23.2.2 Roof and Roofing Materials

As in any other animal housing, the structure design and materials used for roof are extremely important in environmental control of the indoors. The roof structure should provide sufficient shade, preventing direct solar radiation from entering the shed. The roof should allow maximum natural ventilation to assist cooling and gas exchange between the interior and exterior. In a study in Kerala (India), it was observed that majority of cattle sheds had tiled roofing (32 %). The use of tin sheet was 22 %, asbestos 19 %, coconut palm leaves (thatched) 12 %, aluminium sheet 7 % and concrete 3 % (Fig. 23.3).

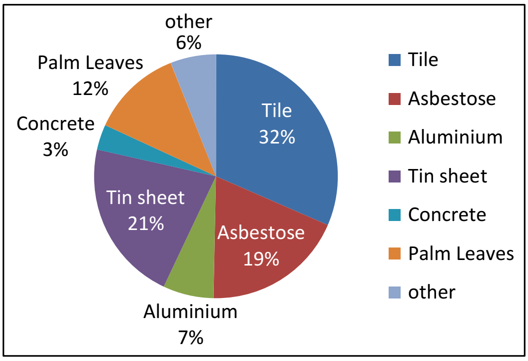


Fig. 23.3 Different materials used as roofing materials

Roof materials suggested should have insulating capacity. When metallic or conducting materials are used, the upper side should be reflective. Aluminium sheets are found to be reflective to solar radiation and are reasonably durable. But in small holder production systems of the tropical world, the cheap and easily available local materials like palm leaves and dried grass should be the material of choice. Efforts are needed to increase the durability of these materials.

23.2.3 Diurnal Variation in Thermal Comfort Inside and Outside the Shed

An important facet in dairy cattle stress management in the tropics is the difference in diurnal variation in temperature between outside and inside of cattle sheds. Even though the roof is providing the much-needed shade during the daytime, it also has the ill effect that it increases the indoor temperature during the night time when compared to the outside temperature. This increases the stress of the animal during night. In the climate change scenario where nights are predicted to be hotter, this may hamper the chance of the dairy cattle for its physiological recuperation in the night. This fact is illustrated here by an experiment conducted in a cattle shed by keeping temperature humidity loggers inside and outside during the high-thermal stress period. Inside–outside analysis resulted in accurately measuring the difference in temperature, RH and THI over a 24 h period (Fig. 23.4). The temperature

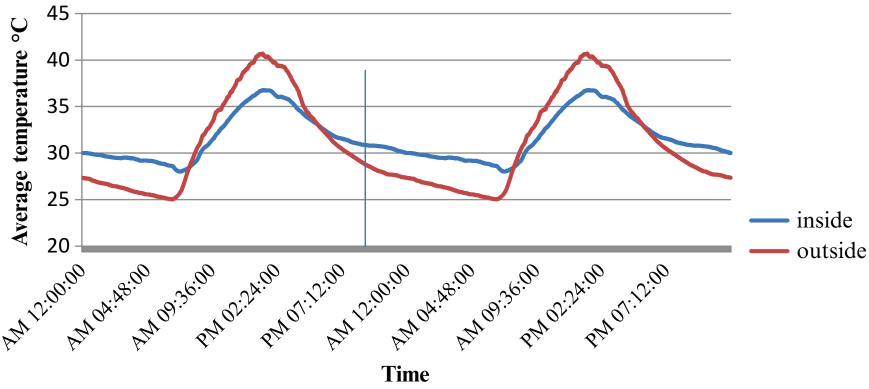


Fig. 23.4 Diurnal variation in temperature inside and outside cattle sheds

outside the cattle shed was found to be lower between the time points 17:41 h and 7:48 h. The maximum difference was found to be at the time point of 6:21 h. The relative humidity on other hand was found to be higher during the above said timings. The outside THI was found to be lower between the time points 17:13 h and 7:43 h. The maximum difference was obtained at the time point 6:07 h.

So it may be assumed that allowing the animal to paddocks during early hours of the day or designing movable roof structures may become a necessity in future. We have already stated that an average THI difference of two is significant in terms of thermal comfort in cattle, this huge difference has to be profitably used in the management of cattle through proper design. This finding is in perfect conformity with the works of Thiagarajan (1989) who investigated the effects of housing and feeding on growth and production of *B. taurus* × *B. indicus* cross-bred cattle. He considered the beneficial effects of open air conditions in hot humid tropical environment and advised to practise loose housing system in hot humid tropical environment in which cattle had continuous access to open paddock shaded by trees. Under the hot humid conditions, high wind velocity in the open seems to favour the cows considerably.

23.2.4 Thermal Stress Alleviators in Cattle Shed

23.2.4.1 Intermittent Wetting

The basic premise of ameliorative intervention was the classical observation of Esmay in 1978 that humidity at the animal skin surface was apparently less than the saturated humidity ratio. This he stated was due to a lack of sufficient wetting. The sweat glands of cattle are not adequate or at least do not provide a visibly wetted skin surface as with man (Esmay 1978).

It has been shown that the humidity ratio of water at the skin surface can be effectively increased by wetting with sprays or in wallows. Studies that provided sprays and showers for beef cattle obtained an average gain increase of 0.37 and 0.22 lb per day per head for two different years in hot climate conditions of southern California. In two tests where fogging nozzles were used with cattle, there were no beneficial effects. In fact, the daily gain of the fogged group was slightly less than that for the control. The foggers may have actually increased the humidity ratio of the air to the point that the evaporation potential from the skin surface was slightly decreased. The application of water directly to the skin of animals, particularly in considerable quantity, also may be an effective sensible heat coolant by conduction (Esmay 1978).

Sweating and panting are two of the primary autonomic responses exhibited by cattle under heat stress. Sweating leads to evaporative heat loss from the skin surface, whereas in panting, sensible heat is used to heat the water vapour and remove heat in the form of vaporised moisture from the lung. When air temperature is between 10 and 20 °C, heat loss by cutaneous evaporation accounts for 20–30 % of the total heat loss, but when the temperature is greater than 30 °C, cutaneous evaporation becomes the primary venue for heat loss, accounting for approximately 85 % of the total heat loss, while the rest is lost by respiratory evaporation (Marai et al. 2005). When ambient temperature equals internal body temperature, sensible heat loss is zero and evaporative heat loss via sweating and panting becomes the only available venue for heat loss. Both sweating and panting have the undesirable side effect of depleting the body's water reserves.

A prolonged expose to a hot and dry condition or exposure to 3 h of 850 W/m^2 of solar load caused rectal temperature to rise above 40.0 °C and respiration rate to rise above 125 breaths/min. Under these conditions, black or predominantly black cows were observed foaming in the mouth, sticking their tongues out and drooling (Gebremedhin et al. 2010). During these events, immediate intervention with water spray of the body helps to alleviate heat stress. A physiological upper limit of moisture production, which is different for each cow, seems to exist. The maximum sweating rate was about 660 g/m^2 –h for dairy cows and feedlot heifers, and the driving force for moisture production seems to be skin temperature (Gebremedhin et al. 2010).

23.2.4.2 Forced Ventilation

The rate at which air moves over the skin of an animal affected the rate of heat loss from the body surface. In hot humid environment, air movement was below 5 kmph. A wind speed of 2.25 m/s was quoted as ideal in hot and dry daytime environment, and the restoration of heat balance is encouraged by wind speeds of 2.25–4.50 m/s after sunset. Starr (1981) stated that air movement generally mitigated climatic stress by increasing heat loss from the body, when the body temperature is higher than the ambient temperature. In the real humid regions, the congregation of animals reduced air circulation and restricted heat loss so that the net effect of shade is low.

An increase in air velocity increased heat loss when the body temperature was higher than the ambient temperature. In tropical zones, the advection of hot air over the animal has increased heat stress, and in cold locations, air motion enhanced cold stress. In climatic zones between these two extremes, air movement generally mitigated climatic stress (Starr 1981). Ludri and Singh (1987) found that increased air movement by fans in hot and humid climate decreased the rectal temperature, respiration and pulse rates in cattle. The process of evaporative cooling is a complex interaction of humidity and temperature difference between air and skin, air velocity, and hair-coat characteristics such as density and depth. Thiagarajan (1989) reported that under the hot humid conditions, the higher wind velocity in the open paddock favoured the cows considerably than the cows in the shelter. He also opined that under hot, humid conditions, ventilation is most important and animals do not need much elaborate housing in order to utilise beneficial effects of free ventilation. Calamari et al. (1995) reported that during a hot day at indoor air temperature of above 25 °C, mechanical ventilation reduced the rectal temperature ($P<0.001$) and respiratory rate ($P<0.05$) and increased the milk yield ($P<0.05$) of the cow. Barrington (1997) suggested that mechanical ventilation systems for dairy cow housing offer several advantages, including a more consistent milk yield, more effective feed conversion, more constant level of total solids in milk and a better environment for milkers. Thermal resistance decreases linearly in hair coat with an increase in air velocity. Increasing air velocity over the hair-coat surface from about 0.2 m/s to about 0.9 m/s raised sweating rate from about 75 g/m^2 – h to about 350 g/m^2 –h, and no further increase in sweating rate occurred as air velocity was increased to 2.2 m/s (Hillman et al. 2001).

23.2.4.3 Combination of Intermittent Wetting and Forced Ventilation

A model incorporating these variables has been developed, where evaporative heat loss resulting from wetting the hair coat as the more effective means of heat loss than sweating (Kimmel et al. 1991). Mena et al. (1993) reported that cooling by combination of sprinkling for 30 s followed by controlled aeration for 6 min reduced both rectal temperature and respiratory frequency. But both variables increased after 20–30 min when the cows were exposed to environmental temperatures after treatments. Montoya et al. (1995) reported that 2.7 l of water per cow per hour evaporated from the cow's hair coat, when cooled by fan and sprinklers. They also stated that the evaporation rate mainly depended on dry-bulb temperature and relative humidity, wind speed and wind direction.

Increasing ambient temperature lowers the temperature gradient between the animal and air and consequently decreases the sensible heat loss. Increased air velocity (between 0.5 and 3.0 m/s) over the cow's surface increases convective heat loss by reducing the insulation of the boundary layer or by reducing the insulation of the hair coat if the velocity is greater than 3.0 m/s (Berman 2004). Higher velocities penetrate into the hair coat and thus increase the convective heat loss from the fur layer and skin surface. Vijayakumar et al. (2009) conducted study on the effect of sprinkling and fan with sprinkling on the growth and physiological response of buffalo heifers during summer and found that temperature was not significantly different from each other, but the afternoon temperature was significantly different among the treatment groups. The difference in the rectal temperature from morning (9:00 h) to the afternoon (14:00 h) for control group was significantly higher (0.34 °C) than the two treated groups, viz. T2 (0.22 °C) and T3 (0.13 °C).

Even though all these aspects are well known, specificity using THI-based cut-offs and assigning specific time periods will improve the efficiency of the wetting procedure. In a stud, the animal's skin was made wet intermittently by sprinkling water (PVC pipe with 1 mm holes used for the purpose of sprinkling water over the animal's body) forcefully for 90 s followed by a period of non-wetting for 12 min in a cyclical manner. The process of intermittent wetting and non-wetting was attained by an automatically working innovative THI controller. The period of non-wetting was accompanied with forced ventilation using a fan of 1,400 rpm kept at an angle of 20° and 1.5 m away and at 2 m from the animal. This method could improve milk production.

23.2.4.4 Roof Wetting

Asbestos, tiles or metallic roofs can be wetted to cool the indoors effectively. The roof can be intermittently made to wet for 2 min followed by a period of non-wetting for 5 min in a cyclical manner. Pipe with sprinklers running over the purlin with holes at 10 cm will effectively wet the roof. This can be automatically controlled by THI controllers.

23.2.4.5 Different Ameliorative Methods Used by Farmers

Some methods adopted by farmers for amelioration of heat stress at Kerala state (India) are shown in Fig. 23.5. Wetting the body by wet gunny bags, bathing the animal frequently, ventilation cowls to increase the ventilation, growing trees around, green grass in the paddocks, growing vegetable creepers over the sheds and hanging wet gunny bags against the direction of the wind are some methods adopted by farmers during high-thermal stress periods.

23.2.5 Methane Mitigation by Proper Waste Management in Cattle Farms

23.2.5.1 Bio Gas Plants

Fermentation of manure in biogas digesters may reduce the spread of pathogens and reduce methane emission. The capacity of digesters depends upon the size of the farm.

23.2.5.2 Electricity from Biogas

Biogas digester could be connected with modified diesel generator for electricity generation and power distribution.

23.2.5.3 Aerobic Composting

Other organic waste products of the farm should be treated with properly designed aerobic composting plants so that the methane production from waste will be minimised.

23.3 Shelter Design Considerations for Pigs in a Climate Change Perspective

Adequate modifications in housing and equipment for rearing pigs are necessary to provide shelter against inclement weather, prevent diseases and control parasites in the projected climate change scenario. Pigs are non-sweating species and as in the case of poultry are very vulnerable to inclement weather. Hence the design modifications are to be suggested accordingly.

23.3.1 Flooring and Floor Space Requirement for Pigs

The floor of the pigsty should be hard and impervious to water and easy to clean, and the floor should be laid with concrete and slope towards the drainage. Eighty to 100 mm of concrete on a consolidated gravel base is sufficient to provide a good floor. A stiff mix of 1:2:4 or 1:3:5 concrete finished with a wood float will give a durable


Use of Fans

Wet gunny bags


Growing vegetation over the roof

Ventilation Cowl


Misting

Fig. 23.5 Different ameliorative methods used by farmers

non-slip floor. The pen floors should slope 2–3 % towards the manure alley and the floor in the manure alley 3–5 % towards the drains (Thirupathy and Usha 2011).

As a new modification, the farmers and research stations are now using vitrified or ceramic tiles by giving due consideration to the grip on the surface. This floor can provide better sanitation and reduced bacterial count on the floor. In all the types, the width of the trough, either feed or water trough, shall not be less than 50 cm.

23.3.2 Roof Type and Materials

In general, it may be stated that pig houses should be simple with open-sided structures as maximum ventilation is needed. A building for open confinement is therefore essentially a roof carried on poles. The roof supporting poles are placed in the corners of the pens where they will cause least inconvenience. A free span trussed roof design would be an advantage but is more expensive. In some circumstances, it may be preferable to have solid gable ends and one tight side to give protection from the wind or low temperatures, at least for part of the year. If such walls are needed, they can often be temporary and be removed during hot weather to allow maximum ventilation. Permanent walls must be provided with large openings to ensure sufficient air circulation in hot weather. If there is not sufficient wind to create a draught in hot weather, ceiling fans can considerably improve the environment.

The main purpose of the building is to provide shade, and therefore, the radiant heat from the sun should be reduced as much as possible. In climates where a clear sky predominates, a high building of 3 m, or more, under the eaves gives more efficient shade than a low building. A wide roof overhang is necessary to ensure shade and to protect the animals from rain. A shaded ventilation opening along the ridge will provide an escape for the hot air accumulating under the roof. If made from a hard material, the roof can be painted white to reduce the intensity of solar radiation. Some materials such as aluminium reflect heat well as long as they are not too oxidised. A layer of thatch (5 cm) attached by wire netting beneath a galvanised steel roof will improve the microclimate in the pens. A roof of thatch is excellent in hot climates, particularly in non-confined systems, but cannot always be used because of fire hazard and because it is attractive to birds and rodents. A pig house with two rows of pens and a central feeding alley would require a ridge height of 5–6 m if covered with thatch.

The type of house for different geographical entities differs. Therefore, while planning for housing, it should be designed in such a way to give maximum comfort for achieving optimum growth. The pen partitions and the 1 m wall surrounding the building, which serves to reduce heat reflected from the surrounding ground, can be made of concrete blocks or burnt clay bricks for durability or perhaps soil-cement blocks, plastered for ease of cleaning. Regular white washing may improve the sanitary conditions in the pens.

The roof may be reinforced cement concrete (RCC) flat type or gable roof. Materials for roofing may be asbestos cement sheets or corrugated steel sheets. In the regions of extreme climatic conditions, the roof may be insulated by providing a layer of thatching to reduce severity of the heat inside the pigsty. There is need and scope for more research on this field especially with the use of better insulated materials which are locally available like coconut leaves and wild grasses used as thatched roofs with modifications to provide more durability and protection from fire accidents.

23.3.3 Waterers and Water Recycling

Water is the single nutrient required in the largest quantity by animals. Pigs require water for a variety of reasons, including most metabolic functions, adjustment of body temperature, movement of nutrients into the body tissues, removal of metabolic waste, production of milk and growth and reproduction. In fact, 80 % of the empty body weight of the newborn pig and about 53 % of a market hog are water. An animal can lose practically all its fat and over half of its protein and yet live, while a loss of one-tenth of its water results in death. It has been known for a long time now that some drinker devices lead to more water wastage than others. In particular, nipple drinkers tend to lead to more water wastage than ball-bite nipple or bowl drinkers. For example, it was reported that on an Alberta farm, ball-bite nipples reduced the amount of water used for drinking purposes by growing-finishing pigs by up to 46 % compared with the standard nipple drinkers.

Drinkers should be positioned 10–15 cm above the pigs' backline to minimise the amount of water waste. If set too low, the pig turns sideways to drink and up to 60 % of water flows out the other side of the mouth. Water flow rate should also be set correctly; an excessive flow rate of 900 ml/min compared with a more conventional rate of 300 ml/min for 30–60 kg pigs produces an extra 78 l of slurry per pig over 40 days.

Waste water can be reclaimed for reuse purposes when conventional treatment is combined with advanced treatment technologies. However, according to a report compiled by Premium Standard Farms, there are three major reasons why water reclamation for reuse purposes is not widely practised: (1) perception associated with direct or indirect reuse for human consumption, (2) the cost of advanced treatment necessary for wastewater reclamation and (3) health concerns with the consumption of reclaimed water. Animal health concerns may be the most difficult challenge to overcome. If all of the wastewater is reused, the concentrations of dissolved ions or total dissolved solids (TDS) will increase in the recycle loop over time. If allowed to build to levels higher than can be tolerated by the livestock, adverse health effects could occur.

23.3.4 Design Consideration in Disease Prevention

Climate change and resultant increase in temperatures may exacerbate the disease outbreaks and hence special care has to be taken. It is in intensive pig keeping systems that disease is a greater risk, because many animals are kept together in a small space. Infectious diseases spread easily and quickly among the animals. In intensive systems, commercial breeds are often used and these tend to be less resistant to disease.

Intensive pig production is a financial undertaking. In free-range and semi-intensive systems, farmers do not generally have funds to spend on medical treatment. It is also possible that pigs are not their only source of income. In such cases, a drop in production may be viewed as less important, and farmers may wish to calculate whether the benefits of saving the sick animal and protecting the others justify the cost of treatment. Many diseases and health-related problems in animals can be linked to a loss of natural resistance as a result of feeding problems, a lack of hygiene or sudden changes in their environment (e.g. temperature, humidity). Provide shelter from the sun and the rain. Regularly move the animals into different enclosures and relocate their shelters. Provide good housing, draught- and dust-free, where temperatures are neither too high nor too low, and do not overcrowd. Maintain good hygiene in the pens and feeding equipment (keep them dry and clean). Prevention is better than cure.

At any outbreak of disease, it is essential to ensure that the disease is not passed on to healthy animals on the footwear, clothing, tools, etc. of those working with the pigs. Even insects, wild animals and earthworms can transmit disease. Therefore, take precautionary measures. Give the sick animal a separate pen. Do not let people into the stable, they might have pigs at home and carry germs away with them. After contact with a sick animal, never touch other animals without first washing your hands and changing your clothes and footwear. The pen should be continually cleaned with disinfectant or sodium hydroxide (NaOH, 5 %). Whenever pigs are sent to slaughter, their housing should be disinfected before new pigs are brought in. Any animals dying of a disease should be burnt to prevent further contamination.

23.3.5 Thermal Stress Alleviators in Pig Farms

The climate to which the pigs are exposed is very important. Appropriate housing facility might control the influence of climate to a certain extent. Pigs are very sensitive to sudden changes in temperature. They cannot stand heavy rain or drought. Strong sunlight is bad for them, as it causes their skin to dry out. Albino pigs especially cannot endure the sun because they have no pigment in the skin and this might lead to burning of their skin. This signifies the necessity for shade. Pigs kept for optimal production should therefore be protected from climatic stress. This is only possible by ensuring that the animals are well housed. The most important factor to consider in organising proper housing is temperature. The pig's body temperature can vary with the temperature of its surroundings, and a steady body temperature is important for a proper growth rate.

Every living animal produces heat, when converting its food for the requirements of growth. The more an animal eats, the faster it grows and the more heat it produces. Heat is also released when an animal is active (e.g. when walking). Warm-blooded animals (birds and mammals) can make use of some of this heat to keep their body temperature level. The normal internal body temperature of a pig is about 38.5 °C. A healthy animal will automatically try to maintain this temperature. Any great deviation from this norm may lead to the animal's death, because all of its body processes are geared to work at this temperature. If a pig's temperature rises above 41 °C, it will die. The same applies if the temperature drops too much. Especially in the tropics, animals generally produce more heat than they need to maintain their body at an ideal temperature. To avoid overheating, they have to get rid of any superfluous heat in one way or another.

One way of dissipating heat is to give off moisture by evaporation. Sweating is an example of this process. Pigs however do not have sweat glands and are therefore unable to do this. Releasing heat by evaporating water from the skin is also possible if there are puddles and pools that the animals can lie and roll in. Moisture evaporates from the wet skin, releasing excess heat from the body. If the water is cooler than the body, the body heat will be transmitted to the cooler surroundings. It cannot do any harm, therefore, to provide the animals with a pool of water, as long as the water is clean and not a health hazard. Pools are very important for improved breeds kept enclosed but are less important for indigenous (local) breeds. Good ventilation is also essential. Evaporation can also take place through the mouth, and in very hot weather, pigs can often be seen panting. This is because, by breathing more quickly, more air is exhaled through the mouth and other air channels, and in this way, more water is evaporated.

23.3.5.1 Wallowing Tank

Wallowing tank may be provided in pig breeding farm suited to zones. The wallowing tank should be made of cement concrete, and the dimension of the tank should be less than 2.5 m × 1.2 m × 0.15 m. Alternatively overhead sprinklers and showers may be provided in order to keep the animals cool during summer.

23.3.6 Methane Mitigation by Proper Waste Management in Pig Farms

Pollution is the major impediment in pig farms. This issue will increase in future especially in climate change scenario and expected increasing population especially in tropics. So proper design considerations with respect to waste management is an important factor in the development of pig industry. Manure management will always be a part of pig production. Management practices will have a significant impact on the environment regardless of the size of the operation. Producers who make wise manure management decisions help to maintain a healthy environment now and for generations to come. To reduce the risk of air or water quality damage from manure, understand how manure impacts air and water quality; keep the public in mind when locating, expanding or maintaining a facility; reduce the amount of material entering the waste stream; collect and store manure to preserve nutrients and minimise gas/odour emissions; apply manure to fields in a way that most fully utilises the available nutrients; follow compositing to increase manure value; establish biogas unit as an alternate energy source; and, for the electricity generation and if possible, integrate with fish production to augment income.

The waste from pig farm includes manure, bedding materials, feed left over of plant/animal origin, carcasses, syringes, needles, bottles and gloves. Proper disposal, reuse, and recycling of these wastes are also necessary to avoid pollution problems. Pig farms require large amounts of water for their production process. The resulting wastewaters contain high concentrations of organic matter, dissolved and suspended solids, turbidity, colour and pathogenic microorganisms and should be disposed so as to not jeopardise human or domestic animal's health and without polluting soils, rivers, lakes and reservoirs. The concern over manure has occurred because it linked to water quality and air pollution. Unfortunately, for much of the public, the words manure and pollution have become synonymous. Because of this actual or perceived problem with manure, the public is demanding producer accountability in regard to manure handling. This is being delegated by new regulations, lawsuits, and negative media coverage. It is imperative to identify and implement proper waste management techniques if the pig farm has to thrive in the country. Most of these practices involve managing manure from the pig to the end use – utilisation by crops. Manure is often seen only as a liability, with substantial costs involved in the removal of the waste. However, some of these costs can be recovered by recognising and handling manure as a byproduct from a nutrient standpoint.

23.3.6.1 Manure Production and Composition

Pigs are estimated to produce daily raw manure of as much as 8.4 % of body weight (urine and faeces) with 3–5 kg of faeces. Generally, growing-finishing pigs weighing 100 kg can be expected to generate 0.39–0.45 kg of waste per day on a dry matter basis (Brumm et al. 1980). This manure contains 1.9 % P, 7.2 % N and 3.2 % K as by-products of digestion. The major differences in composition of the manure are dependent on the methods of collection, dilution and storage and are not diet dependent. The majority of the N excreted from the pig through uric acid in the urine and organic N forms in the faeces (Sutton et al. 1983).

23.3.6.2 Components of Manure Management

The desirable practices include run-off from open lots or manure storages; minimising production site's visibility from public roads and neighbours, located at reasonable distance and direction to neighbours and communities; locating facility to accommodate land application of manure; providing public education and information about plans for expansion; complying with applicable local, state and central regulations; and evaluating current or proposed farm sites for potential environmental hazards. Proper manure management is essential for gaining maximum benefit from manure and reducing the liability or pollution potential. A systematic approach to manure management is necessary, so that all aspects of manure production and handling can be fully utilised. The five main manure management categories can be broken down into the following components: site selection, manure production, collection and storage, treatment and application.

23.3.6.3 Manure Production

The manure production can be reduced in the following ways: control of water and feed and increasing efficiency of feed utilisation and formulation of diets to reduce manure production.

23.3.6.4 Collection and Storage

During the collection and storage of manure, adverse environmental effects can occur from both potential water pollution and odours. The following recommendations are suggested to reduce those potential pollution and safety hazards: use collection systems that eliminate manure ponding on solid surfaces, provide adequate storage capacities, keep rainwater out of storage areas and cover storage systems, manage deep pit systems to minimise gas concentrations inside the barn, stockpile manure on a concrete pad, locate storage systems to avoid pollution potential and where manure and nutrients are needed and always have contingency plans for accidents or overflows.

23.3.6.5 Treatment

The practices such as liquid-solid separation systems, composting, anaerobic lagoons, anaerobic digesters and aerated lagoons can reduce the environmental impact.

23.3.6.6 Manure Handling and Disposal

The major concerns associated with managing manure from swine are related to run-off control from open feedlots, storage requirements and land application of manure collected from confinement facilities. The run-off control issues for handling this type of manure are very similar to those for handling other types of manure. Storage and land application problems from confined production units occur due to the large volumes of water often associated with the material. Depending on method of collection and storage, the collected material can contain from 90 to 99.9 % water at the time it goes into storage.

23.3.6.7 Problems in Land Application

Decisions on the best ways to apply swine manure to land are complicated by compromises between achieving the best soil erosion control and the best conservation of nutrients in manure and the use of these nutrients by growing crops. The manure applied to the soil should be incorporated into the soil surface within 24 h after land application. This practice can significantly reduce odours and can minimise ammonia volatilisation so that N in manure is conserved. Application of manure to cropland following harvest, prior to tillage, is often recommended because the risk of damage from soil compaction is minimised. Spring applications are usually accomplished prior to tillage and planting. Pig manure is considered suitable for rice production, but not useful for vegetables, coffee and fruit-tree cash crops (Dan et al. 2004).

23.3.6.8 Compositing

Solid manure fraction may be composted after mixing with one or more of the ingredients such as straw, plant waste products, ash or lime. Low-cost buildings or pits covered with mud or tarpaulin are good composting. Composting manure without cover will result in poorer manure quality due to emission of ammonia. Composting and storage periods vary from 3 to 5 months. The volume of the containers depends upon the size of the farm (minimum 0.5 m^3 to maximum 11 m^3) and may be constructed of concrete or bricks. The mud pits for manure storage may cause nitrogen leaching and pathogen spread into ground water. Uncovered pits will increase ammonia emission. The distance from manure stores to the drinking water source depends upon the size of the unit (min, 10 m to max, 50 m), but the Danish standard stipulates a minimum distance of 50 m to any drinking water source.

23.3.6.9 Biogas

Fermentation of manure in biogas digesters may reduce the spread of pathogens and of noxious odour emissions. The capacity of digesters may be from of minimum 10 m^3 to maximum 30 m^3. The dimensions of digesters' volume corresponded to treatment of manure may be five to ten pigs per m^3. Biogas digester is connected with modified diesel generator for electricity generation and power distribution. A large-scale farm can use built in effluent pond to store waste, with a cover that stores the biogas. This gas is piped to a combined heat and power (CHP) unit which processes it to make electricity and this electricity is then used to power the piggery. A 'heat recovery' system is also being installed which will use waste heat to heat water, some of which will replace electric heating for young pigs. Anaerobic digestion that happens in the pond, the result at the end of the process, is a nutrient-rich – and odour-free – fertiliser for the adjacent family farm.

23.3.6.10 Malodour Management

Odour control has become a major environmental concern of the swine industry. Swine producers have identified odour complaints as a major industrial environmental issue. Wastes diluted with water are less of a nuisance than undiluted wastes. This would require excessive volumes of fresh water. Dilution of the odorous gases in the air is also a good malodour abatement technique. Appropriate roof height and ventilation and air movement in the pens help high air dilution. Because wind speed increases with height, releasing gases high above the ground would aid in malodour dispersion. Another good idea is to wash pig houses around noon to take advantage of the dispersive capacity of midday winds and sunshine. Oxidising agents, such as hydrogen peroxide, potassium permanganate, paraformaldehyde, ozene (ortho-dichlorobenzene), chlorine and ozone, can be used to control malodours. Cost and practical considerations rule out the widespread use of these chemicals on pig farms except for short durations or in emergencies.

23.4 Shelter Design for Sheep and Goats in a Climate Change Perspective

23.4.1 Goat Housing in Different Climates

Among species, sheep and goats are considered less susceptible to heat stress than cattle (Silanikove 2000). Goats are well adapted under different geographical and environmental conditions including extreme and harsh climates, which could be the reason for their presence in almost all agro-ecological zones of the world. Sheep tolerate low temperatures, and their thermal requirements and the lower critical temperatures are well documented (Webster 1976), while the same have not been much documented in goats. An exception is a publication by Toussaint (1997) who recommended that air temperature in the goat house should be between 6 and 27 °C (optimal: 10–18 °C), humidity 60–80 %, maximum air speed 0.5 m/s and ventilation with a winter flow of 30 m^3/h/animal and summer flow of 120 m^3/h/animal. In parts of Europe where the winter is mild, dairy goats are usually kept in simple uninsulated buildings, whereas insulated buildings are most common in countries with a cold winter climate, such as Norway (Simensen and Bøe 2010). While in a study conducted by Eik (1991), it was observed that Norwegian dairy kids could be successfully raised in non-insulated barns with good performance results.

23.4.2 Height, Design and Space Required for Platform

In order to assure and maintain optimum climate in shelter, location and orientation should be considered. The location must be on lands with the water table at a depth of over 0.50 m and with the slope of 3–5 % to South (Nicolescu et al. 2010). The orientation of shelters must be planned depending on the land conditions after considering the dominant wind direction. An east-west orientation of the longitudinal axis of the shed prevent the sun from too much heating up the stall. A north-south orientation is preferred in humid areas so that sunshine dries up the floor more easily.

Floor designs vary depending on the production system employed and local climate. Cost of construction, ease of cleaning, proper ventilation and drainage and adequate lighting are important aspects to be considered in designing a house. In sheep and goat houses, the height of floor should be maintained at 1–1.5 m above the ground (Sahoo et al. 2013). Earth, concrete or wooden slats are the common types of flooring materials used. A gap of 1.5–2 cm is the preferred width between the slats so that manure falls through but legs of goats are not trapped (Peacock 1996). Recently there has been a preference of animal keepers for slatted floor pens which has the advantage that animals are kept relatively clean without any bedding material at a low space allowance and with a minimum of work input. Important characteristics of pen flooring for farm animals are considered to be thermal conductivity, softness, cleanliness and slipperiness. Thermal conductivity and softness of the floor will often be correlated, as soft floors usually will be well insulated (Nilsson 1988). Goats in natural environments are often resting directly on the rocks in steep cliff areas as reviewed by Shackleton and Shank (1984), which apparently do not indicate a preference for soft bedding. Sheep prefer soft floors with low thermal conductivity when the ambient temperature is low, but such scientific data does not presently exist in goats. The goats spent less time lying and more time being active and eating in the cold than in the moderate temperature period, which indicates that the goats are using behavioural strategies to cope with the low temperature in a similar way as sheep (Bøe 1990). On exposure to cold, a transient increase in free fatty acids and thyroxine was observed suggesting an increased metabolism (Aulie et al. 1971). The fact that the level of the recorded physiological measures declined after a few days suggests that the goats may acclimate after a short period of cold exposure. In contrast, the behavioural responses, such as increased activity maintained throughout the entire cold period, suggest that the goats are in the cool thermoregulatory zone (Curtis 1981).

Boe et al. 2007 observed that goats exposed to a cold temperature period of −8 to −12° spent an increased time standing with the head above the feed. In a temperature of 10–12 °C, straw was the least preferred flooring, while expanded metal was preferred to solid wood. The goats' preference shifted towards flooring materials with a lower thermal conductivity in the cold period. Mattress and solid wood were most preferred in the cold period. Norwegian goat kids in an uninsulated house had a normal growth rate after a few days of adaptation to a temperature of around −4 °C (Eik 1991).

Toussaint (1997) recommended floor space requirements of 0.50 m^2 (minimum) for an adult goat in stall housing, 1.50 m^2 for an adult goat in open housing with an outside yard and 0.30 m^2 for a kid before weaning. With 3 m at the lowest part of the building and 3 m width for a central feeding corridor, each goat should have an air volume of 9 m^3. With the shift from solid floors to perforated or slatted floors, the use of bedding is rarely seen. Some farmers still use beddings especially saw dust, wood shavings, straw, sand, hydrated lime, etc. In a study conducted by Simmensen et al. (2010) in Norway, it was observed that majority of the farmers (80 %) used perforated floors for keeping their goat, of which some farmers used straws or hydrated lime. The use of bedding materials was limited during the kidding season. Out of 20 % farms that used solid floors, majority did not use any bedding, while the rest opted for sawdust/wood shavings and a few used hydrated lime.

23.4.3 Roofing Materials and Structure for Goat Sheds

The roof provides protection from sun and rain and can be of a shed, gable or modified gable style. The roof should be waterproof with sufficient overhang. Simple thatched-type roof is seen in rural areas. Thatched roofs need a greater slope than iron sheeting. A greater slope is also beneficial in areas with high rainfall. A high roof encourages air movement but is more likely to be damaged by strong winds. A roof vent can assist in proper ventilation. Roofs can be constructed from iron sheet, grass/bushes, wood, stone/brick or earth depending on production system, material availability and climate.

In a study conducted in rural West Bengal, India, by Nandi et al. (2011), it was found that in majority of goat houses, paddy straw was used as the roofing material, while in some, earthen tiles and tin sheets were used. The roof picks up most of the solar radiation during summer, whereas in winter, south-facing walls pick up most of the solar radiation. The lambing shed should therefore be aligned along an east–west axis to maximise the surface area facing south. The shed should be constructed at a place where there is no obstruction to direct light. In a study conducted by Rajanna et al. (2013) among sheep farmers of Andhra Pradesh, India, it was observed that majority of them used thatched roof for keeping sheep, while some used asbestos sheets and a few used tiles as roofing materials.

23.4.4 Waterers and Feeders for Goat Sheds

In a study conducted by Alvarez et al. (2013), it was observed that shade on feeders helps to ameliorate some negative effects of solar radiation increasing feeding time and feed intake in female goat kids. A higher percentage of intake was recorded in the shaded feeders than that in the unshaded feeders. Food refusal was higher in the unshaded feeders (30 ± 1.8 %) than that in the shaded feeders (25 ± 1.9 %). The provision of shade is a simple method that helps to minimise the negative effects of solar radiation in grazing (Blackshaw and Blackshaw 1994). Very selective behaviour is an essential component of goat behaviour because it enables goats to stay in difficult areas as well as to cope better with toxic plants (Duncan and Young 2002). Flint and Murray (2001) indicate that the improvement of the feedlot environment can reduce stress and aggressiveness at trough and improve goat performance. The training of young goats by does in pastures is very efficient (Knubel 2001). The experienced goats strongly modify their preferences and the vegetal stratum chosen according to the season (Dziba et al. 2003). Mallik (2003) recommended the use of portable feeder and waterers prepared from galvanised iron sheets for goats reared under Indian conditions with width of feeder being 40–50 cm.

The literature on water intake in goats is scare. In temperate climates, the water intake for goats is reported to be 139 g/kg W0.75 at mid-pregnancy, and lactating goats need 1.28 kg of water to produce 1 kg milk (Giger and Gihad 1991). Ehrlenbruch et al. (2010) measured the water intake in lactating goats to be 6.2 and 4.4 l/day when fed hay and silage, respectively. The water intake was higher from nipple drinkers than from water bowls as reported in a study by Bøe et al. (2011) in goats, while water wastage was quite high in water nipples (23–27 % of water usage) and almost negligible from water bowls. Bøe et al. (2011) reported a clear reduction in water quality in water bowls.

23.4.5 Waste Management in Goat Farms

Ventilation will affect the inside temperature and humidity of the goat house. For a classic goat building 12 m wide, the use of static ventilation is advised (Toussaint 1997). Also the level of noxious gases must not surpass 0.35 % for carbon dioxide or 0.015 % for ammonia and 0.002 % for hydrogen sulphide. Cattle emit 25–118 kg methane per head per annum, while sheep and goats emit only 5–18 kg per head per annum (IPCC 1995). Herreo et al. (2008) estimated that Africa produces 10–13 % of all global methane emissions from livestock with cattle producing 84 % of this and sheep and goats only 16 %. The feeding of condensed tannins containing forages decreased methane emission from goats (Puchala et al. 2005).

In a study conducted by Loh et al. (2005), vermicomposting was done for cattle and goat manure using earthworm *Eisenia foetida*. It was observed that cattle vermicasts had a higher N content than goat vermicasts, but the C/N ratio of fresh manure was higher than that of vermicasts for both materials. Earthworm biomass and reproductive performance, in terms of number of worms after 5 weeks of experiment, were higher in cattle manure than in goat manure. The cocoon production per worm in cattle manure was higher than in goat manure. However, the hatchability of cocoons was not affected by manure treatments.

As per Vasanthi and Kumaraswamy (2000), the green and dry fodder yields of the cereal fodders, the soil fertility status and the content and uptake of N, P and K were significantly higher in the treatments that received sheep–goat manure at 10 t ha^{-1} with 50 % of the recommended NPK schedule than the yields in the treatment that had received NPK alone.

In a study conducted by Rajanna et al. (2013) in Andhra Pradesh, India, it was inferred that majority of farmers stored sheep manure as a heap in open place, while some stored manure in pits and sold them once or twice per year. When majority of the farmers threw carcasses into open fields and unused open wells, a minority used dead animals for consumption, while the rest buried the dead animals. In another report by Ananda Rao (2010), majority of sheep farmers consumed meat from carcass, while the rest adopted burial as a means of disposal.

23.4.6 Housing Considerations for Disease Prevention in Goat Farms

Global warming, associated changes in precipitation patterns, and the frequency and the severity of dramatic weather events such as droughts, hurricanes and floods are having direct and indirect effects on animal health while specific information on the relationship of climate change to goat disease is rare (Peacock and Sherman 2010). As per Kusiluka et al. (1998), ectoparasitic, helminth and coccidial infections resulting in decreased animal performance (decreased weight gains and body conditions) were the most prevalent health problems of goats in all management systems. Foot rot, caseous lymphadenitis, dermatophilosis and mange were encountered only in pastoral herds. Poor housing led to prevalence of gastrointestinal parasites in cross-bred animals that were stall-fed compared to the indigenous animals managed by tethering. It is common in tropical highlands to allow manure to accumulate in animal houses for use in crop field fertilisation, resulting in increased warmth and humidity that favoured proliferation of the parasites (Dipeolu and Ayoade 1982). The higher prevalence of respiratory infections in pastoral goats than in other animals may be predisposed to by high stocking rates, coupled with increased dust (during the dry season), dampness and the chilling effects at nights in the poorly built houses in raining season. Management factors, such as confinement in houses, grazing systems and house hygiene, to a variable extent, influence the prevalence of diseases in goats (Kusiluka et al. 1998). Young kids are vulnerable, and insulation at an early stage may well lead to low mortality figures and ensure steady milk production in later stages (Toussaint 1997). As per Foreyt (1990), protozoan diseases, coccidiosis and cryptosporidiosis are important enteric diseases of sheep and goats resulting in diarrhoea, inefficient weight gains and occasionally death. Control is strict sanitation and quarantine of sick animals. Disinfection of contaminated housing with ammonia or formalin will kill the oocysts and through elimination of carnivore faeces from the premises through management.

23.5 Shelter Design for Poultry in a Climate Change Perspective

Among livestock, the poultry is the most vulnerable species to climate change impact. Hence the design considerations in view of the increasing temperatures are extremely important. Stress alleviation and disease prevention are highly relevant in this context. Poultry farm should be at least 1 km away from the human dwelling and also nearby farms. It should be an elevated area and should not be waterlogging. It should not be near water sources like rivers, ponds, lakes and seas which will increase the air humidity and also host insects. Poultry house should not be surrounded by rocks and mountains which reflect sunlight. The site should have adequate potable ground water.

23.5.1 Floor Foundation and Plinth Height

Good foundation is essential for best insulation and to prevent water seepage into the shed. The foundation should be 1–1.5 ft below the ground level and the plinth height should be 1–1.5 ft in the elevated area and 2 or above in low-lying areas. Concrete floor and good litter material are desirable for easy cleaning and best insulation. Mud floor can also be used to reduce the cost of investment. Floor space should be increased by 10–20 % during hot summer. That means you have to reduce the stocking density by 10–20 %. The side wall should be of 1 ft height and the remaining part should be open sided covered with mesh.

23.5.2 Roof Structure and Design for Poultry Farms

Thatched and tiled roof will be cooler than asbestos or tin sheet roofing. Since majority of heat load enters the shed through the roof, keeping the upper surface of the roof clean and painting it with white colour will reflect the sunlight and reduce the heat inside the house. False roofing will reduce the conduction of heat and also reduces accumulation of hot air under the roof.

Roof overhang: It should be 3–5 ft to avoid direct radiation from sun and also rain into the poultry house. Thumb rule is that the ideal width of the overhang should be half the height of the open space at eaves.

Roof ventilators: In open-sided houses with gable type roof, hot air molecules which are light in weight will go up and settle under the roof. This heat accumulation will increase the temperature of the shed. Air next to the uninsulated roof may exceed 55 °C. To alleviate this problem, we can go for the roof types like full monitor, half monitor and also turbo ventilation system. Through these systems, hot air will escape out and cool air will enter through the sides of the house.

Roof slope: Steep roof slope (45°) tends to attract less radiant heat from the sun than flat roof. It also maximises the distance between the birds and the hot ceiling, which reduces the amount of radiant heat from the hot, uninsulated roof.

Roof insulation: As reported by Czarick and Fairchild (2008), most poultry-house roofs are fabricated from galvanised steel, which will commonly reach temperatures of 50–70 °C on a sunny day. The hot roof not only leads to increased house air temperature but also dramatically increase the amount of thermal radiation the birds are exposed to. Cages and other objects in a poultry house with an uninsulated ceiling would be 1–5 °C above ambient air temperature. The best way to eliminate heat from a ceiling is through insulation. Insulation acts as a thermal barrier, keeping heat from the hot roof from entering the house. Minimum level of R-value of ceiling insulation for a naturally ventilated house is 1.25 m^2 C/W, whereas houses that have high temperatures above 40 °C or temperatures below 0 °C typically require ceiling R-values of 2.25 m^2 C/W or more. There are a variety of methods of insulating a poultry-house ceiling.

A dropped ceiling is most commonly installed in houses with a scissor truss. Metal is installed along the top cord of the truss, and a strong vapour barrier supported by strap/strings is installed on the underside of the bottom cord of the truss. Fibreglass batt or blown cellulose insulation is placed on top of the vapour barrier.

Rigid board insulation: Rigid board insulation is typically constructed of polystyrene or polyurethane insulation. Rigid board insulation is available in thickness of 1.25–4 cm and comes in sheets 1.2–1.8 min width in a variety of lengths. The board insulation is placed on the topside of the truss and the metal is placed on top of the board insulation. Thicker boards are available with 'tongue and grove' construction, which facilitates a tighter seal between the metal roof and the building space.

Spray polyurethane insulation: Spray polyurethane insulation is applied on to the underside of a poultry-house roof to form an airtight insulation barrier. Thickness typically ranges from 2 to 4 cm. Spray polyurethane is a popular method of insulating existing houses owing to the relatively easy application.

Reflective insulation consists of a single reflective film or two pieces of reflective film with some type of 'bubble' insulation between the two pieces of film. Reflective insulations are installed either on top of the truss, just beneath metal roofing, or on the underside of the bottom cord of a truss. Reflective insulation works by reflecting radiant energy from the roofing material back towards the roof and away from the birds. In order to be effective, an air space between the reflective insulation and the hot roof is necessary. Furthermore, the insulation must stay clean. Dust accumulation on the surface of the reflective insulation can dramatically reduce its heat-reflecting ability. Reflective insulations have a very limited ability to reduce conductive heat loss during cold weather and are generally not recommended for installation in houses where low outside temperatures (<30 °C) are commonly experienced. Open-sided houses should be constructed with east to west orientation with its width extending from north to south. This is to avoid direct sunlight into the shed and also to increase the air movement. As the width of the house is the limiting factor for ventilation, it should be limited to 21–30 ft based on the temperature, humidity, wind velocity, type of house and nature of bird for efficient cross ventilation. The poultry house may be of any length from 200 to 1,000 ft, depending on the topography and the soil. Longer sheds are more economical. The minimum height of the poultry house should be 11–15 ft at the ridge and 7–10 ft at the eaves. As the height increases, the temperature at bird level will reduce.

Distance between sheds: Air obstruction by the nearby shed or building can be eliminated by keeping minimum of 10 m between the sheds. The recommended design spacing (D) can be calculated from the following formula:

$$D = 0.4 \times H \times (L)^{0.5}$$

where H and L are the height and length of the obstructing building or other barrier (in ft).

The sheds having birds of different age group should have a minimum gap of 30 m to avoid disease spread from aged birds to younger one.

23.5.3 Thermal Stress Alleviators in Poultry Farms

Shade: Planting simple shade trees can reduce the radiant heat load by 30 % or more by intercepting the sun. There should not be any branches up to the height of the overhang which will hinder the air flow into the house.

Radiation from the ground: Growing grasses around the poultry shed will reduce the radiation from the ground. But the grasses should not be grown more than 1 ft which may also hinder the air movement into the poultry house.

Positive pressure or forced draught ventilation system: Ceiling fans and pedestal fans are installed 3–7 m above the birds and 6–15 m wide apart depending on their size and desired air velocity. The vertical pedestal fans can be tilted at around 5–8° downwards over the birds. As birds are not having sweat glands, positive pressure system is not very effective.

Negative pressure system: Exhaust fan may be used to create negative pressure inside the house which will invite fresh air from outside. One and half 36″ fans may be required for each 100 ft of house length.

Roof sprinklers: Evaporative cooling can be done by roof top sprinkling and spreading the gunny bags on the roof or by hanging the gunny bags or curtains on the sides of the house.

Fogging system: High-pressure fogging systems (400–600 psi) produce droplet sizes of 10–15 μm. Fogging lines must be placed inside the poultry house, close to the incoming hot air. If necessary, additional lines at the centre of the house may also be provided. This system covers higher surface area to volume ratio than a larger droplet produced by low-pressure fogging system. This will reduce in-house temperature by 6–10 °C depending on the outside temperature and RH.

Low-pressure fogging systems (100–200 psi) produce droplet sizes of more than 30 μm. This is used in less demanding situations and the cooling effect will be 4–7 °C only. Low-pressure misting system produces cooling primarily through bird wetting and subsequent evaporation of water off the surface of the birds.

Pad cooling system: In fan and pad system, exhaust fans are used to create negative pressure inside the environmentally controlled house. This vacuum created will lead to incoming of air through the cooling pads. Water circulating system in the cooler pad is capable of circulating a minimum of 10 l of water per minute for every linear metre of pad length. Only 10 % of the water flowing over the pad is evaporated.

Evaporating cooling is ineffective or detrimental in the hot and humid climate. For every 1 °C reduction in temperature by evaporative cooling will lead to 3–4 % increase of RH. The increase in RH will reduce the panting efficiency and increase the risk of heat shock. In tropical climate whenever the temperature is above 80 °F, the relative humidity will be below 80 % and vice versa. This relationship should be kept in mind when operating an evaporative cooling system. When the relative humidity is above 80 %, the amount of cooling produced by pads, foggers and sprinklers is very limited, typically less than 4 °F (2 °C).

23.5.4 Housing System Changes Needed to Combat Climate Change Threat in Poultry Houses

Deep litter system is better than cage system because the gap between the roof and birds is more in deep litter system than cage system and also the litter acts as insulating material. During summer, the litter height should be reduced and the same should be increased during winter. In elevated or high-raised houses, there may not be any obstruction to the wind flow. This will increase the air movement and assist in heat loss by evaporation, conduction and convection as long as the air temperature is lower than the skin temperature. When air temperature approaches the skin temperature, heavy air movement will be comfortable. In addition to that, air movement is required to remove noxious gases like carbon dioxide and ammonia. The minimum requirement of wind velocity should be 0.2 m/s, but it can be increased to 1.0 m/s. In both normal open-sided house and elevated open-sided house, the type of ventilation is cross ventilation. In an environmentally controlled house, the micro-environment inside the poultry house is mechanically controlled, and there is no connection between the inside and outside environment. To reduce the inner temperature, evaporative cooling method like tunnel ventilation (fan and pad system) can be used.

23.6 Shelter Design Considerations for Rabbits in a Climate Change Perspective

23.6.1 Importance of Design Considerations in Rabbit Farming

Rabbit farming has immense potential to improve the socio-economic status of the rural poor. In many tribal and backward areas, rabbit farming has emerged as a cottage industry, and its potential for self-employment is now being realised by small and marginal farmers. In India, rabbit industry is gaining importance for wool production in hilly areas of Himachal Pradesh, Uttar Pradesh, Jammu and Kashmir and lately in Sikkim and Arunachal Pradesh and as a broiler industry in areas of temperate and subtropical climate in West Bengal, Assam, Manipur, Andhra Pradesh, Tamil Nadu, Kerala and Karnataka. Rabbit rearing owing to low capital input involved, lesser space requirement and high profitability has the potential to emerge as a major food production enterprise of our state. But the humid tropical climate of Kerala contributes substantial stress on temperate breeds of rabbits that adversely affect their performance. THI values above 27.8 results in heat-induced physiological stress in rabbits (Marai et al. 2002).

Since rabbits are highly susceptible to stress, especially due to climatic variations, the success of rabbit farming mostly depends on congenial macro- and micro-environments and the effectiveness of the ameliorating measures taken to reduce the stress factors. Environmental conditions and housing systems should be in accordance with the essential biological characteristics of the species. Housing systems have the potential to influence production, increase welfare and minimise the negative effects of the natural environment on the animals.

23.6.2 Low-Cost Cage Construction

A low-cost and innovative cage design was developed by the Department of Livestock Production Management, College of Veterinary and Animal Sciences, Mannuthy, Kerala, India. A two-tier system of cage design was adopted to solve the problem of space constraint faced in many households. Cages were made with 13 mm wire mesh and supported by 37 mm PVC pipes. A thick plastic sheet of good quality was attached in a slanting position between the two tiers so that urine and droppings of the rabbits are drained directly into the side drain and carried outside the shed. Each side of the cage was attached to the next by twisting metal wires between them, thus making the cages low cost. A small door was cut in the front of each cage and again attached by twisting metal wires. A thin metal rod was shaped in the form of a hook and attached to the door for securing the cage. Each individual standard wire mesh cage is 75×60×50 cm in dimension. Prasad and Smitha (2011) have designed a model rabbit cage suitable for the tropical environment. It was observed that majority of the farmers (62.5 %) in Kerala state, India, used tin sheet as roofing material followed by coconut leaves (25 %) and tiles (12.5 %).

23.6.3 Ameliorative Measures and Its Effect

The various ameliorative measures that can be provided to reduce climatic stress on rabbits are to provide ad libitum water through nipple watering system and fans during summer season and improvise the shed with false ceiling and adjustable shades to control dampness in rainy season and exposure to direct sunlight in summer. The latter two ameliorative measures help to significantly lower the shed temperatures. Thus the physiological parameters like respiration rate and rectal temperature can be maintained below stress level. A combined use of all four stress ameliorative measures such as nipple watering system, fans, false ceiling and adjustable shade in rabbit shed can lead to their increased production performance. This includes larger litter size, heavier litter weight and faster preweaning growth rate of kits. Mortality of young ones can also be reduced by incorporating stress alleviation measures in the rabbit shed. Providing shades and false ceiling is far superior to the provision of fans and nipple watering alone though a composite treatment of all four stress alleviation measures gave the best results. A management protocol for better rabbit production, suggested based on the study conducted by Biya (2011), is as follows:

1. Improvisation of the rabbit shed to obtain ideal microclimate by providing shades, false ceiling, fans and ad libitum water supply.
2. Design cages (75 × 60 × 50 cm) using 13 mm wire mesh supported by 37 mm PVC pipes to provide adequate space for doe at low cost.
3. Provision to drain out urine and droppings from cage and shed to reduce the humidity inside the rabbitry.
4. Reduce death of kits due to trampling by keeping the nest box (50 × 30 × 15 cm) with kits outside the cage of does with poor mothering ability.
5. Reduce weaning stress through antibiotic and coccidiostat coverage.

23.7 Special Integrated Designs: Innovate to Survive

Considering the enormity of the challenge as a result of climate change, we need to cut across traditional paradigm of animal agriculture to innovate tangible solution to real practical problems of the field to survive in any worst scenario.

23.7.1 Innovative Integrated Model with Goat, Rabbit, Poultry and Fodder Production

This model illustrates how these design considerations could be used to integrate to optimise production in the limited space available in the tropics (Figs. 23.6 and 23.7). The different components of the model are described in Table 23.1.

23.7.1.1 Dimensions of the Integrated Model

Two galleries supporting each other form the roof for the two-storey animal house in which the ground floor is for poultry and the first floor is for goat. Rabbit is accommodated in hanging cages and Azolla is grown in tanks over rabbit cage. Galleries can accommodate grow bags with micro-irrigation for cultivating fodder for animals, or as kitchen garden for a small family, or for cultivating high value vegetables, flowers, fruits, etc. Separate provisions are there for collecting manure and urine of goats and rabbits which can be used as manure for the items in gallery which helps in organic farming.

The structure should be 16 ft in height, 32 ft in length and 10 ft in width with a floor area of 400 ft^2 (effective utility area of 1,000 ft^2 as two floors and two galleries). Ground floor have two cages of 60 ft^2 each on both ends preferably for adult layers and a central 200 ft^2 space for broiler or layer grower chicks. First floor area is 200 ft^2 which is for goats and with two partitions, one for male and another for animals with advanced pregnancy or with kids. Rabbit cages are hanging outside at the level of first floor. Sixteen cages of

Fig. 23.6 Different components of the innovative integrated model

4 ft^2 each are provided as two rows in front and the back side. Azolla tanks of 20 ft^2 size should be set up above the rabbit cages. Galleries provide steps of 10 ft length and 1 ft width which can accommodate pots or grow bags with micro-irrigation. A tank with a capacity of 500 L is needed for the storage of water. These sheds are provided with automatic drinker facility and no-wastage feeders.

The proposed integrated units will ensure food security through integration of different livestock and helping in carbon recycling. Vertical height utilisation for farming ensures optimum production from minimum space. This model can

Fig. 23.7 Complete unit of innovative integrated model

Table 23.1 Design components of integrated model

No	Component	Description	Area/no
1.	Structure	*Gallery* – iron structure with steps for cultivation	35 steps
		Ground floor – poultry sheds with cement floor under goat shed and layer poultry cage under gallery	320 ft^2
		First floor – plastic slat floor, iron grill and GI weld mesh structure, collection system for of manure and urine	200 ft^2
		Rabbitry – hanging cages for male and female, collection system for of manure and urine	16 cages of 4 ft^2 each
		Azolla – tanks of height 20 cm	2 tanks of 20 ft^2
2.	Automatic drinker assembly and feeders	*Poultry* – hanging feeders and drinkers	10 nos. each
		Rabbit – nipple drinker and feeder	16 nos. each
		Goat – drinking bowl assembly for goat	10 nos.
3.	Gallery cultivation	Irrigated grow bags or pots, water tank of 500 l capacity	300 pots
7.	Manure collection	Flex sheet, PVC channel for urine collection, between pond and shed	200 ft^2

promote roof top cultivation which will further reduce space. Thermal stress is reduced because roof is being used for cultivation. Such units will be self-sufficient for the individual unit and favours family farming as envisaged by Food and Agricultural Organisation (FAO). The varied products will ensure revenue generation year round.

23.8 Conclusion

Proper design of animal houses by utilisation of scientific knowledge is imperative in developing climate resilient animal agriculture to avert production loss in the vent of climate change. Individual physiological peculiarities of different livestock species like dairy, sheep, goat, pig, poultry, rabbit, etc. need to be considered in the design of suitable housing. In a climate change perspective, thermal stress alleviation methods, methane mitigation measures and methods to produce optimally from limited space are of special relevance. Specificity in design and application can be achieved through multidisciplinary approach especially through engineering support in livestock production. Innovative, integrated and self-sufficient approaches suitable to millions of farmers especially in the tropical world is the need of the hour.

References

Alvarez L, Guevara M, Reyes A, Sanchez A, Galindo F (2013) Shade effects on feeding behavior, feed intake, and daily gain of weight in female goat kids. J Vet Behav 8(6):466–470

Ananda Rao K (2010) Analysis of sheep production zones in north coastal zones of Andhra Pradesh. Ph. D. thesis, Sri Venkateswara Veterinary University, Tirupati

Aulie A, Astrup HN, Nedkvitne JJ, Velle W (1971) Serum non-esterified fatty acids and plasma glycerol as indicators of fat mobilization in pregnant sheep subjected to cold stress. Acta Vet Scand 12:496–503

Barrington S (1997) Summer ventilation. Temperature regulation in the dairy cow. Producteur Lait Quebec 17(5):26–29

Berman A (2004) Tissue and external insulates estimates and their effects on prediction of energy requirements and of heat stress. J Dairy Sci 87(5):1400–1412

Bernabucci U, Lacetera N (2010) Metabolic and hormonal adaptations to heat stress in ruminants. J Anim 4:1167–1183

Biya AJ (2011) Assessment and alleviation of environmental stress on productive performance of rabbits. Ph.D thesis, Kerala Veterinary and Animal Sciences University, Pookode, Wayanad, 158 p

Blackshaw K, Blackshaw A (1994) Heat stress in cattle and the effect of shade on production and behaviour: a review. Aust J Exp Agric 34:285–295

Bøe K (1990) Thermoregulatory behaviour of sheep housed in insulated and uninsulated buildings. Appl Anim Behav Sci 27:243–252

Bøe KE, Ehrlenbruch R, Andersen IL (2011) The preference for water nipples vs. water bowls in dairy goats. Acta Vet Scand 53:50

Brumm MC, Sutton AL, Jones DD (1980) Effect of season and pig size on swine waste production. Trans ASAE 23:165–168

Calamari L, Maianti MG, Cappa V, Frazzi E (1995) The influence of air speed on yield and milk characteristics in dairy cows during summer. Ann Fac Agrar Univ Stud Perugia 35(1–2):95–107

Clark JA (1981) Environmental aspects of housing for animal production. Butterworths, London, p 337

Curtis SE (1981) Environmental management in animal agriculture. Animal Environment Services, Mahomet, p 410

Czarick M, Fairchild BD (2008) Poultry housing for hot climates, poultry production in hot climates, 2nd edn. CAB International Publishing, Trowbridge, UK, pp 80–131

Dan TT, Hoa TA, Hung LQ, Tri BM, Hoa HTK, Hien LT, Tri NN (2004) Area-wide integration (AWI) of specialized crop and livestock activities in Vietnam. Project report, Nong Lam University (UAF), HCMC, Vietnam, pp 24–27

Dipeolu OO, Ayoade GO (1982) The epizootiology of infestation of sheep with Ctenocephalides canis in a livestock farm in Nigeria. Bull Anim Health Prod 30:31–34

Duncan AJ, Young SA (2002) Can goats learn about foods through conditioned food aversions and preferences when multiple food options are simultaneously available. J Anim Sci 80:2091–2098

Dziba E, Scogings PF, Gordon IJ, Raats IJ (2003) Effects of season and breed on browse species intake rates and diet selection by goats in the False Thornveld of the Eastern Cape, South Africa. Small Rumin Res 47:17–30

Ehrlenbruch R, Eknæs M, Pollen T, Andersen IL, Bøe KE (2010) Water intake in dairy goats – the effect of different types of roughage. Ital J Anim Sci 9:400–403

Eik LO (1991) Performance of goat kids raised in a non-insulated barn at low temperatures. Small Rumin Res 4:95–100

Esmay ML (1978) Principles of animal environment. Avi Publishing Company Inc, Westport, p 317

Flint M, Murray PJ (2001) Lot-fed goat—the advantages of using an enriched environment. Asian–Australasian. J Anim Sci 41:473–476

Foreyt WJ (1990) Coccidiosis and cryptosporidiosis in sheep and goats. The veterinary clinics of north America. Food Anim Pract 1990:655–670

Frankham R (2005) Stress and adaptation in conservation genetics. J Evol Biol 18:750–755

Gebremedhin KG, Lee CN, Hillman PE, Collier RJ (2010) Physiological responses of dairy cows during extended solar exposure. Trans ASABE 53(1):239–247

Gupta LR, Hariom RS, Grewal SS (2004) Effect of different housing systems on the performance of Murrah buffalo heifers during winter. Indian J Anim Sci 74(12):1239–1240

Hillman PE, Gebremedhin KG, Parkhurst AM, Fuquay J, Willard ST (2001) Evaporative and convective cooling of cows in hot and humid environment. In: Livestock environment VI: proceedings of the 6th international symposium, ASABE, St. Joseph, MI, pp 343–350

IPCC (1995) Global climate change: second assessment report of Intergovernmental Panel on Climate Change. www.ipcc.ch

Kimmel E, Arkin H, Broday D, Berman A (1991) A model of evaporative cooling in a wetted hide. J Agric Eng Res 49(3):227–241

Knubel BFR (2001) Conditioning of food intake in the kid relation in goats. UntersuchungzurKonditionierung der Futteraufnahme in der Mutter-Kind-BeziehungbeiZiegen, Berlin, Freie Univ Diss, p 64

Kusiluka LJM, Kambarage DM, Harrison LJS, Daborn CJ, Matthewman RW (1998) Causes of morbidity and mortality in goats in Morogoro district, Tanzania: the influence of management. Small Rumin Res 29:167–172

Lendelova J, Pogran S (2003) Thermo-technical properties of floor structures for lying cubicles. Res Agric Eng 49(4):146–150

Loh TC, Lee YC, Liang JB, Tan D (2005) Vermicomposting of cattle and goat manures by *Eisenia foetida* and their growth and reproduction performance. Bioresour Technol 96(1):111–114

Ludri RS, Singh M (1987) Feed and water intake and milk production by crossbred cows during summer. Indian J Anim Sci 57:1310–1313

Marai IFM, Habeeb AAM, Gad AE (2002) Rabbits' productive, reproductive and physiological performance traits as affected by heat stress: a review. Livest Prod Sci 78:71–90

Marai IFM, Habeeb AAM, Gad AE (2005) Tolerance of imported rabbits grown as meat animals to hot climate and saline drinking water in the subtropical environment of Egypt. Anim Sci 81:115–123

Mena G, Querrero Y, Gomee C, Serradialia MJM, Guerrero YM, Cabera AG, Manrique JMS (1993) Alleviation of heat stress in dairy cows: sprinkling plus aeration. Arch Zootec 42(5):89–92

Montoya RF, Bucklin RA, Nordstedt RA, Horn JV, Bray DR, Horn VJ (1995) Factors affecting water usage in fan and sprinkler cooling systems for dairy cattle. Appl Eng Agric 11(1):125–130

Nandi D, Roy S, Bera S, Kesh SS, Samanta AK (2011) The rearing system of Black Bengal Goat and their farmers in West Bengal, India. Vet World 4(6):254–257. doi:10.5455/vetworld.4.254

Nardone A, Ronchi B, Lacetera N, Bernabucci U (2006) Climatic effects on productive traits in livestock. Vet Res Commun 30(1):75–81

Nicolescu AN, Zamfir CZ, Enciu A, Ida A (2010) Projection of constructive, functional and mechanizations solutions for small and medium size farms of sheep and goat. Lucrări Ştiinţifice Ser Zootehnie 54:84–86

Nilsson C (1988) Floors in animal houses. Technical design with respect to biological needs of animals in reference to the thermal, friction and abrasive characteristics and the softness of the flooring material. Swedish University of Agricultural Sciences report 61, Lund: Sveriges Lantbruksuniversitet, Uppsala, Sweden

Peacock CP (1996) Improving goat production in the tropics. Oxfam, Oxford, UK, pp 290–293

Peacock C, Sherman DM (2010) Sustainable goat production—some global perspectives. Small Rumin Res 89:70–80

Prasad A, Smitha S (2011) Design, fabrication and field level study of a model rabbit cage with special reference to prevailing rabbit housing systems in Kerala. J Indian Vet Assoc 9(2):47–49

Prasad A, Savanth VV, Anil KS, Saseendran PC (2013) Impact of rubber mat flooring on the thermal comfort of dairy cattle in hot humid regions. Tamil Nadu J Vet Anim Sci 9(4):272–278

Puchala R, Min BR, Goetsch AL, Sahlu T (2005) The effect of a condensed tannin-containing forage on methane emission by goats. J Anim Sci 83(1):182–186

Rajanna N, Mahender D, Thammiraju D, Nagalakshi SD (2013) Housing and health care management practices adopted by sheep farmers in Telengana region of Andhra Pradesh. Vet Res 6(3):64–67

Renaudeau D, Gourdine JL, Silva BAN, Noblet J (2008) Nutritional routes to attenuate heat stress in pigs. In: Rowlinson P, Steele M, Nefzoaoui A (eds) Livestock and global change. Cambridge University Press, Cambridge

Sahoo A, Kumar D, Naqvi SMK (eds) (2013) Climate resilient small ruminant production. National Initiative on Climate Resilient Agriculture (NICRA), Central Sheep and Wool Research Institute, Avikanagar, p 77

Shackleton DM, Shank CC (1984) A review of the social behaviour of feral and wild sheep and goats. J Anim Sci 58:500–509

Silanikove N (2000) The physiological basis of adaptation in goats to harsh environments. Small Rumin Res 35:181–193

Simensen E, Hardeng F, Lunder T (2010) Housing of Norwegian goat herds and associations with milk yield and milk quality. Acta Agric Scand Sect A 60:187–193. doi:10.1080/09064702.2010.509809

Starr JR (1981) Climate and the need for housing. In: Clark JA (ed) Environmental aspects of housing for animal production. Butterworths, London, pp 19–36

Suraj PT (2011) Effect of environmental stress on dairy cattle under different housing pattern in north and western regions in Tamil Nadu. Ph.D. thesis, Tamil Nadu Veterinary and Animal Sciences University, p 198

Sutton AL, Melvin SW, Vanderholm DH (1983) Fertilizer value of swine manure. Purdue University Cooperative Extension Service, Pork Industry Handbook Fact Sheet. Purdue University, West Lafayette, IN

Thiagarajan M (1989) Effect of environmental heat stress on performance of crossbred dairy cattle. Ph.D. thesis, Department of Livestock Production Management, Kerala Agricultural University, Mannuthy, p 98

Thirupathy RV, Usha AP (2011) Strategies for waste management in pig farms, National symposium on waste management: experiences and strategies. Kerala Agricultural University, Thrissur, Kerala, India

Toussaint G (1997) The housing of milk goats. Livest Prod Sci 49:151–164

Vanegas J, Overton M, Berry SL, Sischo WM (2006) Effect of rubber flooring on claw health in lactating dairy cows housed in free-stall barns. J Dairy Sci 89(11):4251–4258

Vasanthi D, Kumaraswamy K (2000) Effects of manure-fertilizer schedules on the yield and uptake of nutrients by cereal fodder crops and on soil fertility. J Indian Soc Soil Sci 48(3):510–515

Vijayakumar P, Pandey HN, Singh M, Dutt T (2009) Effect of heat amelioration measures on growth and physiological response of buffalo heifers during summer. Indian J Anim Sci 79(4):437–441

Webster AJF (1976) Effects of cold on energy metabolism of sheep. In: Johnsen HD (ed) Progress in animal biometeorology, vol 1. Swets and Zetlinger, Amsterdam, pp 218–226

Strategies to Improve Livestock Reproduction Under the Changing Climate Scenario

24

Vikash Chandra, Veerasamy Sejian,
and G. Taru Sharma

Abstract

A hot environment impairs production (growth, meat and milk yield and quality, egg yield, weight, and quality) as well as reproductive performance, metabolic and health status, and immune response. Reproductive inefficiency incurred due to heat stress involves changes in ovarian function and embryonic development by reducing the competence of oocyte to be fertilized and the resulting embryo. The ability of an animal to cope up with environmental stress could be improved through strategic management of reproduction by manipulation of folliculogenesis, hormonal alterations, selective breeding, and application of embryo transfer techniques. Intervention of follicular dynamics with a combination of hormones like FSH, GnRH, and progesterone and ovum pick up (OPU) may result in recovery of competent oocytes. Embryo transfer may facilitate extra advantage of *bypassing* the thermosensitive window of oocyte development (maturation) and early embryonic development stages. Selecting thermotolerant breeds of livestock species and their selective breeding may be good strategy for combating heat stress. However, a combination of heat stress ameliorative measures including nutritional management, shelter management, and reproductive strategies is required for getting maximum benefits.

Keywords

BCS • Climate change • Embryo transfer • Follicular dynamics • Livestock • Nutrition • Reproduction • Shelter

---

V. Chandra • G.T. Sharma (✉)
Division of Physiology and Climatology,
ICAR-Indian Veterinary Research Institute,
Izatnagar, Bareilly 243122, Uttar Pradesh, India
e-mail: gts553@gmail.com

V. Sejian
Animal Physiology Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_24, © Springer India 2015

24.1 Introduction

Climate change models predict an increase in the number of extreme weather events, including an increase in the severity and duration of heat waves. Effects of global warming may not be adverse everywhere as areas experiencing severe cold may get beneficial effects in terms of production and reproduction, while a relevant increase of drought is expected across the world affecting forage and crop production, thus adversely affecting production and reproduction. High environment temperatures may compromise reproductive efficiency of farm animals in both sexes and hence negatively affect milk, meat, and egg production and the results of animal selection. High-producing animals are more susceptible to heat stress due to their high metabolic heat production. About 50 % of the bovine population is located in the tropics, and it is estimated that heat stress may cause economic losses in about 60 % of the dairy farms (Wolfenson et al. 2000). Lowered summer fertility is multifactorial in nature due to the fact that various tissues are being affected and their function is disrupted under heat stress conditions. Heat stress compromises oocyte growth in cows by altering progesterone secretion, the secretion of luteinizing hormone and follicle-stimulating hormone, and ovarian dynamics during the estrus cycle (Ronchi et al. 2001). Heat stress has also been associated with impairment of embryo development and increased embryo mortality in cattle (Hansen 2007; Wolfenson et al. 2000). Moreover, heat stress may reduce the fertility of dairy cows in summer by poor expression of estrus due to reduced estradiol secretion from the dominant follicle developed in a low luteinizing hormone environment. Conception rates may drop about a 20–27 % in summer or decrease in 90-day nonreturn rate to the first service in lactating dairy cows. Heat stress during pregnancy slows down growth of the fetus and can increase fetal loss, although active mechanisms attenuate changes in fetal body temperature when mothers are thermally stressed. Roy and Prakash (2007) reported a lower plasma progesterone and higher prolactin concentration during estrus cycle in Murrah buffalo heifers, prolactin and progesterone profiles during the summer and winter months were found to be directly correlated with the reproductive performance of buffaloes, and that hyperprolactinemia may cause acyclicity/infertility in buffaloes during the summer months due to severe heat stress. Pigs are very sensitive to hot conditions while goats are least affected by heat stress. Heat stress impairs embryonic development and affects reproductive efficiency until 5–6 weeks after exposure to hot conditions. An advanced planning of production management systems is required, with an understanding of animal responses to thermal stress and ability to provide management options to prevent or mitigate adverse consequences (Nienaber and Hahn 2007). Various reproductive strategies have been suggested to overcome the adverse effects of heat stress in livestock species, and a combination of these reproductive techniques along with shelter and nutritional management may be more effective in nullifying the effects of heat stress.

24.2 Impact of Climate Change on Livestock Reproduction

Reproductive processes in the male and female animals are very sensitive to disruption by hyperthermia, with the most pronounced consequences being reduced quantity and quality of sperm production in males and decreased fertility in females. Under heat stress the physiological and cellular aspects of reproductive function are disrupted by either the increase in body temperature caused by heat stress or by the physiological adaptations engaged by the animal to reduce hyperthermia.

Heat stress adversely affects ovarian follicle development and compromises oocyte growth by altering progesterone, the secretion of luteinizing hormone (LH) and follicle-stimulating hormone (FSH), and dynamics during the estrus cycle. Heat stress has also been associated with impairment of embryo development and increased embryo mortality in cattle (Hansen 2007). Moreover, heat stress may reduce the fertility of dairy cows by poor expression of estrus due to reduced estradiol secretion from the dominant follicle developed in a low-LH environment. Heat stress can sometimes increase adrenocorticotropin secretion, which itself can block estradiol-induced estrus behavior. It is also likely that estrus expression is reduced by the physical lethargy experienced by heat-stressed animals. Heat stress during pregnancy slows down growth of the fetus and can increase fetal loss, although active mechanisms attenuate changes in fetal body temperature when mothers are thermally stressed.

The detrimental effects of high ambient temperature and relative humidity on reproductive performance are well known. The impact of temperature is direct as a result of increased body temperature or compensatory changes in blood flow. It may be indirect through the hypothalamus involving changes in appetite or feed intake and body metabolism. Figure 24.1 describes the impact of heat stress on goat reproductive processes. In females, heat stress during the first week of pregnancy results in higher embryo mortality and subsequent abortions. The impact of extreme climatic condition leads to most of the reproductive problems. Heat stress alters the normal follicular dynamics pattern. Follicular estradiol levels have shown to be decreased during heat stress, causing disruption of normal folliculogenesis of the first-wave dominant follicle, and the second-wave dominant follicle appears early but functions normally. Furthermore, heat stress alters steroid production and metabolism; in particular progesterone concentration is altered (Sejian et al. 2011). These imbalances affect estrus, embryo survival, and follicular development in the ovary. Conceptus weight is also affected during heat stress since feed intake is affected due to high temperature (Sejian et al. 2012). In males, heat stress impairs spermatogenesis by elimination of spermatogonial germ cells in the seminiferous tubules and degeneration of Sertoli and Leydig cells. The heat damage in the testes is thought to be due to hypoxia causing oxidative stress and consequently germ cell apoptosis and DNA strand breaks mainly in pachytene spermatocytes and round spermatids. Consequently,

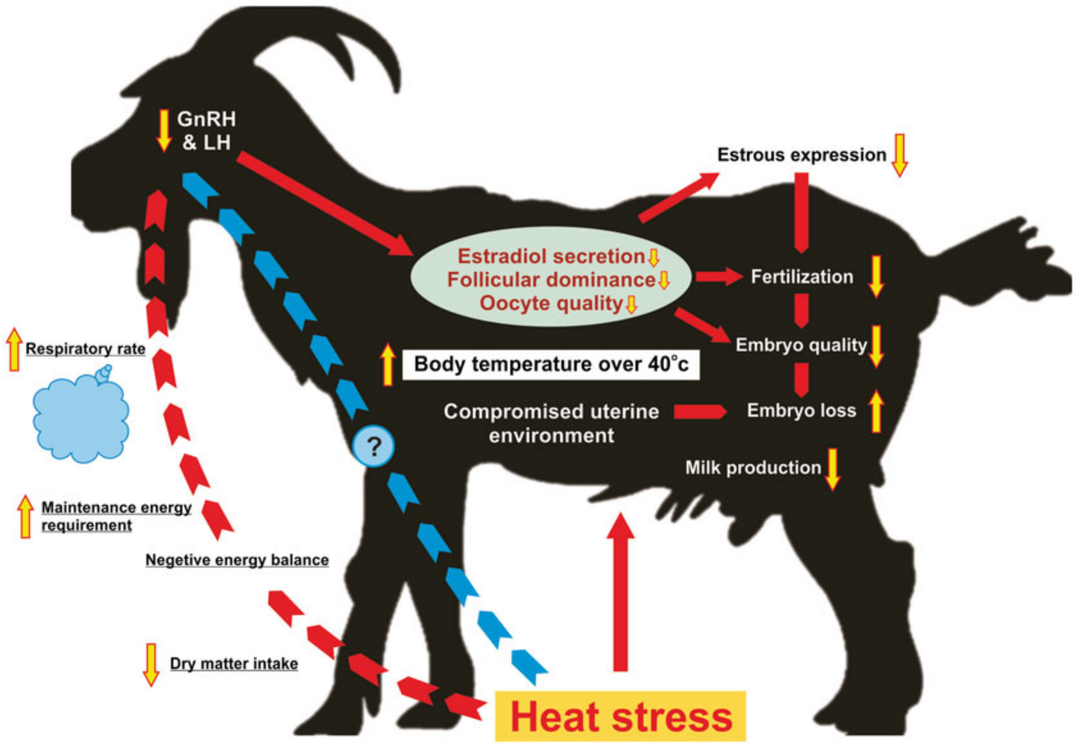


Fig. 24.1 Impact of heat stress on goat reproduction

heat stress has a negative effect on semen attributes. Further, heat stress significantly affects the sexual behavior, scrotal and testicular measurements, semen concentration, seminal volume, and mass activity of semen samples.

Heat stress causes increase in intracellular reactive oxygen species (ROS) and decrease in glutathione (GSH) level which is detrimental to embryo survivability. Oxidative stress due to reactive oxygen species (ROS) produced by cellular metabolism has regulation on various reproductive processes like cyclic endometrial and luteal changes, follicular development, ovulation, fertilization, embryogenesis, implantation, placental differentiation, and growth. Oxidative stress causes several pregnancy-related disorders such as preeclampsia, spontaneous abortion, intrauterine growth retardation leading to pregnancy loss, defective embryogenesis, and teratogenicity (Gupta et al. 2007).

24.3 Strategies to Reduce the Impact of Climate Stress to Improve Livestock Reproduction

There are different strategies available to counter the impact of climate change on livestock reproduction. These strategies can be broadly grouped under two categories: (1) management strategies and (2) advanced reproductive strategies. Figure 24.2 describes the various strategies to counter climate change impact on livestock reproduction.

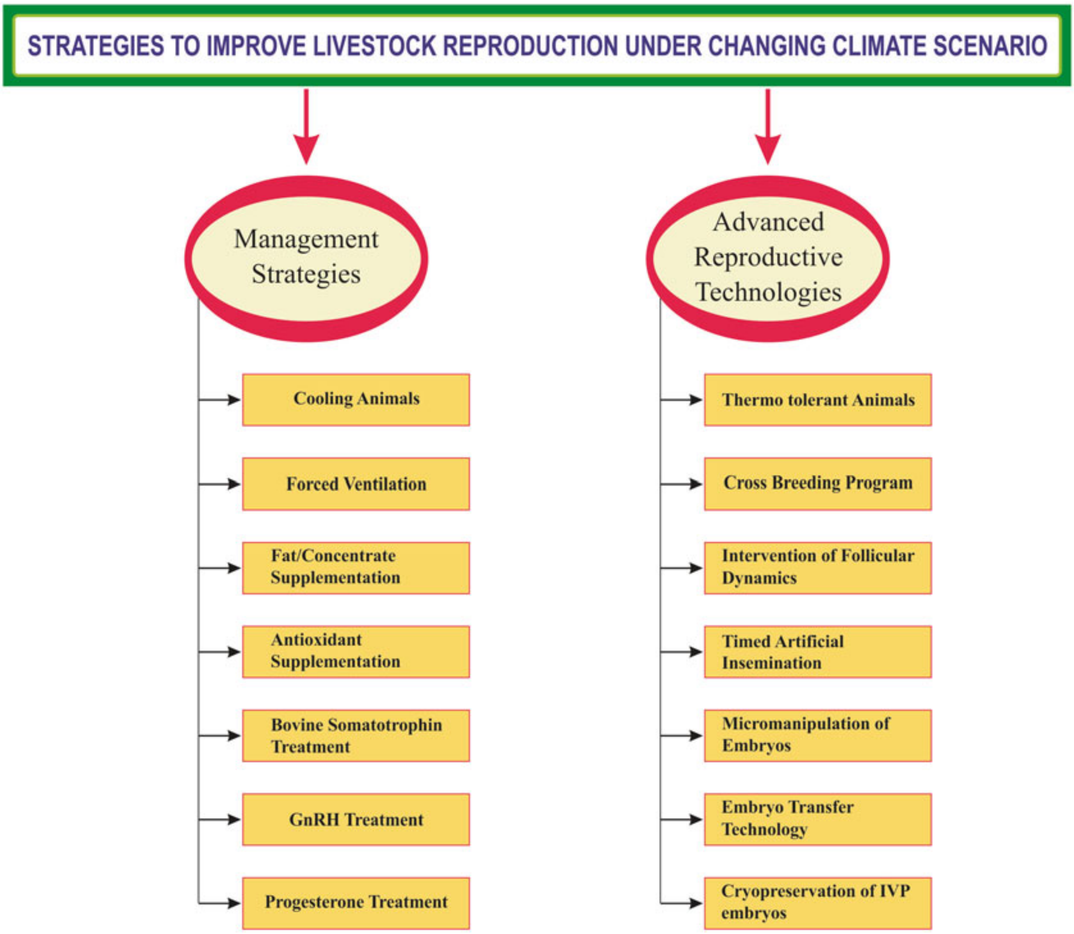


Fig. 24.2 Different strategies to improve livestock reproduction under the changing climate scenario

24.3.1 Management Strategies to Improve Livestock Reproduction

24.3.1.1 Shelter and Other Management Strategies

The time of greatest susceptibility for livestock reproduction is immediately after the onset of estrus and early postbreeding. Heat abatement is essential in the weeks preceding breeding, as well as the first week after breeding. One way to minimize effects of heat stress is to provide housing that alleviates heat stress. This can be expensive. The degree to which housing should be modified to reduce heat stress will depend upon geographical location and extent of heat stress. Providing adequate shade and water to cows on pasture can help keep them cool, resulting in increased embryo survival. The simplest structures for providing cooling are shade structures. These can be inexpensive structures based on the use of shade cloth or more permanent structures. A common and fairly effective system for cooling cows is free stall or loose housing with sprinklers and fans. Including foggers or misters can promote evaporative cooling as air moves through the barn. Flamenbaum and Galon (2010) identified the most appropriate cooling system commonly based on a combination of frequent direct watering of the cows, followed by forced ventilation air blowing onto the cows. A typical cycle is 5 min long and consists of 30 s of watering followed by 4.5 min of forced ventilation. This improved the conception rate in dairy cow. Heat-stressed cows willingly immerse themselves in water, so cooling ponds are sometimes used to allow cows to exhibit this behavior. Bellowing in ponds drop a cow's body temperature and can improve reproductive performance driving heat stress away. These artificially constructed ponds are often built with constant movement of freshwater into the pond.

In the barn and holding areas, the use of fans and sprinklers will help to cool the cow and the air around her. It should be ensured that the sprinklers are set to the appropriate time interval and that the droplet size is large enough to soak the cow to the skin – not a mist, which will sit on top of the hair and insulate the cow. Sprinklers should be running for between 1 and 3 min in every 10–15 min. It is critical that the sprinklers be turned off and fans are running for evaporation to occur, resulting in the cows feeling cooler because some of their body heat is used to evaporate the water. Avoid overcrowding pens and keep up on fly control to prevent bunching.

Another important factor in maintaining reproduction in the summer is nutrition. Research has demonstrated that negative energy balance is correlated with impaired reproductive performance. When cows reduce intake as a result of heat stress and fall into a negative energy balance situation, there are negative effects on plasma concentrations of insulin, insulin-like growth factor-1 (IGF-1), and glucose, which result in poor follicular development, poor quality of oocytes, and reduced expression of heat. Minimizing dry matter intake losses during heat stress is critical. Keeping cows cool will result in more frequent meals and reduce slug feeding. It is a good idea to feed fresh feed more often, place extra waterers in return alleys, and provide shade at the bunk area. Review your ration before the heat hits to make sure there is adequate fiber, potassium, sodium, and buffers if needed. Further, hormonal treatments using bovine somatotropin, GnRH treatment at time of insemination, and elevated progesterone injections post insemination significantly improved summer fertility.

24.3.1.2 Specific Nutritional Strategies to Improve Livestock Reproduction

Properly balanced rations provide adequate energy to reduce problems of herd health and reproduction associated with decreased dry matter intake (DMI) during heat stress. Requirements for specific nutrients appear to differ during thermal stress compared to thermoneutral conditions. Increasing ration energy density with additional grain or fat sources has been shown to be advantageous in improving reproductive efficiency during summer months. Preliminary research has shown fungal cultures can reduce body temperature and respiration rate and beta-carotene has been successful in increasing fertility and pregnancy rate in cows calving during the summer. There is need to establish prediction equations for requirements of all nutrients fed to livestock in different reproductive states at varying degrees of thermal stress. Other logical and relatively simple nutritional management strategies should be instituted on a broader basis. For example, increasing the number of feedings per day may entice animals to take more meals and keep feed fresher, thus increasing total daily consumption. Scheduling feeding strategically with, or right after, other routine events, such as milking, could result in increased daily consumption. As part of a shade management system, placement of feed and water so that they are always in the shade is paramount. Though untested, it is possible that provision of feed and water and perhaps artificial lighting on the dirt lot would result in increased consumption at night. Additionally, it would appear likely that total daily feed intake could be increased if nocturnal feedings were more frequent. This additional feed intake during extreme weather conditions will help the animal to cope up to adapting as well as to reproduce normally.

Dietary fats could favor reproductive processes through actions related to energy balance or through specific actions of individual fatty acids on tissue function. Fats are glyceride esters of fatty acids that can have a direct effect on the transcription of genes that encode proteins that are essential to reproductive events (Mattos et al. 2000). Dietary fats typically increase concentrations of circulating cholesterol, the precursor of progesterone to improve the reproductive efficiency. Fat supplementation has also been shown to stimulate programmed growth of a preovulatory follicle. Reactive oxygen species are a possible source of infertility because ovarian steroidogenic tissue, spermatozoa, and preimplantation embryos become compromised as a consequence of free radical damage. Nutritional tools, such as antioxidant feeding (vit. A, selenium, zinc, etc.) and ruminant-specific live yeast, can help. The use of antioxidants such as vit. E, vit. A, selenium, and selenium-enriched yeast helps in reducing the impact of heat stress on the oxidant balance, resulting in improved reproductive efficiency and animal health (Sejian et al. 2014).

Inclusion of specific nutraceuticals in the diet to improve reproductive function offers an exciting new dimension to dairy cattle management. Pre- and postpartum feedings of organic selenium yeast (0.33 mg/kg), during summer in the selenium-deficient area, improve the selenium status of lactating dairy cows, enhance neutrophil function (i.e., phagocytosis and oxidative burst) and humoral immune/antibody responses, reduce incidence of fever, and improve both uterine health and subsequent fertility to second service. Strategic supplementation of fatty acids accordingly to physiological stage can selectively benefit immune function, maximize production, and improve reproductive responses of lactating dairy cows. Following the transition period, feeding calcium salts of fish oil reduces pregnancy loss after the first service and increases pregnancy per insemination after the second service. This beneficial effect of feeding calcium salts of fish oil is augmented when calcium salts of safflower oil were fed previously in the transition period. Feeding fish oil in the breeding period following safflower oil in the transition period stimulates pregnancy per AI for the second service in the warm season, whereas feeding palm oil in the breeding period following safflower oil in the transition period has no beneficial effect on second service pregnancy per AI. Supplementary feeding of lupine grain for 14 days and the “ram effect” can be combined as a strategy for increasing ovulation rate in sheep. Net reproductive performance of both ewes and rams is improved due to lupine supplementation at mating (Nottle et al. 1997).

24.3.1.3 Body Condition Scoring as a Tool to Optimize Reproduction in Livestock

Body condition scoring (BCS) is a system of describing or classifying breeding animals by differences in relative body fatness. It is a subjective scoring system but provides a fairly reliable assessment of body composition. BCS is a simple but useful procedure, which can help producers in making management decisions regarding the quality and quantity of feed needed to optimize productive and reproductive performance. Under Indian farming condition, a 5-point body condition scoring system similar to the one followed in the United States is preferable. BCS provides a reasonable indicator of nutritional status of ewes at different production phases, which allows to assess ewe's nutrition level and to decide when and how to supplement the flocks. A series of studies conducted on the influence of BCS on sheep reproduction suggests that both ewes and rams belonging to BCS between 3.0 and 3.5 performed much better than lower and higher BCS for most reproductive parameters studied (Sejian et al. 2010; Maurya et al. 2010). This signifies the importance of optimum BCS of ewes for better reproductive performance. Further, the poor performance of 4.0 BCS sheep when compared to 3.0–3.5 BCS reflects the economic importance of the study in terms of wastage of supplementary feeding. This indicates that sheep under a hot semiarid tropical environment should be maintained at moderate (3.0–3.5) BCS both at mating and at lambing stage to ensure optimum return from these animals rather than supplementing to increase the body condition score to a higher level. Further, these studies indicate that active management of breeding sheep flock to achieve the optimum BCS of 3.0–3.5 will ensure optimal reproductive performance of these animals. This will ensure economically viable return from these flocks. Table 24.1 describes the recommended BCS for different reproductive stages in sheep under a hot semiarid tropical environment.

Table 24.1 Some recommended (optimal) condition score values for the various stages of the production cycle of sheep under hot semiarid condition

Class of sheep	Optimum condition score
Breeding	3.0
Mating	3.0–3.5
Early to mid-gestation	3.0
Late gestation	3.5
Lambing	3.5
Twining	3.5–4.0
Lactation	3.0
Rams at mating	3.5
Weaners	2.5 or more

24.3.2 Advanced Reproductive Strategies to Improve Livestock Reproduction

24.3.2.1 Intervention of Follicular Dynamics

The preovulatory follicle is a key component of the reproductive systems, and impairment of its function during thermal stress may affect other reproductive events, such as secretion of gonadotropins, progesterone, and estradiol and subsequently the development of the corpus luteum (CL) and embryo. Aberrant follicular development is observed in hot season. Reduction in plasma inhibin concentration was detected in heat-stressed lactating dairy cows (Wolfenson et al. 1995). The dominance of the large follicle is suppressed during heat stress, and the steroidogenic capacity of theca and granulosa cells is compromised. Reduction in follicular dominance during the period of heat stress is associated with a decrease in inhibin secretion by granulosa cells and subsequent alterations in FSH that leads to an increase in the development of large follicles (e.g., non-ovulatory follicles and cysts) in cattle (Wolfenson et al. 2000).This may happen due to attenuated follicle dominance, but due to elevated ambient temperature, early embryonic losses occur and pregnancy is not sustained. The pool of small antral follicles gets damaged during summer, and as long as these follicles are sustained in the ovaries, fertility will remain low (aftereffect of summer). Sensitivity of the early growing follicles to heat stress is a likely explanation for the fact that oocyte quality is only gradually restored in the autumn and that restoration of oocyte competence for cleavage in the autumn can be hastened by treatments that increase follicular turnover (Roth et al. 2002). It is speculated that fertility may not be restored until all the damaged follicles destined for ovulation have been removed from the ovary that may be the possible explanation of restoration of fertility in the autumn. Actually the follicle is a multi-compartmental structure in terms of biosynthesis of steroids and intrafollicular communication between the oocyte and follicular tissue. Seasonal variations in follicular steroidogenesis may be because of two reasons: first because of low substrate availability due to lowered feed intake which may be said as "indirect effect" and second by alteration in gonadotropin secretion which in turn may affect follicular function. Heat stress can reduce the magnitude of the preovulatory surge of LH and estradiol-17β. There are also direct effects of elevated temperature on nuclear maturation, spindle formation, cortical granule distribution, free radical formation, mitochondrial function, and apoptosis. Estradiol and androstenedione production by granulosa cells and theca cells is decreased due to heat stress, and the theca cells appeared more susceptible to heat stress. Progesterone plays an important role in follicular turnover (de Castro et al. 1999). Progesterone secretion by luteal cells is also lowered during summer. Low plasma progesterone affects steroidogenesis in the dominant follicle and CL and thereby alters reproductive function in the subsequent estrus cycle. Low progesterone may cause aberrant follicular development which may result in abnormal oocyte maturation in the ovulatory follicles.

Delayed effect of heat stress on follicle quality may be overcome by mechanical removal of follicles by OPU from ovaries or by stimulating follicle turnover. FSH treatment increases the number of medium-sized follicles in the follicular waves following heat stress and induced an earlier emergence of high-quality oocytes (Roth et al. 2002; Friedman et al. 2010). Stimulation of gonadal function by GnRH improves follicular function, as frequent follicular waves induced during fall increased follicular estradiol content in preovulatory follicles aspirated from previously heat-stressed cows (Roth et al. 2004). Synchronization with GnRH and PGF2α also improves fertility (Friedman et al. 2011).

The stage of the estrous cycle at the time of the OPU session influences the recovery rate, oocyte quality, and in vitro embryo production (IVP). Conflicting results have been reported regarding the ideal follicular phase to maximize performance of OPU. Greater recovery rates have been reported when the OPU was performed closer to the follicular wave emergence (Machatkova et al. 2004), while greater in vitro competence of oocytes was obtained during the early dominance phase (Hendriksen et al. 2004). Increased IVP was achieved when FSH was used in four equal doses twice daily beginning at the time of follicular wave emergence. In this case, OPU was performed 24 h after the last FSH treatment (Rodriguez et al. 2010).

24.3.2.2 Progesterone and Fertility

Following recruitment of healthy preovulatory follicles which results in a successful postovulatory fertilization are the processes associated with the development of a CL and maintenance of pregnancy. Early embryonic mortality (from fertilization to detection of pregnancy) is the major cause of low conception. The survival of early stage embryos is related to normal luteal progesterone production (Robinson et al. 2008). An association between normally high progesterone concentration and more advanced embryo development has been shown as early as day 5 of pregnancy (Green et al. 2005). Long-term chronic exposure to heat stress decreases plasma progesterone (Chandra et al. 2007), and this decreased progesterone production may be caused by impaired luteinization of CL exhibiting depressed progesterone concentration, depressed synthesis of progesterone from luteal cells, detrimental carry-over effect of heat stress on ovulatory follicle, and subsequent effect on formed CL secreting lower progesterone (Torres-Junior et al. 2008). Concentrations of progesterone before ovulation can affect subsequent fertility (Bisinotto et al. 2010; Denicol et al. 2012), possibly because of actions on oocyte function, and a reduction in circulating progesterone concentrations before ovulation caused by heat stress (Wolfenson et al. 2000) could conceivably compromise the oocyte. The level of endogenous progesterone is widely variable because of several variables: adrenal release of progesterone, metabolism in the liver, hemodilution, degree of thermal stress, age of cow, stage of lactation, and milk yield and type of feeding. Progesterone concentration is lowered mainly in chronic stress and not in acute and short-term stress. Most studies showed that acute exposure to high environment temperature in psychrometric chamber may elevate or does not affect progesterone concentration. This higher concentration of progesterone at acute stress may be attributed to the elevated adrenal secretion of progesterone or to the severity of the thermal stress (Bridges et al. 2005).

Progesterone supplementation during early pregnancy has proven beneficial in some studies. Supplementation of exogenous progesterone under conditions of summer heat stress has the potential to improve fertility, provided that (a) the endogenous level of progesterone secretion is compromised and (b) the thermal stress is at the level that permits embryo survival (mild thermal stress). Accessory CL may be useful in supporting the plasma progesterone which may be facilitated by the induction of ovulation from first-wave dominant follicle by treatment with GnRH agonist or hCG. In general, efficiency to increase progesterone concentration is greatest when accessory CL is induced by hCG. GnRH administration at insemination or 12 days later can improve fertility of lactating cows during heat stress (Lopez-Gatius et al. 2006). Another approach to increase progesterone concentration is by inserting intravaginal devices containing progesterone (CIDR) post AI. A study by Wolfenson et al. (2009) stated that CIDR treatment increased conception rate by 6 % but not significantly. However, the CIDR treatment increased conception rate by 22.5 % in cows with low body condition score at peak lactation, and cows that exhibited uterine disorder at partition had an increase in conception rate from 25.6 to 47.8 % with insertion of the CIDR device.

24.3.2.3 Strategies to Decrease Estradiol

Inskeep (2004) indicated that estrogen secretion from a large follicle from days 14 to 17 of pregnancy may negatively affect embryo survival. Binelli et al. (2001) suggested the attenuation of luteolytic stimuli as a strategy to decrease early embryonic mortality. Moreover, this hormone has a central role in PGF production and luteolysis. Thus, strategies resulting in the absence of dominant follicles, reduction of their steroidogenic capacity, or reduction of endometrial responsiveness to estradiol during the period of maternal recognition of pregnancy should increase the probability of conceptus survival and pregnancy rates. One simple way to reduce plasma concentrations of estradiol is to remove follicles by transvaginal ultrasound-guided aspiration of follicles. Aspiration of the first-wave dominant follicle on day 6 of the estrous cycle decreased PGF release (as measured by plasma concentrations of its metabolite, PGFM) in response to an estradiol injection given on day 17 in comparison with non-aspirated controls. Injection of GnRH on day 5 and hCG on day 13 of a synchronized estrous cycle induced ovulation of the first-wave dominant follicle and an accessory CL, and emergence of the second wave would be synchronous (Bergamaschi et al. 2006). GnRH-hCG approach takes advantage of both the progesterone supplementation and the estradiol reduction strategies to modify uterine function and has the potential to affect positively pregnancy rates in cattle.

24.3.2.4 Administration of Other Antiluteolytic Agents

Strategies like the use of anti-inflammatory drugs, fat feeding, and administration of bovine somatotropin (bST) target the uterus and the conceptus directly. Synthesis of PGF results from a coordinated cascade of intracellular events. A rate-limiting step in this cascade is the conversion of arachidonic acid to prostaglandin-H2 (PGH2) by the enzyme prostaglandin endoperoxidase synthase 2 (PTGS2 or COX-2). The PGH is subsequently converted to PGF. Strategies targeting the inhibition of PTGS2 activity, and consequently PGF synthesis, during maternal recognition of pregnancy should increase embryo survival and pregnancy rates. Treatment of Holstein heifers with flunixin meglumine, an inhibitor of PTGS2 activity, on days 15 and 16 after insemination increased pregnancy rates on days 29 (76.9 vs. 50 %, $P<0.04$) and 65 of gestation (69.2 vs. 46.2 %, $P<0.09$) (Guzeloglu et al. 2007), while administration of flunixin meglumine at 1.1 mg/kg of BW at 13 days after AI did not improve pregnancy establishment in beef cows and heifers (Geary et al. 2010). PTGS2 protein expression in conceptus tissues starts on day 18 of pregnancy. Therefore, inhibition of PTGS2 activity from that moment onwards may in fact be detrimental to conceptus development. Decreasing substrates for PGF synthesis should result in a uterine environment less conducive for luteolysis, which may result in greater embryonic survival. Feeding of long-chain fatty acids can modulate PGF production in the endometrium. Feeding the n-3 fatty acids attenuates PGF production (Mattos et al. 2004), whereas the opposite effect was observed when n-6 fatty acids were fed to cattle (Pettit and Twagiramungu 2004).

Secretion of interferon (IFN) is positively associated with conceptus size (Mann et al. 1999); therefore, larger conceptuses should be better able to block PGF synthesis and luteolysis. One possible way to stimulate conceptus growth is through the administration of bST. bST increases secretion of IGF-1, insulin, and growth hormone (Bilby et al. 2004), and the elevation in the IGF-1 would protect the oocyte and embryos from damage caused by heat stress. In vitro administration of recombinant bST increased fertilization rates, hastened embryo development, and increased embryo quality (Moreira et al. 2002; Santos et al. 2004; Ribeiro et al. 2014).

24.3.2.5 Timed Artificial Insemination

Timed artificial insemination (TAI) programs provide an organized approach to enhance the use of artificial insemination (AI) and the progress of genetic gain and to improve reproductive efficiency in dairy and beef herds. The final follicular growth and the diameter of the dominant follicle at TAI are key factors that may significantly affect the oocyte quality, ovulation, the uterine environment, and consequently pregnancy outcomes. The use of superovulation (SOV) followed by AI is a technique that generates greater numbers of embryos per donor. TAI associated with embryo transfer (ET) is a powerful tool to disseminate high-quality genetics and improve reproductive performance mainly in heat-stressed dairy cattle and repeat breeders (Hansen et al. 2001; Baruselli et al. 2011).

Controlling LH pulsatility and ovarian follicular development by progesterone can influence oocyte quality. During the SOV protocol, low circulating concentrations of progesterone may interfere with follicular growth and oocyte and embryo quality. Higher progesterone concentrations during the SOV protocol may be necessary to regulate LH pulsatility, which avoids the occurrence of premature nuclear maturation, and may be responsible for the improved oocyte/embryo quality following SOV protocols, especially in lactating Holstein cows (Baruselli et al. 2012).

24.3.2.6 Embryo Transfer: Bypassing Damage to Oocytes and Embryos

Major negative effects of heat stress on reproduction may be related to its deleterious effects on the oocyte quality, decreasing fertilization rates, and early embryonic losses. Oocytes are damaged by heat stress during follicular growth and oocyte maturation. Following fertilization, the embryo itself is susceptible to maternal hyperthermia. This way heat stress further enhances preimplantation embryonic mortality. Several attempts have been made to overcome these adverse effects of heat stress in large ruminants by the treatment of GnRH, but in spite of these attempts, pregnancy rate had been low. Thus, successful pregnancy during heat stress requires that anyhow the oocyte is prevented from damaging effects of heat stress to assure successful fertilization and formation of an embryo, and this way, the embryo should escape the stage of developmental block caused by heat stress. One feasible and efficient way to escape this developmental block may be the use of embryo transfer (ET) technology, as bovine embryo transfer has already been shown to be effective in increasing fertility during heat stress.

Minimizing adverse effects by ET is based on the idea that (1) most effects of heat stress on fertility involve actions during folliculogenesis or on cleavage-stage embryos and (2) by the time the embryo is transferred at the morula or blastocyst stage, it has already acquired resistance to elevated temperature. As the embryonic development advances, the embryo progressively acquires resistance to adverse effects of heat stress (Hansen 2007a).

Embryos are typically transferred into recipient females when they reach the morula or blastocyst stages of development, typically at day 7 post ovulation. Thus, transferring day 6–8 embryos may escape these most thermosensitive periods, and pregnancy rate may be improved in summer. The use of ET is considered a potential strategy for minimizing the negative effects of heat stress on bovine reproduction (Baruselli et al. 2011). Embryo transfer can improve pregnancy rate when embryos are produced by superovulation or in vitro fertilization. Embryos produced by superovulation are superior to the embryos produced by in vitro fertilization (Hansen and Block 2004). Pregnancy rates were lower by transferring cryopreserved embryos than by transferring fresh embryos (Stewart et al. 2010), though the embryo culture media used for embryo culture have a significant effect on the success rate of pregnancy. Insulin-like growth factor-1 (IGF-1) acts as a survival factor for preimplantation embryos exposed to heat stress (Hansen and Block 2004), and addition of IGF-1 in the culture media enhances bovine/bubaline preimplantation embryo development (Sirisathein et al. 2003; Chandra et al. 2012) as IGF-1 and IGF-2 receptors are present in all preimplantation stage embryos (Chandra et al. 2011). Treatment with IGF-1 can make embryos resistant to heat shock (Jousan and Hansen 2007), and there might be variation between embryos in the degree of thermotolerance at the blastocyst stage. However, when genetic consideration is secondary, embryos produced from oocytes collected from abattoir ovaries are most cost-effective.

24.3.2.7 Genetic Selection and Proliferation of Thermotolerant Animals

Sustainable livestock production in climate change scenario may be attained through producing heat-resistant strains of animals. It has been seen that certain breeds of beef and dairy cattle are better in regulating body temperature during heat stress than others. Thus, genetic improvement in resistance to heat stress may be achieved by applying genetic selection or crossbreeding. There are wide variations in genetics in resistance to heat stress among livestock species (Hayes et al. 2009). *Bos indicus* breeds have been found to be more heat tolerant than *Bos taurus*. Compared with *B. taurus* cattle, *B. indicus* cattle exhibit increased total numbers of oocytes, increased oocyte viability, increased blastocyst rate, and a reduced rate of nuclear fragmentation in in vitro produced blastocyst (Baruselli et al. 2012).

A beef cow of the Brahman or Nelore breed can maintain productivity in hot environments because it is genetically competent to regulate body temperature during heat stress. There are some genes in Northern European dairy cattle that confer animals with some resistance to heat stress. Genes exist not only for regulation of body temperature during heat stress but also for cellular response to elevated temperature. Identification of the genes controlling cellular thermotolerance or of genetic markers linked to those genes may enable the selection of cattle possessing embryos with increased resistance to disruption by elevated temperature. Basirico et al. (2011) studied the relationship between two single nucleotide polypeptides (SNPs) in the 5′ UTR of the heat shock protein 70 gene and resistance of peripheral blood mononuclear cells from lactating Holsteins to exposure to 43 °C for 1 h in vitro. Moreover, the allele that was associated with increased survival also resulted in increased expression of the heat shock protein 70.1 (HSP70.1) gene. It is worth noting that both of these SNPs were related to calving percentage in seasonal calving in Brahman cows.

“Slick” gene, first described in the Senepol breed of beef cattle that originated in the Virgin Islands, is a dominant gene that causes very short hair growth. Slick Holsteins are found better to regulate body temperature during heat stress than cows with normal hairs (Dikmen et al. 2008). In Venezuela, Olson et al. (2003) found that

Carora-Holstein crossbreds with the slick gene had lower rectal temperatures and higher milk yield than Carora-Holstein crossbreds with normal hair length.

The advantage of selection for thermotolerance is that the reduction in milk yield and fertility during the summer would be minimized. In contrast to these benefits, one must weigh two disadvantages. First, it is to be expected that cows that are more resistant to heat stress will also be less resistant to cold stress. The second possible disadvantage is selection for thermotolerance could accidentally lead to selection against milk yield. An increase in milk yield causes cows to produce more heat and that might make them less thermotolerant.

24.3.2.8 Reducing the Burden of Unproductive Livestock Production of Progenies of Desired Sex

In the coming years, the world will be facing problem of food security for humans as well as for animals due to shortening of available natural resources and cultivable lands. So, the need of the day is that the strategies should be focused upon controlling the population of livestock by increasing the productivity of animals and reducing the number of animals. Farmers should have animals of desired sex, viz., male animals for meat purpose and female animals for milk production. This can be done by using sexed semen or sexed embryos. This will result in excellent replacement for beef and dairy herds. Sexed sperm could be especially useful for superovulation; in that case, it is often desirable to obtain calves of one sex or another for a particular mating. One dose of sexed sperm can be used to produce many embryos. Flow cytometry-mediated sperm sorting is a very effective tool in separating X- and Y-sperm with more than 90 % accuracy.

Sexing of preimplantation embryos is commonly combined with the large-scale commercial embryo production and ET industry, whereas embryos of a predefined sex can definitely allow the application of certain management schemes for dairy or meat production industry (Herr and Reed 1991). Selective sex predetermination together with the multiple ovulation and embryo transfer (MOET) procedures can effectively aid in improvement of the genetic gain of the herd (Colleau 1991). Preimplantation embryo sexing can be achieved by cytogenetic, immunological, and metabolic methods or by using male-specific chromosomal DNA probes. However, the use of SRY gene-specific DNA probes, together with the use of the PCR embryo-derived biopsy samples, is superior in terms of efficiency and running speed (Herr and Reed 1991).

24.4 Conclusion

Although new knowledge about animal responses to the environment continues to be developed, managing livestock to reduce the impact of climate remains a challenge. Among the environmental variables affecting livestock, heat stress seems to be one of the more intriguing factors making difficult animal reproduction of many world areas. There are several strategies that are available to both prevent and counter the adverse impact of climate change on livestock reproduction. These include housing animals in facilities that minimize heat stress, use of timed AI protocols to overcome poor estrus detection, and implementation of embryo transfer programs to bypass damage to the oocyte and early embryo caused by heat stress. There are also several promising avenues of research that may yield new approaches for enhancing reproduction during heat stress. These include administration of antioxidants; intervention of follicular dynamics; hormonal interventions using bST, GnRH, and progesterone; and production of progenies of desired sex. Opportunities also exist for manipulating animal genetics to develop an animal that is more resistant to heat stress. Various reproductive strategies have been suggested in this chapter to overcome the adverse effects of heat stress in livestock species, and a combination of these reproductive techniques along with shelter and nutritional management may be more effective in nullifying the effects of heat stress.

References

Baruselli PS, Ferreira RM, Sales JNS, Gimenes LU, Sa Filho MF, Martins CM, Rodrigues CA, Bo GA (2011) Timed embryo transfer programs for management of donor and recipient cattle. Theriogenology 76:1583–1593

Baruselli PS, Sa Filho MF, Ferreira RM, Sales JNS, Gimenes LU, Vieira LM, Mendanha MF, Bo GA (2012) Manipulation of follicle development to ensure optimal oocyte quality and conception rates in cattle. Reprod Domest Anim 47(Suppl. 4):134–141

Basiricò L, Morera P, Primi V, Lacetera N, Nardone A, Bernabucci U (2011) Cellular thermotolerance is associated with heat shock protein 70.1 genetic polymorphisms in Holstein lactating cows. Cell Stress Chaperones 16:441–448

Bergamaschi MACM, Machado R, Figueiredo RA, Barbosa RT, de Oliveira CA, Giassetti MI, Binelli M (2006) Otimização da função luteínica em vacas Nelore (*Bos taurus indicus*) suplementadas com GnRH e hCG. Acta Sci Vet 34(supl. 1):343 (abstract)

Bilby TR, Guzeloglu A, Kamimura S, Pancarci SM, Michel F, Head HH, Thatcher WW (2004) Pregnancy and bovine somatotropin in nonlactating dairy cows: I. Ovarian, conceptus, and insulin-like growth factor system responses. J Dairy Sci 87(10):3256–3267

Binelli M, Thatcher WW, Mattos R, Baruselli PS (2001) Antiluteolytic strategies to improve fertility in cattle. Theriogenology 56:1451–1463

Bisinotto RS, Ribeiro ES, Martins LT, Marsola RS, Greco LF, Favoreto MG, Risco CA, Thatcher WW, Santos JEP (2010) Effect of interval between induction of ovulation and artificial insemination (AI) and supplemental progesterone for resynchronization on fertility of dairy cows subjected to a 5-d timed AI program. J Dairy Sci 93:5798–5808

Bridges PJ, Bruise MA, Fortune JE (2005) Elevated temperature (heat stress) in vitro reduces androstenedione and estradiol and increases progesterone secretion by follicular cells from bovine dominant follicles. Domest Anim Endocrinol 29:508–522

Chandra V, Hooda OK, Singh G, Hoque M (2007) Effect of heat stress on follicular development and ovarian steroid hormone in black Bengal goats. Indian J Anim Sci 77(2):139–143

Chandra V, Sai Kumar G, Taru Sharma G (2011) Temporal expression pattern of insulin-like growth factors (IGF-1 and IGF-2) ligands and their receptors (IGF-1R and IGF-2R) in buffalo (*Bubalus bubalis*) embryos produced *in vitro*. Livest Sci 135:225–230

Chandra V, Ashish M, Taru GS (2012) Effect of growth factors (epidermal growth factor, platelet derived growth factor and insulin like growth factor-1) on buffalo embryos produced *in vitro*. Indian J Anim Sci 82(12):1550–1514

Colleau JJ (1991) Using embryo sexing within closed mixed multiple ovulation and embryo transfer schemes for selection on dairy cattle. J Dairy Sci 74:3973–3984

de Castro T, Rubianes E, Menchaca A, Rivero A (1999) Ovarian dynamics, serum estradiol and progesterone concentration during the interovulatory interval in goats. Theriogenology 52:399–411

Denicol AC, Lopes G Jr, Mendonça LG, Rivera FA, Guagnini F, Perez RV, Lima JR, Bruno RG, Santos JE, Chebel RC (2012) Low progesterone concentration during the development of the first follicular wave reduces pregnancy per insemination of lactating dairy cows. J Dairy Sci 95:1794–1806

Dikmen S, Alava E, Pontes E, Fear JM, Dikmen BY, Olson TA, Hansen PJ (2008) Differences in thermoregulatory ability between slick-haired and wild-type lactating Holstein cows in response to acute heat stress. J Dairy Sci 91:3395–3402

Flamenbaum I, Galon N (2010) Management of heat stress to improve fertility in dairy cows in Israel. J Reprod Dev 56(S):36–41

Friedman E, Glick G, Lavon Y, Roth Z (2010) Effect of low dose follicle stimulating hormone administration on follicular dynamics and preovulatory follicle characteristics in dairy cows during summer. Domest Anim Endocrinol 39:106–115

Friedman E, Voet H, Reznikov D, Dagoni I, Roth Z (2011) Induction of successive follicular waves by gonadotropin-releasing hormone and prostaglandin F2α to improve fertility of high producing cows during the summer and autumn. J Dairy Sci 94:2393–2404

Geary TW, Ansotegui RP, MacNeil MD, Roberts AJ, Waterman RC (2010) Effects of flunixin meglumine on pregnancy establishment in beef cattle. J Anim Sci 88(3):943–949

Green MP, Hunter MG, Mann GE (2005) Relationships between maternal hormone secretion and embryo development on day 5 of pregnancy in dairy cows. Anim Reprod Sci 88:179–189

Gupta S, Agarwal A, Banerjee J, Alvarez JG (2007) The role of oxidative stress in spontaneous abortion and recurrent pregnancy loss: a systematic review. Obstet Gynecol Surv 62(5):335–347

Guzeloglu A, Erdem H, Saribay MK, Thatcher WW, Tekeli T (2007) Effect of the administration of flunixin meglumine on pregnancy rates in Holstein heifers. Vet Rec 160:404–406

Hansen PJ (2007a) Exploitation of genetic and physiological determinants of embryonic resistance to elevated temperature to improve embryonic survival in dairy cattle during heat stress. Theriogenology 68S:S242–S249

Hansen PJ (2007b) To be or not to be- determinants of embryonic survival following heat shock. Theriogenology 68(suppl1):S40–S48

Hansen PJ, Block J (2004) Towards an embryocentric world: the current and potential uses of embryo technologies in dairy production. Reprod Fertil Dev 16:1–14

Hansen PJ, Drost M, Rivera RM, Paula- Lopes FF, Al-Katanani YM, Krininger CE, Chase CC (2001) Adverse impact of heat stress on embryo production: causes and strategies for mitigation. Theriogenology 55:91–103

Hayes BJ, Bowman PJ, Chamberlain AJ, Savin K, van Tassel CP, Sonstegard CS, Goddard ME (2009) A validated genome wide association study to breed cattle adapted to an environment altered by climate change. PLoS One 18:e6676

Hendriksen PJM, Steenweg WNM, Harkema JC, Merton JS, Bevers MM, Vos PLAM, Dieleman SJ (2004) Effect of different stages of the follicular wave on in vitro developmental competence of bovine oocytes. Theriogenology 61:909–920

Herr CM, Reed KC (1991) Micromanipulation of bovine embryos for sex determination. Theriogenology 35:45–54

Inskeep EK (2004) Preovulatory, postovulatory, and postmaternal recognition effects of concentrations of progesterone on embryonic survival in the cow. J Anim Sci 82:E24–E39

Jousan FD, Hansen PJ (2007) Insulin-like growth factor-I promotes resistance of bovine preimplantation embryos to heat shock through action independent of its anti-apoptotic actions requiring PI3K signaling. Mol Reprod Dev 74:189–196

Lopez-Gatius F, Santolaria P, Martino A, Deletang F, De Rensis F (2006) The effects of GnRH treatment at the time of AI and 12 days later on reproductive performance of high producing dairy cows during the warm season in northeastern Spain. Theriogenology 65:820–830

Machatkova M, Krausova K, Jokesova E, Tomanek M (2004) Developmental competence of bovine oocytes: effects of follicle size and the phase of follicular wave on *in vitro* embryo production. Theriogenology 61:329–335

Mann GE, Lamming GE, Robinson RS, Wathes DC (1999) The regulation of interferon-tau production and uterine hormone receptors during early pregnancy. J Reprod Fertil 54:317–328

Mattos R, Staples CR, Thatcher WW (2000) Effects of dietary fatty acids on reproduction in ruminants. Rev Reprod 5:38–45

Mattos R, Staples CR, Arteche A, Wiltbank MC, Diaz FJ, Jenkins TC, Thatcher WW (2004) The effect of feeding fish oil on uterine secretion of PGF2α, milk composition, and metabolic status of periparturient Holstein cows. J Dairy Sci 97:921–932

Maurya VP, Sejian V, Kumar D, Naqvi SMK (2010) Effect of induced body condition score differences on sexual behavior, scrotal measurements, semen attributes, and endocrine responses in Malpura rams under hot semi-arid environment. J Anim Physiol Anim Nutr 94:e308–e317

Moreira F, Badinga L, Burnley C, Thatcher WW (2002) Bovine somatotropin increases embryonic development in superovulated cows and improves posttransfer pregnancy rates when given to lactating recipient cows. Theriogenology 57:1371–1387

Nienaber JA, Hahn GL (2007) Livestock production system management responses to thermal challenges. Int J Biometeorol 52:149–157

Nottle MB, Kleemann IDO, Grosser TI, Seamark RF (1997) Evaluation of a nutritional strategy to increase ovulation rate in Merino ewes mated in late spring-early summer. Anim Reprod Sci 47:255–261

Olson TA, Lucena C, Chase CC Jr, Hammond AC (2003) Evidence of a major gene influencing hair length and heat tolerance in *Bos taurus* cattle. J Anim Sci 81:80–90

Petit HV, Twagiramungu H (2004) Conception rate and reproductive function of dairy cows fed different fat sources. Theriogenology 66:1316–1324

Ribeiro ES, Bruno RGS, Farias AM, Hernández-Rivera JA, Gomes GC, Surjus R, Becker LFV, Birt A, Ott TL, Branen JR, Sasser RG, Keisler DH, Thatcher WW, Bilby TR, Santos JEP (2014) Low doses of bovine somatotropin enhance conceptus development and fertility in lactating dairy cows. Biol Reprod 90(1):10, 1–12

Robinson RS, Hammond AJ, Wathes DC, Hunter MG, Mann GE (2008) Corpus luteum-endometrium-embryo interaction in the dairy cow: understanding mechanism and clinical relevance. Reprod Domest Anim 43(suppl 2):104–112

Rodriguez P, Tribulo A, Ramos M, Ongaratto FL, Bo GA (2010) Comparison of oocyte recovery rates and morphology obtained by OPU after different hormonal treatments in cattle. In: XXVI World Buiatrics Congress, Santiago, Chile

Ronchi B, Stradaioli G, Verini Supplizi A, Bernabucci U, Lacetera N, Accorsi PA, Nardone A, Seren E (2001) Influence of heat stress and feed restriction on plasma progesterone, estradiol-17β LH, FSH, prolactin and cortisol in Holstein heifers. Livest Prod Sci 68:231–241

Roth Z, Arav A, Bor A, Zeron Y, Braw-Tal R, Wolfenson D (2002) Effect of treatment with FSH or rbST on the quality of oocytes aspirated in the autumn from previously heat stressed cows. J Dairy Sci 85:1398–1405

Roth Z, Bor A, Braw-Tal R, Wolfenson D (2004) Carry over effect of summer thermal stress on characteristics of the preovulatory follicle of lactating cows. J Therm Biol 29:681–685

Roy KS, Prakash BS (2007) Seasonal variation and circadian rhythmicity of the prolactin profile during the summer months in repeat-breeding Murrah buffalo heifers. Reprod Fertil Dev 19:569–575

Santos JEP, Juchen SO, Cerri RLA, Galvao KN, Chebel RC, Thatcher WW, Dei C, Bilby C (2004) Effect of bST and reproductive management on reproductive and lactational performance of Holstein dairy cows. J Dairy Sci 87:868–881

Sejian V, Maurya VP, Naqvi SMK, Kumar D, Joshi A (2010) Effect of induced body condition score differences on physiological response, productive and reproductive performance of Malpura ewes kept in a hot, semi-arid environment. J Anim Physiol Anim Nutr 94(2):154–161

Sejian V, Maurya VP, Naqvi SMK (2011) Effect of thermal, nutritional and combined (thermal and nutritional) stresses on growth and reproductive performance of Malpura ewes under semi-arid tropical environment. J Anim Physiol Anim Nutr 95:252–258

Sejian V, Maurya VP, Kumar K, Naqvi SMK (2012) Effect of multiple stresses (thermal, nutritional and walking stress) on the reproductive performance of Malpura ewes. Vet Med Int. doi:10.1155/2012/471760

Sejian V, Singh AK, Sahoo A, Naqvi SMK (2014) Effect of mineral mixture and antioxidant supplementation on growth, reproductive performance and adaptive capability of Malpura ewes subjected to heat stress. J Anim Physiol Anim Nutr 98:72–83

Sirisathein S, Herandez-Fonseca HJ, Bracket BG (2003) Influence of epidermal growth factor and insulin like growth factor-1 on bovine blastocyst development *in vitro*. Anim Reprod Sci 77(1–2):21–32

Stewart BM, Block J, Morelli P, Navarrette AE, Amstalden M, Bonilla L, Hansen PJ, Bilby TR (2010) Efficacy of embryo transfer in lactating dairy cows during summer using fresh or vitrified embryos produced *in vitro* with sexed sorted semen. J Dairy Sci 93(E-suppl1):821

Torres-Junior JRS, Pires MFA, De Sa WF, Ferreira ADM, Viana JHM, Camargo LSA, Ramos AA, Folhadella IM, Polisseni J, De Freitas C, Clemente CAA, Sa Filho MF, Paula-Lopes FF, Baruselli PS (2008) Effect of maternal heat-stress on follicular growth and oocyte competence in *Bos indicus* cattle. Theriogenology 69:155–166

Wolfenson D, Thatcher WW, Badinga L, Savio JD, Meidan R, Lew BJ, Braw-Tal R, Berman A (1995) Effect of heat stress on follicular development during the estrus cycle in lactating dairy cattle. Biol Reprod 52:1106–1113

Wolfenson D, Roth Z, Meidan R (2000) Impaired reproduction in heat stressed cattle: basic and applied aspects. Anim Reprod Sci 60–61:535–547

Wolfenson D, Friedman E, Lavon Y, Roth Z (2009) The effect of exogenous progesterone on conception rate of cooled cows during summer and autumn. Reprod Fertil Dev 21:17

Strategies to Improve Livestock Genetic Resources to Counter Climate Change Impact

25

Soumen Naskar, Gopal R. Gowane,
and Ashish Chopra

Abstract

Global diversity of livestock in the form of many different species and breeds in a variety of production environments is indicative of the fact that it has developed over time in sync with the ecosystem. The developing world is particularly enriched with livestock breed portfolio. Natural selection has mainly acted on fitness including adaptability and reproductive success, whereas selection practised by livestock keepers and animal breeders has been need based. As against highly structured breeding programmes and intensive selection in developed world, livestock of developing world have largely been subjected to differential selection pressures in the form of their ability to survive in harsh production environments and challenged inputs. The last few decades have witnessed large-scale erosion of livestock genetic diversity. Climate change (CC) through its direct and indirect effects including its mitigation measures is believed to have influenced the erosion. Faster loss of animal genetic diversity poses greatest threat to the sustainability of the sector. The presence of varied livestock species and their breeds with widely variable performances offers the opportunity for genetic improvement. In the absence of it, we risk progress in this sector. Reorientation of livestock breeding is required to address the issues of CC. Although resource-use efficiency is imperative, careful trade-off between livestock production, productivity and

---

S. Naskar (✉)
ICAR-National Research Centre on Pig,
Rani, Guwahati, Assam 781131, India
e-mail: snrana@gmail.com

G.R. Gowane
Division of Animal Genetics and Breeding,
ICAR-Central Sheep and Wool Research Institute,
Avikanagar, Via-Jaipur, Rajasthan 304501, India

A. Chopra
Arid Regional Campus, ICAR-Central Sheep
and Wool Research Institute, Beechwal, Bikaner,
Rajasthan 334006, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_25, © Springer India 2015

adaptability will be required. Breeding strategies for livestock genetic resources to counter CC impact will not be fundamentally different in the future. Natural stratification of species and breeds of livestock shall be an important guide in the design. Appropriate policy framework, large-scale cooperation in knowledge and resources and awareness will be crucial.

Keywords

Adaptability • AnGR • Breeding strategy • Conservation • Genetic improvement • Production system • Sustainability

Animal agriculture continues to remain as one of the most important sources for income generation and tool for nutritional security, livelihood and poverty alleviation in developing and least developed countries. Growth trend of industrial and organised mode of animal production in developed countries also confirms its ever-increasing and important role in food security. The livestock sector as a whole is dynamic and has grown over the period facing newer challenges, developing suitable strategies to curtail and circumvent it. Key ingredient in facing the challenges with resilience has been the flexibility of operation and diversity of production and production system. The swiftness of the production system to adjust has been the cornerstone that has been possible because of the many factors, one of the key of which is the diversity of gene pool in the form of many different livestock species and breeds of a species including crossbred and synthetic population. The dynamic livestock sector embraces for a relatively newer challenge – climate change (CC). Not only the livestock species but also its production system has evolved over hundreds of years facing climatic and weather variables and extremes. It may not be illogical to think that the sector will match the demands of CC through structural and functional change including its organic function. The key question that remains to be answered is the preparedness in the face of CC so that livestock production and productivity are not grossly affected. What is largely unexplored because of absence of authentic data and sufficient experimentation is whether the variable and veritable gene pool will continue to deliver the same goods and services with incremental growth without major change in case CC outpaces the inherent and serial adaptability of the livestock production and production system.

The pillar of the livestock improvement to meet the burgeoning needs of humankinds has been the improvement of genetics. The genetic improvement of livestock has been a function of natural selection and human intervention. Whereas fitness and adaptability have shaped the course of natural selection, livestock keepers and animal breeders have brought improvement through application of their wisdom, science and technologies. Although rate of genetic gain is slow and steady, it is relatively permanent and thus indispensable. The predominant motive in artificial selection has been need based; however, societal as well as ecological values of livestock might not have been overlooked while practising selection by their keepers. Key ingredient for selection to be effective and useful is variation in the population. The diversity and variability in the phenotype and genotype of livestock offers the opportunity for genetic improvement. The last few decades have witnessed unparallel loss of livestock genetic diversity for varied reasons. CC through its direct and indirect effects is supposed to have accelerated the erosion. Faster loss of animal genetic diversity poses greatest threat to the sustainability of animal agriculture directly and thereby to nutritional security and livelihood of its keepers along with high impact on the ecosystem.

In the following section, attributes of livestock genetic resources in interaction with climate and CC, analysis of practised breeding strategies and resultant priority of livestock genetic improvement issues with respect to climate resilience are discussed.

25.1 Interplay of Animal Genetic Resources (AnGR) and Climate (Change)

The diversity of livestock species and its many different breeds including the ones developed by its rearers and breeders is sufficiently indicative of the interplay of animal genetic resources (AnGR) with climate. Natural distribution pattern of livestock species and breeds has been a function of the ecosystem. Climate being an integral part of the ecosystem influencing production and reproduction, nutrient availability and disease pattern, the diversity of livestock species was ensured. Thus, the course of evolution has been in no stage insulated from the interaction with climate and its variables. Thirty-three mammalian and avian livestock species are described by Food and Agriculture Organization's (FAO) Domestic Animal Diversity Information System (DAD-IS). When we look at a particular livestock species, another discernible feature is the natural stratification of livestock breeds by climatic zones suiting to the macro-environment and based on production system and practice. FAO's global assessment of livestock breed diversity puts the figure to 7,040 local breeds and 1,051 transboundary breeds (FAO 2009). Developing countries host about two-thirds of breed portfolio. Further variability is explained by the selective expression of gene(s) depending on the climate and weather variables.

Livestock species has equally undergone the course of natural evolution determined by the fitness acting on selective reproductive success. Since the onset of domestication, humankind has used it to suit their diverse needs. Although the predominant motive has been the improvement in production and productivity, nontangible factors like sociocultural and environmental service have also importantly influenced livestock species and breed biodiversity portfolio. In the process, livestock has acquired necessary physical and physiological changes. When looked to the cellular level, it has resulted in differential display of genes, their action and interaction. In many cases, it has resulted in signature conformation with novel gene mutations.

25.1.1 Significance of Climate Change for the Management of AnGR

Livestock breeds have been conscientiously developed along with the climatic variables naturally. Whenever farming needs have defined the breeding objective, a healthy balance of production and productivity, feed efficiency, general vigour, disease tolerance and longevity has got predominance on macro-scale. Thus, both natural and artificial selection have largely been in sync with climate and production system so that it can produce goods and offer services and at the same time withstand climatic stress. For industrial or landless production system, other traits except production and productivity have not received due attention because of easy access to inputs. There are notable exceptions like the beef industry which has imbibed functional traits serially.

It is now well understood that the diversity of livestock species and breed portfolio offers the opportunity for facing challenges more effectively and helps in risk mitigation. In this connection, it is worthwhile to note that maximum livestock diversity is observed in developing and least developed countries with a variety of production systems like smallholder, mixed crop-livestock and pastoral offering diverse production, sociocultural and environmental services. In developed world, the portfolio has become limited suiting to industrial needs of milk, meat, egg and fibre. Thus, whereas local breeds along with traditional breeding system dominate developing and poor countries, limited transboundary breeds with global reach developed through scientific well-structured breeding programmes are mostly seen in developed countries. Traditional production system is largely not protected for environmental variables and open grazing is popular in contrast to large-scale intensive production system which is mostly protected against environmental variables through shelter and control of microenvironments. Heterogeneous plant communities with widely variable nutritive values, crop residues, pasture feeding and low-quality forage characterise the feed type available to livestock in majority of the developing and poor countries as against concentrate, cereal, easily digestible fodder and good pasture in developed world which is largely not influenced by seasonal variability. When it comes to disease and parasitic challenges, tropical world is more unfavourable to its livestock as compared to temperate world.

The direct challenges posed by climatic variables like high temperature, humidity and restricted access to potable water and the indirect challenges such as low-quality feed and fodder, increased diseases and mortality have resulted in the development of livestock breeds which are well adapted in tropical world. Most of them can thrive well and produce a wide variety of goods and services. The range of goods include milk, meat, egg, wool and fibre, skin and hides, draught power and transport, manure for soil fertility and bio-fuel. The definition of the broad-based role of tropical and traditional livestock production system also includes a range of sociocultural services like insurance and asset function during emergencies, religious role, heritage, alternative system of medicinal use, sports and recreation, social status of owner and a host of environmental services like efficient use of crop by-products and residues, weed and shrub control, dispersal of seeds and constituent of cultural landscapes.

However, when enumerating the role and contribution of livestock by commonly agreed and easily comparable economic terms, it is by and large restricted to traded products only like milk, meat and egg. This has resulted in considerable undervaluation of it as a humankind asset function. Even in the absence of complete capture of the true value of the product and services offered by livestock resources, it is accepted beyond doubt that the genetic diversity of AnGR is vital for adapting production systems to future changes.

The relevance of maintaining diversity in AnGR for the present and the future remains with the fact that animals must be genetically well matched to production environments in which they are (to be) kept and able to meet the demands for products and services. Altered scenario under CC may require adjustment of breeding objectives and/or adaptation of husbandry practices, but genetic diversity always remains as a prerequisite for adapting production systems to future changes.

It may be appreciated that the projected challenges associated with CC like thermal stress, poor nutrition and increased disease risk will not be fundamentally different than what the livestock faces today specially for the tropical world. It becomes a major concern for the conditions that changes outpace the adaptability and/or the future portfolio of genetic diversity no longer offers the option to adapt because of being already lost.

Livestock rearing being one of the oldest professions of humankind gave rise to diverse production environment and systems. For all reasons, livestock husbandry has matched the expectation of nutritional security and livelihoods. However, ever-increasing demand for animal products with human population explosion led to unparallel demand leading to the so-called livestock revolution. The sector being dynamic has kept the pace, and CC for all purpose may add another layer of influence. Livestock revolution saw globalisation of livestock production led by the industrialised system of production in developed world. More than 90 % of genetic material exports originate from developed countries, and share of trade from developed to developing countries increased from 20 to 30 % between 1995 and 2005 (Gollin et al. 2008). The industrial system of livestock production produces 55, 68 and 74 % of global pork, eggs and poultry meat production, respectively, utilising internationally sourced animal genetics and feed and large-scale use of sophisticated technologies (FAO 2003; Steinfeld et al.

2006). Most of the developing and poor countries in the pursuit of purchasing genetic progress as short-cut instead of developing suitable animal germplasm using native genetic resources of their own has imported genetic materials of high producing ability which has otherwise been developed for production environments of developed world based on high-inputs. This led to the spread of elite and restricted genetic base to the world over, the so-called international transboundary breeds.

As compared to industrial livestock production, majority of the developing and poor countries basically harbours smallholder production along with pastoral system of livestock rearing with a host of native livestock breeds known for their resilience. These native breeds have always been a cultural entity rather than a defined class of homogenous population. The so-called livestock-based development programmes in developing and poor countries based on import of genetic progress led to severe erosion of their own livestock diversity. Although developing countries host about two-thirds of breed portfolio, about 9 % of reported breeds are extinct and 20 % are currently classified as being at risk globally. The risk status of 36 % of breeds is unknown (FAO 2009). About 31 % of cattle breeds, 35 % of pig, 38 % of chicken and 33 % of horse breeds are currently at risk or already extinct (FAO 2009).

Although short- and medium-term gain of importer countries can never be denied, its long-term effect has already shown vulnerability whereby the improved livestock struggles to retain its superiority with relatively poor inputs and services in different production environments.

The growing dichotomy between large-scale intensive livestock production and smallholder mixed crop-livestock or pastoral system of livestock production further adds uncertainty and vulnerability to future changes. These may warrant redefining the role and value of AnGR in broadest possible term including its sociocultural and environmental value. Most native livestock breeds of developing and poor countries produce at low to medium level with challenge inputs – poor feed, fodder and pasture, high disease incidences and worm load and higher mortality. However, sufficient within-breed variation exists, allowing exploit of additive genetic variation through selective breeding.

More perplexing is the fact that livestock production both contributes to and is affected by CC. Eighteen per cent of global GHG emissions are attributed to livestock via land use and land-use change which includes grazing, feed crop production, manure management and enteric fermentation (FAO 2006a, 2010a).

Although it is widely understood that CC will affect the product and services rendered by diverse livestock species and breeds, regrettably it is yet to be integrated to the adaptation and mitigation strategies of CC. One of the biggest challenges in quantifying the role of CC on livestock is the absence of quality data and appropriate model. Although adaptation traits are widely covered, in many a case, they are restricted to anecdotal evidences and detailed data of it along with thermo-neutral zone (TNZ) is not available. Again, because of globalisation of animal genetics, mainly by international transboundary breeds, the geographical distribution of the breed(s) is overlaid by diverse production systems. Further, they often have similar environmental envelopes since several species have been domesticated in the same region. Another bigger void is that many stakeholders do not consider CC as a possible threat to the long-term sustained use of livestock biodiversity and the product and services thereof.

25.1.2 Challenges Associated with Climate Change to AnGR

As discussed earlier, selection in general has largely been in sync with climate and production system so that it continues to produce goods and services in the presence of predictable stresses with time horizon of its development. However, many a different factors influence it. There is a wide variation in adaptability of different livestock species and breeds to stressors. Most native animals of tropical countries have remarkable ability to adapt to environmental stressors. However, fast dilution of native germplasm, large-scale transboundary movement of narrow pool of *superior* animal genetics ignoring genotype and environment interaction (GEI), and absence of sharing of knowledge are widening the vulnerability of AnGR. The range, scale and possible magnitude of the influence of stressors are continuously updated, and the present paradigm of knowledge may not be in the advanced stage of understanding their impact. In the following section, challenges posed by most possible stressors are discussed.

25.1.2.1 Direct Effect

Direct effect of CC that is likely to affect livestock diversity and the product and services offered by the livestock significantly in long-term horizon is heat stress. Temperature is predicted to increase globally in certainty with reduction in precipitation in many parts of the world, more so for the already arid regions (IPCC 2007). It will result in increased heat stress to livestock. Heat stress continuously challenges the homeostasis of livestock, and appetite and FI become the first casualty. When lifetime production of animal is considered, it is significantly affected because of reduction in fertility and increased mortality. Milk production, fertility and longevity in Holstein-Friesian cattle are reported to decline as temperature increases (West 2003). A modelling exercise for the Great Plains region of the United States indicated substantial declines in beef, dairy and pig productivity in parts of the study area (Mader et al. 2009). For most of the species, body temperature beyond 45–47 °C is considered to be lethal. Effect of heat stress on animal production and productivity will be variable based on climatic region, production system and speciation distribution. Livestock of arid region are supposed to be affected by highest degree. Monogastric species being less thermotolerant than ruminants will suffer more in areas with increased thermal stress.

Response of animals to any stress including thermal is a function of fitness and adaptation. Wide variability in adaptation of livestock to thermal stress is observed which is governed by morphological and physiological features. Morphological characteristics of the skin, viz. colour, thickness, concentration of sweat glands and hair coat, number of hairs per unit area, length and diameter of the hair, angle of the hair to the skin surface and degree of pigmentation, vary between temperate and tropical livestock. Physiological features like respiration rate, endocrinological profile and metabolic heat production in interplay with morphological features determine the response to heat stress. However, the underlying principle covering complex interaction of physiological, genetic and behavioural factors for combating heat stress is yet to be understood clearly (McManus et al. 2008).

Tropical livestock in general withstand thermal stress better than their temperate counterparts like zebu cattle (FAO 2006b). There are some other species which are uniquely distributed like camelids in arid areas and yaks in harsh high altitudes. CC will be a greater threat to the geographically isolated or restricted livestock species and breeds through extreme weather events (EWE) like flood, drought and hurricanes. This particular area is so less documented although heavy mortality and extreme stress are quite common with disasters. Temperate livestock of developed world that are dominant in industrialised mode of production are insulated from the climatic variables and are generally not well adapted. At the same time, their metabolic heat production is higher. Livestock of developing and least developed countries which has been imported from developed world will face increased threat of heat stress because of ignoring GEI and production environments.

The first and most convenient way of combating heat stress, i.e. shelter management, will be imperative. Other sophisticated measures as used in industrialised system of production will not be feasible in small-scale and traditional production resulting in increased heat stress. Temperate livestock may continue to enjoy the benefits of manipulations of micro-environments till the time associated inputs for maintaining it become limited and uneconomic because of CC.

Although adaptation traits in general have low heritability, they will become more relevant in

CC scenario. In homogenised and stable production environments, they may not show any appreciable genetic gain indicating towards selection limit (Hill and Zhang 2009). But with change in production environments associated with CC, they are likely to be responsive because of change in existing fitness profile and increase of heterozygosity.

25.1.2.2 Indirect Effect

Direct effect of CC on livestock interacts with the other induced changes in the agroecosystem like altered feed and nutrient availability as well as disease epidemiology. Intervention to counteract CC and policy measures are also likely to influence the livestock diversity and its produce. For many parts of the world, indirect effects of CC may influence the livestock production more pronouncedly than through direct effect.

25.1.2.2.1 Feed and Nutrition

CC has every potential to affect the availability of livestock feed in a host of ways and may pose major challenges for the livestock sector as a whole as well as specific production systems. These in turn will affect AnGR. It is well known that climate directly affects the quality and quantity of the forages. Higher temperatures increase lignifications and decrease the digestibility. It is likely that CC will induce a shift from C3 to C4 grasses (Morgan et al. 2007). Further, it may increase shrub coverage in some grasslands (Christensen et al. 2004). Plant species have differential capacities to spread in response to CC. Just like livestock breeds, plant species that flourish in limited environments are more likely to be affected by climate-related agroecosystem changes than generalist species that can survive in a variety of different environments (Foden et al. 2008). By taking advantage of it, generalist or colonising species will expand their ranges leading to increased range being invaded by otherwise uncommon weeds, pests, pathogens or disease vectors.

In fact, the increases in temperature in temperate areas may benefit early season plant growth and thereby productive forage species may get an upper hand. It may be conducive for keeping high-performance livestock breeds that require good nutrition. Contrary to this, already semiarid areas are likely to experience lower rainfall. Wide variability in rainfall pattern along with frequent droughts may further accentuate the problem of shorter growing period that is likely to happen in many parts of the tropics (IPCC 2007; Thornton and Herrero 2008). This will lengthen the duration of nutritional stress. Animals may have to walk longer distances in search of feed and cope with less availability of potable water. This in turn will result in overgrazing in relatively less affected areas and newer disease and parasites challenges. The areas where winter will be more severe will limit the grazing of animals because of ice and snow cover like the *dzud* disasters that occur from time to time in Mongolia (Pilling and Hoffmann 2011).

Industrial livestock production system is largely characterised by globally sourced economic feed inputs. Escalation of cost of inputs like grain (Rowlinson 2008) which may or may not be because of CC will pose a serious challenge and may force shift in production portfolio as has been witnessed in Southeast Asian countries such as Indonesia (Sudaryanto et al. 2001). This may force increased focus on exploitation of locally available feed resources (Holechek 2009) and better nutrient utilisation.

Large differences in response to nutritional stress are observed among different livestock species and breeds. For example, camels do not show much susceptibility to heat stress-induced nutritional challenges unlike other species. On the other hand, *Bos indicus* perform relatively better with low-quality forages although feed conversion efficiency is higher in *Bos taurus* with good-quality feeds. Small ruminants perform better with low-quality feed and forages when compared across species. Even species and breed differences exist with diet selection which may be a function of their metabolic profile (Blench 1999). The degree of influence of nutritional stress on production and reproduction and underfeeding induced mobilisation of body reserves vary among species and breeds and may have a genetic basis (Hall 2004). However, anecdotal evidences dominate over scientific revelation with respect to differential response to nutritional stress.

25.1.2.2.2 Diseases and Parasites

Many infectious diseases especially that are vector-borne are significantly influenced by climate. The disease-causing pathogens, vectors and hosts and their interaction are directly as well as indirectly affected by climate. Thus, CC is likely to affect spatial and temporal distribution of diseases including influence on their intensity. Incidences and distribution of many vector-borne diseases including bluetongue, dengue, leishmaniasis and trypanosomiasis have significantly changed during the recent past (de La Rocque et al. 2008). However, sufficient reasons do not exist to ascribe their rise to CC. The dynamic interaction of climate with constituents of diseases may see geographical expansion of vector-borne infectious diseases like bluetongue and Rift Valley fever to those places where it is less likely to occur otherwise. It indeed may influence the transmission and course of diseases (Rogers and Randolph 2006).

However, simply expansion of a range of a disease-causing pathogens or vectors does not necessarily result in disease transmission to a larger scale (de La Rocque et al. 2008). In fact, larger population movement and increased trade may have contributed more to the atypical spread and intensity of diseases than direct effect of CC which might have helped disease cross their classical barriers such as deserts and oceans.

Seasonal influences on disease incidences may be more pronounced in the future. Specific short-term weather events and seasonal rainfall are known to trigger outbreaks of many diseases like African horse sickness, anthrax, bluetongue, peste des petits ruminants and Rift Valley fever (Van den Bossch and Coetzer 2008). It may be of considerable significance since the frequency of EWE such as floods and droughts is expected to rise with CC (IPCC 2007).

Although the diversity of AnGR plays a pivotal role in adapting production system to the changes including climate-induced, it in turn is vulnerable to these changes. The threat may operate in two ways: disease epidemics may cause death of a large number of animals and control measure including the much-used culling of animals may cause severe depletion of livestock strength in affected areas. The effect is more pronounced when a breed or species is geographically isolated or has limited distribution. The loss of livestock in large scale because of culling as a means of control measure has been due to diseases like African swine fever, avian influenza, classical swine fever, contagious bovine pleuropneumonia and foot-and-mouth disease in recent times. The majority of the livestock death for the referred diseases has been due to culling and not because of disease epidemics. It may be noted that these diseases are not largely known to be influenced by CCs. However, it may be so that CCs may have influenced the disease epidemics through indirect means by their influence on management system and general immune status. To cite an example of the threat that culling measures cause to the diversity, a sizeable portion of poultry genetic resources has been lost in Tripura state of India because of mass culling to combat avian influenza.

Irrespective of the control measures, CC and seasonally influenced increased incidences and range of diseases will see preference for livestock species and breeds that are disease resistant or tolerant. Many livestock breeds, mainly from developing countries, are reported to be resistant or tolerant to trypanosomiasis, tick burden, tick-borne diseases, internal parasites, dermatophilosis or foot rot (59 cattle, 33 sheep, 6 goat, 5 horse and 4 buffalo breeds) (FAO 2007a). However, underlying physiological and genetic mechanisms including causal mutations associated with differential response to diseases for the above-referred livestock breeds are yet to be deciphered in most cases and thus considered to be largely anecdotal.

25.1.2.2.3 Deviation from Normal Species and Breed Stratification

Natural stratification of species and breeds exists ensuring environmental and production niche. Generally, local breeds adapt well, and thus, species and breed substitution becomes relevant only when changes in climate condition outpace the adaptability both naturally and through man-made measures. Species substitution by increased use of dromedaries because of climate and vegetation changes has already been witnessed in parts of Africa (Gouro et al. 2008). The same has happened at breed level also. However, movement of species and breeds because of CC may be considered both as a threat and opportunity. Herd portfolio comprising multiple species and breeds is a common strategy in traditional livestock farming for production as well as environmental niche and is considered to be more CC resilient. Along with it, popularity of small ruminant like sheep and goat is a measure of CC resilience in small farms of developing world (Seo and Mendelsohn 2007). However, globalisation of breeding programmes and purchase of genetic gain have affected resilience to varying degree in different parts of the world.

Impact of CC may be exacerbated by environmental degradation and CC adaptation may prove to be more costly. A classical case of it is explained by Zhang and Hong (2009) whereby local ruminant breeds are reported to be affected because of restriction imposed on grazing with the objective of reducing rangeland degradation in provinces of western China.

Many studies predict that farmers will switch from cattle and chicken to goat and sheep (Herrero et al. 2008; Seo and Mendelsohn 2008). Some other studies model that ruminants will increase in rangelands as long as there is sufficient vegetation growth (Seo and Mendelsohn 2008). It is predicted that livestock keeping will replace cropping in marginal mixed crop-livestock systems as they become ecologically and socially more marginal (Jones and Thornton 2009). By contrast, shift of livestock populations from rangeland-based grazing to mixed systems is predicted based on improved feeding of crop by-products by Herrero et al. (2008). Indian experience reveals that farmers who keep livestock along with agriculture farming are more successful in handling drought-induced distress.

The concept of climatic envelopes as applicable for wildlife is not so straightforward in livestock species because of very high human intervention. It is simply because of the fact that the breeds' capacity to survive is not simply a function of adaptation but also of management and socio-economic and cultural strength.

25.1.2.2.4 Impact of Climate Change Mitigation Measures on AnGR

Emission of greenhouse gasses (GHG) occurs throughout the production chain of livestock although enteric methane emission is primarily the focus. Discussion and efforts to curtail it include reduction in animal numbers, resource-use efficiency, increasing productivity and feed conversion efficiency, enrichment of feed and a host of technologies. Emission rate is highly variable and depends on the composition of animals and the nature of the production system. Monogastric animals such as pig and chicken have better feed conversion efficiency and produce less methane than ruminants. Within species, breeds and lines that have been continuously subjected to rigorous selection generally have better feed conversion ratio (FCR) with high production performance in input-intensive production system. Across the species, these superior animals dominate the global genetics. On the other hand, in traditional livestock rearing, the animals have mostly been subjected to different selection pressures with focus on their ability to survive in harsh production environments or low input. These adapted animals when judged through feed conversion efficiency may not be very efficient, but they provide a range of products and services many of which are not accounted for in economic terms while assessing their output and productivity. Thus, in the absence of a broad-based definition of the output, there is an increased tendency of branding them as polluter. However, if emission along the whole production chain is considered, carbon footprint of an input-intensive production system may be less impressive because of heavy reliance on fossil fuels and problems with the management of manure. Moreover, efficiency shall not only be measured in terms of converting feed inputs to human food but also of differences in the animal's ability to use feedstuff that cannot otherwise be used by humans. Thus, any regulatory framework with market-based core values may result in sidelining production systems that are deemed to be high emitters of GHGs resulting in the decline of associated AnGR diversity. Further, promoting animals that may not adapt well to stressful production environments may result in compromise in fertility and survivability which will render the system unsustainable.

As has been told, GHG emission depends on the production system. For example, GHG emission per unit of meat produced is less with intensive feedlot systems than extensive grazing systems when beef cattle production is considered. Intensive and mixed farming dairy production has lower emission than grassland-based systems as has been reported by Gerber and Vellinga (2009) who also reported on life-cycle assessment of global GHG emissions per kilogramme of fat- and protein-corrected milk (FPCM). While comparing milk and beef production, milk protein can be produced with less methane emission than beef (Williams et al. 2006). Thus, dairying might become the major focus of cattle production, and beef may become a by-product of dairying in an intermediate GHG reduction scenario (Hoffmann 2010). This may see prominence of dual-purpose breeds and crossbreeding (Flachowsky and Brade 2007).

Grazing system which is particularly popular in traditional livestock rearing possesses the highest contrasting feature. On one side, it results in high methane production because of low-quality forages consumed by the ruminants. On the other, it is the backbone of animal production in developing world which ensures livelihoods to large numbers of livestock keepers who are mainly resource poor. More interesting is the fact that grazing systems mainly involve the lands that are otherwise unsuitable for crop production. This means that animal products are derived without direct competition with crops for human consumption. The concept of ‘human edible return’ as suggested by Gill and Smith (2008) may be a better indicator for assessing livestock efficiency. This may also partly substantiate that livestock keeping provides an alternative to more damaging types of land use. However, increasing trend of restricting extensive grazing specially in dryland areas may pose severe threat to associated AnGR diversity. In the same vein, the suggestion of lowering stocking rate for promoting carbon sequestration does not match with popular and increasing trend of livestock grazing as a tool in wildlife and landscape management.

25.1.3 Climate Change and Production System

The influence of CCs on production system is exerted through its direct and indirect effects and explained in earlier sections. The change in the organic nature of the production system because of CC is discussed here. In the face of CCs, the livestock keepers have the option of either adapting their animals to the changed environments or changing the production environment without many changes in the animal genetic portfolio. Since livestock species and breeds that we see today have evolved over many generations assimilating environment and production challenges, breeding programme to maintain animal genetic portfolio so that it continues to render the same goods and services may not be fundamentally different from what we practise today. However, the process may not be smooth. It may witness shift of choice of the species and breeds either locally or regionally affecting the production system. Technologies available for the intensive animal production system may not be readily available and economic to the smallholder production system. Further, the rate of technology adoption varies greatly both by choice and capacity. This will result in further vulnerability of traditional and pastoral systems.

25.2 Adaptability of AnGR and Breeding Strategies to Counteract Climate Change

Adaptation is a dynamic process, wherein living beings are modified phenotypically over the significant course of time as a response to several environmental stimuli which modulate the genomic expression of the organism to suit the needs of time. An interesting thing about the adaptation of the organisms to environmental stimuli is that the information obtained from external stimuli is learned by living systems that in turn help to change the genetic and phenotypic expression that finally inherits in the subsequent generations. AnGR have faced a lot of challenges in the past and the way ahead is tougher. The challenge of CC comes with varying degrees of problems and those need to be counteracted systematically. The most trusted method to bring the change in the livestock is rigorous selection for the desired traits. However, the selection for adaptability in the era of changing climate seems to be the most difficult path to tread.

25.2.1 Adaptability of AnGR in Place

AnGR play a very important role in our life due to complete dependence of mankind on them. Throughout the course of evolution, AnGR have modified themselves according to the need of mankind through the process of domestication and selection, although it was by and large for the benefit of man. The Intergovernmental Panel on CC (IPCC) has defined 'adaptation' as 'initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected CC effects' (Hoffman 2010). Adaptation includes all activities that help people and ecosystems reduce their vulnerability to the adverse impacts of CC and minimise the costs of natural disasters. There is no one-size-fits-all solution for adaptation; measures need to be tailored to specific contexts, such as ecological and socio-economic patterns, and to geographical location and traditional practices (IFAD 2013a). Adaptability is then a measure of potential or actual capacity to adapt, for example, if one breed is used in different environments. Adaptation traits are usually characterised by low heritability. In relatively stable environments, such traits have probably reached a selection limit; however, they are expected to respond to selection if the environment shifts, resulting in change of fitness profiles and increase in heterozygosity (Hill and Zhang 2009). Many generations of natural selection and human-controlled selective breeding and husbandry, in a wide range of production environments, have given rise to great genetic diversity among the world's livestock. Breeds and populations that have been exposed to climatic extremes, heavy disease and parasite challenges, poor-quality feed, high elevations or difficult terrain have often developed adaptations that enable them to thrive where other animals struggle to survive. Although advances in feeding, housing and veterinary care have increasingly enabled the establishment of production systems that isolate animals from such stresses, locally adapted animals remain essential to many livestock-keeping livelihoods especially in marginal areas (Pilling and Hoffman 2011).

While CC is a global phenomenon, its negative impacts are more severely felt by poor people in developing countries who rely heavily on the natural resource base for their livelihoods (IFAD 2013a). Rural poor communities rely greatly for their survival on agriculture and livestock keeping that are among the most climate-sensitive economic sectors. Livestock producers have traditionally adapted to various environmental and climatic changes by building on their in-depth knowledge of the environment in which they live. However, the expanding human population, urbanisation, environmental degradation and increased consumption of animal source foods have rendered some of those coping mechanisms ineffective (Sidahmed 2008). In addition, changes brought about by global warming are likely to happen at such a speed that they will exceed the capacity of spontaneous adaptation of both human communities and animal species (IFAD 2013b). Research on production systems and local and indigenous knowledge systems during the last 10–15 years has yielded ample evidence that in many cases the locally available breeds represent the 'best fit' in terms of adaptability to the physical and animal husbandry environment. If this is the case for the production system(s) under consideration, and unless there is clear evidence for the benefit of using an exotic breed, a decision to use the locally available AnGR would be a reasonable outcome of the decision-making process (FAO 2010a). AnGR have been modulating the phenotype according to the change in climatic factors, but at a very slow pace. However, in today's CC era, the need to change is altogether different and demands a fast rather very fast pace that seems to be difficult from every perspective.

25.2.2 Adaptability of Production Systems in Place

Production systems in modern era are highly specialised. Production environments, and the intensities and purposes of production, vary greatly within and across countries. Developed countries have objective-oriented and result framework-documented production systems, whereas in developing and underdeveloped part of the world, still the production systems are integral to their livelihood and stakeholders are mostly ignorant about the business model of the production system, say, for example, sheep husbandry in India. Indian shepherd considers his sheep as an integral part to his livelihood and thus does not pay much attention to the modes of rapid revenue generation through better science and economics. Sheep husbandry in India is with the people who are poor, and also it is the lifeline for them as it helps in sustaining their livelihood. Proper marketing and technical inputs for feeding, breeding and health are usually based on age-old wisdom rather than modern scientific knowledge. That results in sociological animal husbandry practices rather than scientific practices. However, this type of production system has one advantage that it can be shifted to any kind of system as the need arises. On the contrary, the highly specialised production systems of developed world have a very little scope to deviate from their existing systems. Therefore, to study the adaptability of the production systems, it is necessary to first characterise the environment associated with the production system. FAO (2010a) has detailed pointwise the crux of characterising the environment associated with the production system as given below:

- Briefly characterise the nature – including major seasonal features – and the state of ecosystems affected by the production system. Consider groundwater, forest and forest habitat, other flora, wild fauna and soil.
- Are components of the ecosystem sensitive to changes in livestock management?
- Are components of the production system sensitive to the possible effects of global CC?
- Is there evidence that the production system causes environmental damage?
- How does the production system enhance ecosystems (e.g. providing organic fertiliser or maintaining habitats)?
- Do constraints or opportunities result from interactions between the production system and the environment? Are some of these constraints seasonal?

Animal agriculture systems have been categorised on the basis of agro-ecological opportunities and demand for livestock commodities. In general, these systems are shaped by prevailing biophysical and sociocultural environments, and without external inputs, they have traditionally been mostly in sustainable equilibrium with such environments. Many of these systems that are the result of a long evolution are currently under pressure to adjust to rapidly evolving socio-economic conditions; large intensive livestock production units, in particular for pig and poultry production, have emerged over the last decades in many developing regions in response to the rapidly growing demand for livestock products. Several researchers have classified the production systems according to the criteria of existing systems (Steinfeld et al. 2006) such as: (1) integration with crops, (2) relation to land, (3) agro-ecological zone, (4) intensity of production and (5) type of product. These criteria have been used by several authors to classify the systems in several categories; however, the basic remains the same. In the future, production will increasingly be affected by competition for natural resources, particularly land and water, by competition between food and feed and by the need to operate in a carbon-constrained economy. Developments in breeding, nutrition and animal health will continue to contribute to increasing potential production and further efficiency and genetic gains (Thornton 2010).

Although varied natures of the production systems that involve animal, land and man exist and are best suited to the existing conditions, the challenges of the future are demanding. It has always been said that the adaptation of the livestock and also of the production systems to the agro-ecological niches they are placed in is a product of several years of slow change. However, the rapid change due to increased human activities leading to sudden rise of temperature in the last few decades and expected changes in the future if the trend continues (it shall continue!) pose several threats in pipeline. The first steps in adapting production systems to the effects of CC are likely to involve attempts to alter husbandry practices rather than to make major changes in the utilisation of AnGR, such as introducing new breeds or adjusting breeding strategies (Pilling and Hoffman 2011). However, the sudden replacement of the breeds or changes in the breeding objectives does not seem to be the only options as they too need a significant amount of time. Various technologies can be used to protect animals from the direct effects of rising temperatures. Similarly, vaccinations and other preventive measures can be used against many of the diseases and parasites that may spread into new areas as a result of CC (Pilling and Hoffman 2011). Every so-thought-out remedy seems to come with challenges. The biggest one is, suppose the alternate strategy fails in an event of threat due to CC, then what? People round the world are working for this, and many a times, boomerang to the roots seems to be the best solution.

In most of the African and Asian countries, the sociological mode of livestock keeping is in practice since ages. The least change in the animal husbandry practices helped the communities in this region to maintain the diversity of the livestock to a good extent. All the livestock from cattle, sheep, goat, poultry, pig, etc. have many different breeds, which are important not only for their product but also for traits like heat tolerance, disease resistance, longevity, aesthetic value and many more. This diversity will be the only solution to the challenges of tomorrow.

25.2.3 Breeding for Climate Change Adaptation and Mitigation

Nature has possibly already created every alternative for future threats; the need is to identify them, act swiftly and respect the nature and the resources it gives to us. Breeding is a science that has mimicked the process of evolution (selection for desired adapted traits) through man's interference. How can breeding be useful for the process of adaptation in the era of CC is a tough question. Not only this but also mitigating the effects of CC on animal productivity and production by breeding strategies is also a function of imagination and positive projections as we do not have sufficient scientific data as of now. An adaptive trait is an aspect of the developmental pattern which facilitates the survival and/or reproduction of animals in a certain succession of environments (Dobzhansky 1956). Fitness is an important trait for any species which centres on the adaptation of individual species in a given environment to propagate their genes in subsequent generations. Livestock keepers throughout the world have been practicing animal husbandry and breeding in unfavourable environment for centuries. As a result, many breeds of the unsympathetic environment have developed many adaptive traits that enhance survivability. Today, with advancement in the scientific acumen, efforts are needed for enhancing the competence of breeding for harsh environments and also for making the future planning and execution for developing strains which can withstand the unforeseen climatic changes (Naskar et al. 2012). In the following few sections, we will discuss in detail the breeding strategies for adaptation to CC mitigating the challenges posed by CC in the near future.

To sustain the traits of local importance and to have improvement in these traits, a very good practice of keeping a community bull usually owned by temple in a village was adopted since ages in India. These days, there has been decline in this concept as penetration of crossbreeding and other means has increased in villages of interior India too. However, looking into the old concept of keeping community bull in each village, it seems that it has greatly helped in improving the desired traits of interest in the flock of cattle in that region. Today, characterising the traits of interest as far as CC is concerned and reviving the concept of community bull, wherever local breeds or strains need conservation, can very well be practised. WoDaaBe of Niger is another example of cultural habits of exchange of germplasm (Kratli 2007). In livestock-keeping communities, social interactions often involve animals. Friendships are sealed with animal loans; marriages involve the payment of a bride price; animals are offered as wedding gifts; disputes and compensation claims are settled with animals. These and other traditional practices, such as animal exchanges, herd splitting and herding contracts (known locally among the WoDaaBe of Niger as *mafisa*, *haBBana'e* and *bulisana*, respectively), entail numerous movements of animals. The cultural customs are therefore of direct relevance to animal breeding. While breeding is rarely the primary motivation for such customs, they influence breeding because any movement of animals from one herd or flock to another implies an exchange of genetic material.

The continuing approach of breeding strategy will be explored further, but before that, it is essential to understand whether we have enough groundwork for adopting a proper and successful breeding policy. According to FAO (2010b), livestock policy is indispensable for formulating a breeding policy. To cite a case, reference may be made to the enactment of the same in United Republic of Tanzania in 1991. In 2003, a second attempt led to the presentation of a draft animal breeding policy. However, the Ministry of Agriculture realised that no livestock policy was yet in place and gave priority to establishing one, which was done in 2006. In March 2008, an FAO workshop on policies and strategies for the development of AnGR was held in Dar es Salaam, with the objective of revitalising the draft animal breeding policy. A new task force was given the job of reformulating the policy. Similar cases in other countries, such as Burundi, illustrate that before formulating a breeding policy, it is important to establish a comprehensive livestock policy that defines livestock development objectives and associated strategies (FAO 2010a). Another example where clear-cut directives are issued for breeding the indigenous cattle of Africa is the case of N'Dama cattle (ICAR/FAO 2000). The directors of the livestock/veterinary services and of the research organisations dealing with livestock in Gambia, Guinea, Guinea-Bissau, Senegal and Sierra Leone made the following qualitative statement on breeding goals: The N'Dama will remain the cattle breed of choice for the low-input system from the Gambia southwards. Throughout the region, the breed is regarded as triple purpose (for milk, meat and traction), and emphasis for improvement will be on milk and meat without the loss of disease resistance and other adaptive traits. This type of straightforward approach is very urgently required in countries where local germplasms are fast disappearing due to dilution of the germplasm.

25.2.3.1 Developing a Suitable Breeding Strategy

Throughout the world, breeding programmes for improving the productivity of the livestock are in progress. These strategies use the already set rules and knowledge about the basic principles of genetics. Many programmes go for strict adoption of within-breed selection with stringent selection criteria for a trait of economic interest. Selection or straight breeding implies genetic improvement based on variation among individuals within the population. This approach brings a permanent change in the structure of the population but with relatively slow rate. Another approach is crossbreeding, where two different breeds are crossed and improver breed bring fast genetic improvement in the receptor breed. Crossbreeding can also be used for mixing two desired traits of interest in the population. Biotechnological techniques are also in use these days to enhance the productive and reproductive performance at a faster rate. In a few instances, biotechnological tool has been integrated with the breeding programmes that has resulted in reduced generation interval and enhanced productivity (Mishra et al. 2007).

According to FAO (2010a), among the many factors that must be considered in the development of a breeding programme are the animal species involved; the types of traits considered; the availability, accessibility and affordability of different breeds; the production environment; the time frame for the planned genetic improvement (improvement through straight breeding usually takes longer than through crossbreeding); and the infrastructure of the livestock sector and the resources allocated to the programme.

For successful initiation of any breeding programme, it is essential to identify the trait of interest that needs to be improved in the targeted population. In an event of probable global warming and CC, there shall be shift in the traits of interest from productivity to adaptability and fitness. What we expect from the challenge of CC is again the shift of stress to animal from production to balance between production and traits of fitness. It will be a tough task not only for the livestock but also for the stakeholders especially breeders and farmers associated with the animal husbandry with regard to how to keep the balance between these two contrasting traits. CC poses a great threat to the AnGR. Threats are numerous starting from effect on individual animals to the population as a whole. The change in the pattern of disease occurrence and distribution, geographical disease barrier erosion, heat stress as a common factor demanding more heat-tolerant individuals, scarcity of the food resources and water as a general factor, overall decline in the production level of the animals as a compensatory mechanism for stress tolerance, reproductive disturbances and loss of animal genetic diversity at population level will be a few among the many effects of CC on AnGR (Naskar et al. 2012). The overall increase in temperature will have its impact on the physiological stress and thermoregulatory control, nutrition and disease status of the animals.

25.2.3.1.1 Heat Tolerance

The challenge ahead is to manage the livestock genetic resources amiably in accordance with the expected change in the climate. Among the many stressors in animal production system, heat stress is one important factor that needs most attention. Heat stress is known to alter the physiology of livestock, reduce male and female reproduction and production and increase mortality (Hoffman 2010). Livestock's water requirements increase with temperature. Heat stress suppresses appetite and FI; thus, feeding rations for high-performing animals need to be reformulated to account for the need to increase nutrient density. Body temperatures beyond 45–47 °C are lethal in most species. Heat stress is an important factor in determining specific production environments (Zwald et al. 2003). There are several factors that determine the differences for the heat tolerance in livestock. Some species are more tolerant than others; same is the case with breeds within species. We do not have a concrete scientific data to comment on the fact that how the selection for production affects the heat tolerance in animals; however, it is well established that temperate breeds perform better in production, whereas tropical breeds are better for heat tolerance. A good volume of literature is available on adaptation differences between zebu and taurine cattle (Frisch 1972; King 1983; Burns et al. 1997; Prayaga et al. 2006). *Bos indicus* is generally more heat resistant than *Bos taurus* (Burns et al. 1997). When we talk about the heat tolerance level of *Bos indicus*, it is a result of hundreds of years of adaptation and evolution to the harsh climate of Asian, Arab and African countries.

In an event of increase in the climatic temperature, there will be a need to incorporate the trait of heat tolerance in the breeds which are less resistant to heat stress. Current trend in which genetic selection in dairy cow is primarily influenced by milk yield is likely going to give rise to increase in 'elite' germplasm with increased susceptibility to heat stress (Naskar et al. 2012). Genetic adaptation to adverse environmental conditions including heat stress is a slow process and is the result of natural selection over many generations (Ames and Ray 1983). Good environment favours high production whereas bad environment hampers it. Production of any kind, milk or meat characteristics or wool traits requires congenial environment to have better GEI (Naskar et al. 2012). Selecting animals for heat tolerance needs a new understanding by livestock holders and development agencies.

Adaptation traits are usually characterised by low heritability. Selection on the basis of observation of heat stress seems to be difficult and costly. Crossbreeding for heat tolerance per se needs to be traded carefully vis-à-vis production. In Brazil, Indian cattle breeds have been used for genetic improvement that involves the use of Nellore cattle. Now, this move seems to be a good option, where a breed with trait for heat tolerance is used for enhancing productivity. However, where the industries are based on high milk yielding ability of the cattle, whole animal crossbreeding will not be useful. In such instances, use of molecular markers or transgenic approaches for incorporating the heat tolerance genes seems suitable. Heat shock protein 70 (Hsp70) are ubiquitously expressed proteins which protect animals against heat shock (HS) or stress, whether extreme hot or cold. These proteins virtually exist in all living organisms including microorganisms. They are an important part of the cell's machinery for protein folding and help to protect cells from stress. Finding the polymorphism at genetic level for Hsp70 and their correlation with the observed heat stress resistance are useful tools for discovering sturdy animals. There are reports where it was recorded that the polymorphisms in the bovine HSP90AB1 gene were associated with heat tolerance in Thai indigenous cattle (Charoensook et al. 2012). Another gene 'slick' was identified as a gene that improves heat tolerance in dairy cattle. The discovery is very important to the beef cattle industry, since it should greatly facilitate the slick gene's introgression, into other economically important breeds, such as Holstein or Angus, to improve their heat tolerance (Olson et al. 2003). Cattle with slick hair were observed to maintain lower rectal temperature (RT). The gene is found in Senepol cattle and Criollo (Spanish origin) breeds in Central and South America. This gene is also found in a Venezuelan composite breed, the Carora, formed from the Brown Swiss and the Venezuelan Criollo breed. The decreased RT observed for slick-haired crossbred calves compared to normal-haired contemporaries ranged from 0.18 to 0.4 °C. Liu et al. (2010) examined the genetic polymorphism of the ATP1A1 gene in Holstein cows. Nucleotide substitution of G to A at position 14,103 in exon 14 and C to T at position 14,242 in intron 14 of the bovine ATP1A1 gene was identified having a significant correlation between ATP1A1 gene polymorphism and the coefficient of heat tolerance ($P<0.01$) and with respiratory rate ($P<0.01$).

For many breeds of sheep, goat, buffalo, pig and poultry, several genes are responsible for heat tolerance. However, in each breed, selection for heat tolerance does not seem logical. In the breeds of tropical climate, especially in Asia, Africa, etc., the livestock are adapted to the harsh climate. In the future, if the temperature rises (if it rises significantly!), then the breeds will probably adapt to those changes, as has been the case in the past. In breeds where commercialisation has reached to its peak such as in pig and poultry in the Western world and in-house production systems are used, it will be cheaper and efficient to provide micro-climate that controls the outside temperature than to change the genetic structure of the population for heat tolerance.

25.2.3.1.2 Production, Productivity and Feed Efficiency

Production and productivity of the livestock are very important criteria for profitable animal husbandry practices. To increase the production of the livestock, efforts have been made in recent past through several genetic improvement programmes, where milk yield; beef yield; live weight gain in sheep, goat and pig; egg quality and quantity; and several other traits have been improved significantly. In the era of CC, the production and productivity of the animals will be at stake, as the changing climate will pose a threat in terms of stressors that negatively influence the productivity of the livestock. An experiment for fine wool production by crossbreeding was adopted in the semiarid region of Rajasthan, India, in which Rambouillet and Russian Merino were crossed with the local breeds to evolve a fine wool breed called Bharat Merino. However, it was seen that the harsh environment in the semiarid region posed constraints for this genotype to fully exhibit its potential. These animals were then shifted to a subtemperate region (Mannavanur, south India) where already a flock of Bharat Merino sheep was maintained, which resulted in better performance of the genotype (Gowane et al. 2010). It reflects the importance of climate on the productivity of animals and the extent to which it can affect breeding programmes.

Milk productivity in dairy farming is a reflection of interactions between the production potential of the livestock, nutritional knowledge, veterinary care, availability of technologies, investment, active extension service, research as well as readiness to agree and accept innovations (Naskar et al. 2012). Productivity also depends on the kind of nutritional input given to the animals. All livestock production depends on access to the feed and water that animals need to survive, produce and reproduce. The future of livestock production systems, and of the associated AnGR, depends on the continued productivity of various feed-producing areas – all of which are potentially affected by CC (Pilling and Hoffman 2011).

In any breeding programme, the main target for improving the production and productivity must be complimented with the parameters that take into consideration the feed efficiency of the animals such as high FCR, reduced age at maturity, reduced mortality, as they all have a significant say in the productivity per unit in animal husbandry practices. Assuming that future dairy systems may become more reliant on pasture than grain feeding, Hayes et al. (2009) proposed to select sires whose daughters will cope better with low feeding levels and higher heat stress. They identified markers associated with sensitivity of milk production to feeding level and sensitivity of milk production to THI in Jersey and Holstein. Because feed-efficient animals are also more cost-effective and productive, the Australian beef industry now includes net feed efficiency as an integral part of its breeding programme (Beef CRC). Indian zebu cattle, sheep, goat and other species mostly rely on pasture feeding than on grains. These animals are mostly very efficient in effective utilisation of low-quality feed and require very less input. However, selective breeding to increase the feed efficiency may not be widely applicable specially in extensive system of production and small-scale holding. The breeds of different agro-climatic zones worldwide are evolved and adapted to the locally available feed resources that have in turn changed the physiology of the livestock for feed efficiency. Today, the option open for CC situation is management of the AnGR for feed efficiency; herein, change in the feeding systems can be suggested.

One such desired change where feeding system, if manoeuvred, can result in significant reduction is in the methane production from the livestock. Methane gas is a potent greenhouse gas produced in the rumen of livestock during the normal process of feed digestion and represents a significant loss of feed energy that increases feed costs. For example, a lactating dairy cow produces about 400 g of methane each day. These methane losses quickly add up. In 1 year, the amount of methane a dairy cow produces is equivalent to the greenhouse gas emissions from a mid-sized vehicle driven 20,000 km. Because methane production increases as the animal eats more feed, improving feed conversion efficiency, the amount of feed consumed per kilogramme of milk produced or weight gained, decreases methane output. Diets that are more digestible lower the amount of methane emitted per product produced. It may also be possible to breed more efficient cattle that produce less methane. Many strategies such as feeding oils and oilseeds, higher grain diet, legumes, rumen modifiers or animal selection for reduced methane production are suggested for reduced methane production. In India, animals are reared on different feeding systems/diets comprising locally available roughage and feed ingredients according to the animal physiological needs in different AERs of the country. Enteric CH_4 emission estimated for Indian livestock using animal population of 2003 was 9.10 Tg, wherein indigenous cattle and buffalo had the major contribution (Singh et al. 2012). Nutritional intervention in Indian livestock for reduced methane emission is suggested.

Location-specific nutritional interventions can be taken up for altered dietary composition to reduce CH_4 production.

25.2.3.1.3 Disease Tolerance and Resistance

In animal production system, disease tolerance and disease resistance are two different aspects. In the disease tolerance, animal is inflicted with the attack of parasite; however, it has a mechanism by which the negative effects of the disease are not exhibited on the production and reproduction performance of the animal. Disease resistance defines a case wherein the animal's immune system does not allow the antigen to enter the system, and thus, the animal is protected from the disease. In farm animal science, tolerance to infections is sometimes termed disease resilience (Albers et al. 1987). Resistance is different from tolerance. Disease resistance is the *host trait* that prevents infection or reduces the number of pathogens and parasites within or on a host. For animal production system, both disease resilience and resistance traits are important.

There is considerable variation among individuals in the response to infectious disease and vaccination, a significant proportion of which can be shown to be genetic (Davies et al. 2009). Identifying the causal genes involved in disease resistance is no straightforward. Parasitic diseases like gastrointestinal (GI) nematodes and trypanosomiasis are worldwide an important cause of reduced production efficiency in ruminants and partly even limited livestock production in some regions of the world. GI nematodes are among the most important infections faced by livestock, especially affecting poor keepers (Perry et al. 2002). A potential alternative to alleviate the problems is breeding for disease resistance. Extensive research on the genetics and breeding for worm resistance has been carried out in Australia, New Zealand, South Africa (de Greef 2009) and also in India (Singh et al. 2009). Tick counts, faecal worm egg counts (FEC), RT and coat scores have been used as indicator traits of adaptability of beef cattle to assess the suitability of particular genotypes to tropical environment. Singh et al. (2009) evaluated Avikalin (Rambouillet x Malpura) breed of sheep for faecal egg count at naive and exposed stage of natural infection (predominantly *Haemonchus contortus*), and two divergent lines were created by selecting progenies from sires with low (R line) and high (S line) mean faecal egg count (FEC). The performance of selected animals from both lines was compared over the years, and no untoward effects on different performance traits were observed.

Climate affects vectors, pathogens, hosts and host-pathogen interactions from the level of cellular defence to that of the habitat. Hoberg et al. (2008) provide an overview of predicted responses of complex host-pathogen systems to CC. CC may affect the spatial distribution of disease outbreaks and their timing and intensity. Outbreaks of African horse sickness, peste des petits ruminants, Rift Valley fever, bluetongue virus, facial eczema and anthrax are triggered by specific weather conditions and changes in seasonal rainfall profiles (Hoffman 2010). Climatic effects on host-vector and host-parasite population dynamics will further the geographic expansion of vector-borne infectious diseases to higher elevations and higher latitudes and affect the transmission and course of the diseases (Rogers and Randolph 2006). One example is availability of mosquitoes *Culicidae* (vector for disease like malaria) in the higher altitudes of the Himalayan ranges at 7,500 ft high in Mukteshwar. It is evident that mosquitoes were never seen at that height due to low temperatures; however, due to increase in the average temperature, the presence of these vectors is felt which is dangerous with regard to the spread of dreaded diseases like malaria, yellow fever, etc. in the virgin areas. FAO (2007a) lists breeds, mainly from developing countries, that are reported to be resistant or tolerant to trypanosomiasis, tick burden, tick-borne diseases, internal parasites, dermatophilosis or foot rot (59 cattle, 33 sheep, 6 goat, 5 horse and 4 buffalo breeds). Trypano-tolerant N'Dama cattle respond more rapidly and with a greater magnitude to infection compared to the trypano-susceptible Boran cattle. Gorman et al. (2009) showed major gene expression differences exist between cattle from trypano-tolerant and trypano-susceptible breeds. Breeding for disease resistance in the era of CC is increasingly being looked at as a promising option and several experiments are going on worldwide. The use of new molecular techniques to identify the candidate genes and then the use of transgenic technique to introgress this gene of interest (if found a major gene) in the animals are in waiting.

25.2.3.2 Conservation

The Global Plan of Action for AnGR (FAO 2007b) recognises the significance of CC and the need for conservation programmes and strategies to account both for gradual environmental changes in livestock production systems and the effects of disasters and emergencies. Genetic diversity signifies a unique resource to respond to the present and future needs of livestock production and human needs. Nevertheless, livestock diversity is shrinking rapidly. Among the domesticated populations, it is estimated that one to two breeds are lost every week (Schearf 2003). However, the impact of these losses on the global or the local diversity remains undocumented. According to the State of the World's AnGR, 20 % of all reported breeds are at risk of extinction; however, the population status of many breeds is still unknown, and the problem may thus be underestimated. Most developing countries and some developed countries do not currently have AnGR conservation strategies or policies in place. Without strategically planned interventions, using both in situ and ex situ conservations, erosion will continue and may accelerate (FAO 2007b). There is an urgent need to document the diversity of our livestock genetic resources and to design strategies for their sustainable conservation. Looking at this problem from a bigger perspective, the mission is massive, and it has prompted the Food and Agriculture Organization and other international organisations to develop databases [ILRI Domestic Animal Genetic Information System (DAGRIS) and DAD-IS]. In India, the National Bureau of Animal Genetic Resources (NBAGR) has also developed an information system on AnGR of India (AGRI-IS) to inventorise and monitor trends in breed characteristics and population.

There are several reasons for losses of the genetic diversity of domestic animals; however, CC remains one of the most important criteria. To conserve the available genetic resources is a task ahead so that the resources shall be available for sustainable use and management for the future generations. The Global Plan of Action for AnGR and the Interlaken Declaration (FAO 2007b) have prioritised some points wherein appropriate conservation measures should ensure that farmers and researchers have access to a diverse gene pool for further breeding and research. This genetic diversity provides an essential resource to cope with the impacts of CC, pest and disease outbreaks, and new and growing consumer demands. Strategic and considered investment in the conservation of AnGR is of critical importance, and international collaboration is essential to halt the serious decline of these resources.

In situ conservation programmes are the best options, wherein the resources are available and chances of strengthening the resources are high. Many genetic improvement schemes worldwide also involve in situ conservation as a major objective. In situ measures facilitate continued co-evolution in diverse environments and avoid stagnation of the genetic stock. In situ conservation measures are best based on agroecosystem approaches and ideally should be established through economically viable and socially beneficial sustainable use (FAO 2007b). There are several instances where these programmes need extra input from the agencies that run these programmes. In developing countries like India, mostly these programmes are run by government agencies and thus completely funded. However, here too, for successful accomplishment of these programmes, participatory approach of workers with the real stakeholders is necessary. On farm programmes, active participation of the farmers along with the research workers is mandatory for in situ conservation programmes.

Ex situ conservation basically refers to conservation away from the home tract and production system where the resources are developed. This category involves both maintenance of live animals and cryopreservation. Improvement and natural selection also lead to disturbance of the

Hardy-Weinberg (HW) equilibrium in such populations. Cryopreservation on the other hand is for future use, when probably the breeds shall be extinct, or a specific desired character goes missing. Semen, ova, embryos, tissue, etc. for potential future use are cryopreserved. The Global Plan of Action recognises that global or regional facilities may play a role in ex situ conservation. Many stakeholders express support for the idea of their countries' participation in such endeavours, with regional initiatives being the most popular option (FAO 2010b). Cryopreservation of domestic animal embryos has become an integral part of embryo biotechnology especially programmes related to germplasm conservation (Fahning and Garcia 1992; Dobrinsky 2002). The transfer of germplasm resources as embryos rather than animals on hoofs is economical, warrants less risk of disease transmission and possesses added advantage of allowing exotic stocks to develop in recipients well adapted to local conditions. The prospect that CC will bring more frequent catastrophes and major disruptions to livestock production probably increases the significance of establishing back-up ex situ collections of AnGR and the importance of situating these collections in dispersed locations (Pilling and Hoffman 2011).

25.2.3.2.1 Characterisation

AnGR which are available today are a product of several centuries of evolution and adaptation to the local agro-climatic zones in which they are located. In an event of probable catastrophes or threat of CC, there is a possibility to shift these resources to new locations where safe livelihood is assured along with matching production systems. In such a case, it becomes mandatory to have complete knowledge of the genetic and phenotypic characteristics of the AnGR before taking any major decision with regard to shift in the production system or place or any other factor. Many breeds in the developing and underdeveloped countries are yet to be characterised and posses a worth information with regard to traits of importance. There are several breeds which are important for disease resistance traits, feed efficiency traits, heat tolerance traits, etc., and all these breeds must be characterised for their probable future use.

Assessments of the risk posed to AnGR by climatic and other disasters require knowledge of the geographical distribution of breeds and populations. Prioritisation and planning of conservation programmes and measures to promote sustainable use of AnGR require knowledge of the respective breeds and of their production environments, demographics and geographical distributions (Pilling and Hoffman 2011). Detailed advice on phenotypic and molecular characterisation and on surveying and monitoring of AnGR is provided in the respective draft FAO guidelines (FAO 2010c, d, e). Ideally, such studies and surveys should be part of cohesive national strategies addressing countries' needs for AnGR-related data and information (Pilling and Hoffman 2011). The potential effects of CC should be taken into account in the development of such strategies, both in terms of the information targeted and in terms of the frequency with which monitoring surveys need to be repeated (FAO 2010c). Such strategy shall help for better planning and help for mitigating the challenges that will be posed by CC.

25.2.3.2.2 Funding and Sustainability

The conservation and characterisation programmes are in majority funded by government agencies worldwide. As per Global Plan of Action for AnGR (FAO 2007b), implementation will require substantial and additional financial resources and long-term support for national, regional and international AnGR programmes and priority activities, provided such incentives are consistent with relevant international agreements. The process should encourage and support the participation of governments and all relevant stakeholders. Regional and international collaboration will be crucial.

CC represents an increasing threat to so many planet species – including our own. Science tells us now is the time to act. Targets and promises need to be put into action – before it is too late. WWF-UK has engaged itself in conservation activities especially those related to wildlife and nature. There are many agencies worldwide that are setting an example of this type. Barring these agencies, public funding remains a major source for conservation programmes. Large-scale awareness programmes of civic societies for conservation of livestock are an important prerequisite for success. The public funding can still raise an issue as to why taxpayer's money needs to be spent on animal conservation. Awareness regarding the impact of CC on human life and its association with the livestock has to be studied and advertised to the public in detail through media, discussions, print and several other avenues. The need for conserving the golden gene pool for tomorrow must come within, and for that, awareness is essential. In many countries including India, a very good example of such initiative is the tiger conservation programme. The government has initiated and successfully carried out the awareness among the people regarding the need and utility of conserving the tiger and also other wildlife. This has not only resulted in public funding but also has attracted a lot of private funds too. Conservation of domestic animal biodiversity in an era of CC is a much gigantic task than conserving wildlife. This is so, because the threats are largely unknown and probable impacts cannot even be imagined. A concerted effort to raise the fund like collaboration with other organisations such as multi-government funding, private funding, FAO, World Bank, etc. may be essential.

25.2.3.3 Planning Altered Species and Breed Stratification

To decide whether the breeding programmes will be carried out on the locally available breed or alternate breeds remains the choice of stakeholders and beneficiaries. Looking into the probable effects of CC, it is very much possible that in temperate parts of the world, introduction of new germplasm which can tolerate the effects of CC may be practised. Ideally, decisions as to which breed should be introduced and for what use should be based on an evaluation of the alternative breeds and their crosses in the production environment in which it is planned to be introduced. Although introduction of the new breeds in different production systems is still an option, it must be looked at very cautiously. Traits of interest such as heat tolerance, disease resistance, efficient feed and water consumption and also better production have to be incorporated in an index. The planning with regard to the use of crossbreeding, transgenic approach or just introduction of new breeds as such should also consider the available production system and adaptability of the new germplasm in such environment. Introducing a new breed to a new environment however has a lot of issues surrounding it, but one important thing is to avoid the negative consequences of it. Australia maintains a strict policy on importing alternative breeds of sheep. One policy objective is to protect the quality of its wool clip, where one black fibre per million is sufficient to reduce value considerably. Therefore, the proportion of black fibres in the fleece is a critical attribute of an imported breed. A second policy objective is to keep scrapie (a sheep disease) out of the country. Therefore, no breeds that might introduce the disease are considered for importation (FAO 2010b).

Breed stratification according to the landscape of the production system is also essential. An example of breed stratification for sheep in India based on the user's purpose, interest, availability of the resources and objective of the breeding system has been described by Shinde et al. (2013). The alternate species or breed stratification is a demand-based choice. In general, all species will be adversely affected by global warming and there will be fewer animals per farm as a result. The livestock business that demands more input and amiable environment is likely to be affected first, an example being the beef cattle industry. Sheep and goat are the animals of the future. Throughout the world, they have very high population growth rate in spite of heavy consumption. CC is expected to determine a decrease in beef cattle and an increase in sheep and goats. This change of species from large ruminant to small ruminant is very much possible in India, Africa, Asian countries and also in the Western world, if the situation arises. Smallholder farmers who are able to switch to sheep and goats may not be as vulnerable to higher temperatures as large-scale farmers who cannot make this switch. Farm size can shape the way farmers respond to CC. Smallholder farmers are diversified, relying on dairy cattle, goats, sheep and chickens, while large-scale farmers specialise in dairy and especially beef cattle. As a result of CC, large-scale farmers are likely to shift away from beef cattle and chickens in favour of dairy cattle, sheep and goats. Livestock keeping will be a safety valve for smallholder farmers if warming or drought causes their crops to fail (Seo and Mendelsohn 2006).

25.2.4 Matching AnGR with Production Systems

Matching AnGR with production systems means looking for the optimal breed to satisfy the needs of the production system (FAO 2010b). As it has been discussed earlier, the locally adapted and available breeds throughout the world are the best choice as far as their utility, adaptability and future use are concerned. This is so, because the available production system has forced the livestock resources to mould or modify themselves to existing situations and any deviation from this combination of AnGR and production system does not seem viable. Farmers or the stakeholders who are involved in the animal husbandry practices know well how and why the livestock they keep best suits their need and the need of production system.

A beautiful example in this context is the case of Indian Chilika buffalo (FAO 2010b). Chilika buffaloes are prevalent in the islands and periphery of Chilika Lake on the coast of eastern India (Khurda, Ganjam and Puri districts in the state of Orissa). The animals are well suited to the backwaters of the lake and enter the knee-deep waters to feed on weeds and grasses, generally during the night. During the daytime, they rest on the shore, under the trees. The Chilika buffaloes have an important ecological role – their dung and urine support zooplankton, which support the lake's fish population, which in turn supports livelihoods around the lake. Other breeds are not well adapted to the local production system, and introduced animals have proved unable to meet the multiple roles performed by the Chilika buffaloes. Murrah buffaloes or Murrah-Chilika crosses, for instance, do not survive in this environment, because they are less well adapted to the humid conditions and due to the absence of non-saline drinking water. Now, this must be seen very seriously, as to how the real stakeholders of the AnGR know the importance of the resources, and these criteria must be given due weightage while deciding on the importance of breeds, their conservation programmes and related issues.

Another example of matching production system with AnGR is given here in the context of sheep in the semiarid region of Rajasthan, India. In India, several efforts for introducing the crossbreeds of sheep with exotic inheritance of Rambouillet or Merino ram were made in the semiarid region of Rajasthan. However, the acceptability of the farmers for these crosses was not high in spite of their high production potential. Ultimately the crossbreeds of sheep were finally shifted to the temperate regions. The production system available in the semiarid region of Rajasthan demands exhaustive grazing of the sheep that demands covering distance of 30 miles or so per day in the harsh climate. Such demand can only be met by locally evolved and adapted breed 'Malpura'. Since the last 10 years, rainfall pattern in this area has changed drastically, and it is receiving hardly 400 mm of rainfall per year. This has resulted in the scarcity of resources available in the field due to which farmers have started taking their sheep on migration as an alternative strategy. Migration has become common during drought season (Rathore 2004). Malpura sheep was in between crossed with the Marwari sheep from arid region during migration, which resulted in the production of crossbreeds which are sturdier, have long legs and are best for migration purpose. These sheep are now preferred whenever farmers need to go on migration. Kheri sheep is a product of farmers' own intellect, where need-based intervention yielded the desired results (Gowane and Arora 2010).

FAO (2010b) has published guidelines regarding how to proceed for matching AnGR with production systems that involve the following tasks:

1. Define the overall breeding goal for the production system of interest.
2. Collate available information on experiences in the conduct of breeding programmes.
3. Collate available information on the roles and characteristics of locally available breed(s).
4. Examine possible alternative breeds.
5. Decide whether the breeding programme will be based on locally available or alternative breeds.
6. Conduct a feasibility study for the introduction of alternative breeds and take a decision.
7. Prepare the germplasm introduction plan.
8. Implement the germplasm introduction plan.

These tasks may be of use for planning introduction of new breeds to the different agro-climate or production systems and to assess the impact of such intervention. However, for any step to be executed, the views of local prime stakeholder must be given due importance in decision making.

25.3 Genetic Tools for AnGR to Counteract Climate Change

25.3.1 Genes of Importance to Counteract Climate Change

Selection of animals with improved thermal tolerance is one of the ways to counteract the harsh effect of CC. The primary impact of CC is the rise in ambient temperature. Although several reports are available on the adverse impact of heat stress on livestock production, the reports pertaining to genes involved in heat stress adaptation are very meagre. The following section will provide information on genes involved in thermotolerance in livestock.

25.3.1.1 Heat Shock Factors (HSF)

At cellular level during the onset of increased cell temperature, a transcription factor family known as the HSF has been considered as important first responders (Page et al. 2006). HSFs are known to interact with specific DNA sequence in the promoter HS elements. The HS element is a stretch of DNA located in the promoter region of susceptible genes containing multiple sequential copies (adjacent and inverse) of the consensus pentanucleotide sequence 5′-nGAAn-3′ (Morimoto 1998) mostly found in HSP genes. These transcription factors coordinate the cellular response to thermal stress and affect the expression of a wide variety of genes including HSPs (Akerfelt et al. 2007). A total of four HS factors have been identified so far (Morimoto 1998), out of which three, viz., HSF-1, HSF-2 and HSF-4, are found in mammalian systems and HSF-3 is present in avian systems. In cattle, the HSF-1 gene has been mapped to chromosome 14 (Winter et al. 2007). During HS, HSF-1 is activated by thermal stress and found mainly in the nucleus in trimeric form (Sarge et al. 1993) which binds to the HS elements and is primarily involved in elevated gene expression level of HSPs (Pirkkala et al. 2001).

25.3.1.2 Heat Shock Proteins

Many candidate genes for thermal tolerance have been identified, out of which HSPs are the major responders during thermal stress. HSPs were originally identified as proteins whose expression was markedly increased by HS (Lindquist 1986). HSPs are usually expressed in normal cells too to play important functions in normal cell physiology. Their numbers in cells are increased when an animal is subjected to various stressors such as heat, cold and oxygen deprivation. The HSP40, HSP60, HSP70 and HSP90 families of proteins are the example of the first biochemical activity group. The second biochemical activity is regulation of cellular redox state. HSP32, better known as heme oxygenase-1 (HO-1), is an example of this group (Otterbein and Choi 2000). The third principal biochemical activity of HSPs is the regulation of protein turnover (Parsell and Lindquist 1993). Ubiquitin, which is expressed in unstressed cells, up-regulated by HS, is a classical example of this group.

Patir and Upadhyay (2007) indicated that thermal exposure of Murrah buffaloes caused induction of HSP70 and declined the immune status of buffalo heifers. HSP70.1 and HSP70.3 in mouse (Huang et al. 2001) and HSP72 in human

(Fehrenbach et al. 2001) have been identified as candidate genes for thermal resistance. Gaughan et al. (2009) studied the effect of chronic heat stress on plasma concentration of secreted HSP70 in growing feedlot cattle and found that its concentration is a reliable indicator of chronic stress. Prostaglandin A1 (PGA1) induces HSP synthesis in bovine mammary epithelial cells resulting in protection against cellular stresses (Collier et al. 2007). Zhang et al. (2002) identified polymorphisms of the regulatory and coding regions of the HSP70 gene associated with different heat tolerance capabilities in broiler chickens. A functional promoter and 3′-UTR variants of highly conserved inducible HSP70.2 gene in pigs significantly affected mRNA stability and cell response to stress (Schwerin et al. 2001, 2002).

Sodhi et al. (2013) identified several distinct nucleotide changes in HSP70.1 gene of 14 diversified Indian zebu cattle breeds and six buffalo breeds. They also identified four microsatellite markers within the buffalo HSP70.1 gene and three microsatellites within the bovine HSP70.1 gene that could further be evaluated as molecular markers for thermotolerance. Basiricò et al. (2011) investigated the association between inducible HSP70.1 single nucleotide polymorphisms (SNPs) and HS response of peripheral blood mononuclear cells (PBMC) in dairy cows and suggested mutations in the 5′-UTR region of inducible HSP70.1 may be useful as molecular genetic markers to assist selection for heat tolerance. While analyzing the heat and cold challenge responses in terms of expression of different HSP family genes and HSP70 protein in the PBMC of goat, increased levels of expression of *HSP27* in both heat and cold stress conditions was reported by Mohanarao et al. (2013).

Mehla et al. (2014) through microarray study in four Sahiwal heifers exposed to heat stress demonstrated that gene expression changes through activation of HSF-1 and HSPs. An experiment of both induced in vitro and environmental stress conditions by Deb et al. (2014) indicated that Sahiwal cattle may express higher levels of Hsp90 than Frieswal cattle to regulate their body temperature and increase cell survivality under heat stressed conditions.

25.3.1.3 Halothane Gene in Pigs

Porcine stress syndrome (PSS) gene is associated with a condition called malignant hyperthermia induced by environmental stressors. PSS gene is commonly referred to as halothane (HAL) gene, because this condition can be triggered by exposing pigs to the anaesthetic halothane gas. This is a major gene inherited on single locus with two alternate alleles, dominant (N) and recessive (n). Pigs possessing recessive allele are more sensitive to stress conditions. Homozygous recessive (nn) genotype is associated with production of PSE pork characterised by its pale colour, lack of firmness, dripping of exudates from cut surfaces and denaturation of muscular proteins (Monin et al. 1999). Malignant hyperthermia in nn pigs is a muscular disorder characterised by an abnormal response to stress, exercise and anaesthetics (Klip et al. 1986; Monin et al. 1999). Different HAL genotypes produce different amounts of HSP70, suggesting a role for dominant HAL gene (N) in promoting cell survival in response to stressful conditions (Khazzaka et al. 2006). Successful introgression of halothane normal allele into a Pietrain line that otherwise had a high frequency of the halothane-positive allele is reported (Hanset et al. 1995).

25.3.1.4 Slick Hair Gene in Cattle

The slick hair gene is found in Senepol cattle and Criollo (Spanish origin) breeds in Central and South America. Studies have shown that Senepol cattle and their crosses with Holstein, Charolais and Angus animals are as heat tolerant as Brahman cattle. This has been attributed to the slick hair coat of Senepol cattle, which is thought to be controlled by a single dominant gene and has been mapped on bovine chromosome 20 (Mariasegaram et al. 2007). These breeds have been developed from crossbreeding of N'Dama cattle to include favourable heat stress traits. However, origin of slick hair gene in Senepol remained uncertain. Cattle with slick hair were observed to maintain lower RT. The effect of the *slick hair* gene on RT depended on the degree of heat stress and appeared to be affected by age and/or lactation status. The decreased RT observed for slick-haired crossbred calves compared to normal-haired contemporaries ranged from 0.18 to 0.4 °C (Olson et al. 2003).

25.3.1.5 Nramp1 Gene

Natural resistance-associated macrophage protein 1 (Nramp1) has been identified as a major gene in many species (Vidal et al. 1993) expressed in late endosomes of macrophages. Nramp1 regulates antimicrobial activity of macrophages (Barton et al. 1995). In mouse, a point mutation in the coding region of the gene Nramp1 causes a single amino acid change from Gly to Asp at position 169, and it results in a susceptibility phenotype of mice in the early phases of infection with *S. enterica* serovar *Typhimurium*, *Leishmania donovani* or various species of *Mycobacterium* (Vidal et al. 1995). $(GT)_n$ microsatellite polymorphism at 3′-UTR of Nramp1 has been found to be associated with resistance/susceptibility to *Brucella abortus* (Adams and Templeton 1998; Barthel et al. 2001), salmonella and paratuberculosis (Pinedo et al. 2009) infection in cattle and buffalo (Ganguly et al. 2008). This gene holds promise in disease resistance which may be relevant in changing climatic situations to combat many diseases in the future.

25.3.1.6 Other Genes

Recently, many genes have been reported to be involved in heat stress and affected by HS and interact with HSPs. With the help of gene chip arrays, it has become possible to screen the expression of thousands of sequences simultaneously. Several gene chip array experiments have been performed that specifically examined the role of HS on gene expression. An experiment reported in 1996 (Schena et al. 1996) used an array containing 1,000 genes to examine changes in gene expression in human T cells and demonstrated the feasibility of using this technology to identify new candidate heat-responsive genes. Approximately 50 genes not traditionally considered to be HSPs have been found to undergo changes in expression in response to heat stress (Sonna et al. 2002). There are many genes with known physiological functions which are induced by cold stress. p53 and p21 are the most important genes to play significant role in cell physiology during cold exposure (Matijasevic et al. 1998; Ohnishi et al. 1998). Many genetic factors apart from the slick hair gene have been identified which influence the colour pattern of the cattle and hence may be useful in differential selection and performance under different heat stress conditions. The spotted locus in Hereford cattle and Kit locus on bovine chromosome 6 are few of the examples and have been extensively studied (Fontanesi et al. 2010). A cDNA microarray analysis found 140 transcripts to be upregulated and 77 downregulated in the Sahiwal cattle blood after heat treatment (Mehla et al. 2014).

Several genes have been identified in poultry which play a major role in heat tolerance. Naked neck (Na) a dominant gene responsible for reducing feather cover and sex-linked recessive gene for dwarfism (dw) responsible for reduced body size and thereby reduced metabolic heat output are few of the examples. The frizzle (F) gene is another important gene related to the economic performance of the stock under hot humid conditions.

25.3.1.7 Emerging Technologies Shaping the Future of Livestock Breeding

As we know, a vast natural variation exists in our livestock population that will form the basis for further genetic improvement and selection by including new traits to meet the challenges in the coming decades. Following are new technologies which will be the limelight in the future to accelerate genetic gains in livestock to cope with the threats of CC.

25.3.1.8 Genomic Selection

Genomic selection (GS) is a marker-assisted selection (MAS) method, in which high density-markers covering the whole genome are used simultaneously for individual genetic evaluation via genomic estimated breeding values (GEBVs). GS is based upon linkage disequilibrium between the markers and the polymorphisms present in various traits of importance (Meuwissen et al. 2001). Hayes et al. (2013) described the method of exercising GS. The equation that predicts breeding value from SNP genotypes must be estimated from a sample of animals, known as the reference population, that have been measured for the traits and genotyped for the SNPs. This prediction equation can then be used to predict breeding values for selection candidates based on their genotypes alone. The candidates are ranked on these estimated breeding values, and the best ones are selected to breed the next generation.

GS is advantageous over selection based on phenotype because meritorious animals in GS can be identified early with genomic prediction. There are many traits which are difficult or expensive to measure like GHG emissions, feed efficiency, disease inheritance, reproductive traits like fertility, etc. Large dairy ruminants are traditionally selected on the basis of progeny testing as merit of breeding bulls is evaluated on the milk production of his daughters. An advantage of GS is that generation interval can be reduced to 2 years and also result to almost double the rate of genetic gain (Pryce and Daetwyler 2011). Due to the above reasons, GS has got wide and rapid acceptance among dairy industries in all over the world. However, GS in beef cattle is adopted at lower pace due to reasons that reference population in beef cattle is smaller than dairy cattle. In addition, as compared to few dairy breed, there are several beef breeds of importance around the world. Requirement of sufficient reference population to achieve expected accuracy of genomic breeding value in beef cattle is challenging; therefore, international collaborations are required to pool reference population across countries (Hayes et al. 2013). However, accuracy is compromised in this case due to differences in linkage disequilibrium phases between SNPs and causative mutations across breeds (Daetwyler et al. 2012a).

GS is also being practised in meat, wool and dairy sheep (Duchemin et al. 2012). Daetwyler et al. (2011) utilised available 50,000 ovine SNPs to predict estimated breeding values for wool and meat traits in sheep. The effects of all SNP markers in a multi-breed sheep reference population of 7,180 individuals with phenotypic records were estimated to derive prediction equations for GEBVs for greasy fleece weight, fibre diameter, staple strength, breech wrinkle score, weight at ultrasound scanning, scanned eye muscle depth and scanned fat depth. Breeding value of 540 industry sires was used as a validation population and the accuracies of GEBVs were assessed according to correlations between GEBVs and sheep breeding values. Results showed that accuracy of GEBVs will increase with the increase in size of reference population.

In meat sheep, genomic predictions have been made for health attributes in lambs; Daetwyler et al. (2012b) predicted carcass and novel meat quality traits in a multi-breed sheep population that included Merino, Border Leicester, Polled Dorset and White Suffolk sheep and their crosses. Further, there are already some promising estimates of the accuracy of genomic predictions for feed conversion efficiency in chickens, dairy cattle and pigs. Pryce et al. (2012) postulated a term residual feed intake (RFI) which is the difference between actual and predicted FI that may be a useful selection criterion for greater feed efficiency. A group of DNA markers explaining genetic variation in RFI would enable cost-effective GS. In their study, eight SNPs with large effects on RFI were located on chromosome 14 at around 35.7 Mb, and these may be associated with the gene NCOA2, which is known for controlling energy metabolism. Genomic prediction of female fertility with high accuracy is also available to be used for GS (Wiggans et al. 2011). Improvement in FI and feed efficiency of livestock is strongly associated with methane emission levels. It is suggested that genomic predictions of FI may be used as indirect GS for low methane emission (Haas et al. 2012). FI plays an important economic role in beef cattle and is related with feed efficiency, weight gain and carcass traits. The genome-wide association study (GWAS) for dry matter intake (DMI) and RFI of Nellore cattle was studied in which three SNPs surpassed the threshold of Bonferroni multiple tests for DMI and two SNPs for RFI. These markers are located on chromosomes 4, 8, 14 and 21 in regions near genes regulating appetite and ion transport and close to important QTL as previously reported to RFI and DMI, indicating that two processes are important in the physiological regulation of intake and feed efficiency (Santana et al. 2014).

GS can also be exercised to improve performance of animals in heat stress conditions. To select cattle adapted to changing environments, Hayes et al. (2009) conducted a GWAS to detect SNPs associated with the sensitivity of milk production to environmental conditions and validated many markers located on chromosomes 9 and 23, associated with sensitivity of milk production to feeding level and sensitivity of milk production to temperature humidity index (THI). There is a need to identify signatures of selection related to heat stress and individual genes associated with mechanisms to fight climate challenges by the use of genomics (Rothschild and Plastow 2014). Many genes in the insulin pathway have been identified and associated with the capacity of camel to go long periods of time without water in hot dry environments (Jirimutu et al. 2012). Huson et al. (2013) and Elbeltagy et al. (2014) examined many possible signatures of climatic stress in sheep and goats. Similar study to examine stressed chickens has revealed many significant genomic differences by Lamont et al. (2013) which could be possible genomic markers to select avian in the future. Similarly, a novel SNP in the ATP1A1 gene has also been associated with heat tolerance traits in dairy cows (Liu et al. 2010).

There are some diseases which are present in wild counterparts of domesticated animals without any serious effect, but have deleterious effect in domesticated livestock species. African swine fever is one of the examples which is present in warthogs without any serious consequences but is deadly in domesticated pigs. Comparison of genomic sequences of indigenous pigs to that of domesticated pigs to determine regions of susceptibility/resistance will lead to open a new approach to GS (Mujibi et al. 2014). Such efforts also may provide targets for genome editing or other modifications to create resistant or more tolerant animals that could be utilised in these environments.

Assembling large number of reference populations will be the major challenge in implication of GS in the coming future. In this process, very large number of phenotyped individuals will be required to make accurate predictions. International collaborations to increase the size of reference populations and to find the economical ways for genomic screening will decide the future of GS.

25.3.1.9 Significant Quantitative Trait Loci of Climate Change Adaptation in Livestock

A quantitative trait locus (QTL) is a genomic region that is associated with or modulates the variation in a measurable phenotype (Williams et al. 1998). In particular, certain QTLs may account for a comparatively large portion of the variance in different complex traits, which could be analysed by studying the pattern when separating alleles are derived from opposing spectrums at a major QTL (Williams et al. 1998). The identification of specific genomic regions that affect economically important traits in farm animals holds great interest for the livestock industry as it aims at incorporating genomic markers linked to QTL into breeding programmes, by making use of MAS (Anderson 2001). In the search of QTL and major genes, different approaches have been investigated including genome-wide scans using relatively high density panels of microsatellites or SNP markers across the genome together with genome-wide association studies or candidate gene approaches (Ron and Weller 2007; Hayes and Goddard 2010). Liu et al. (2010) studied the polymorphism of ATP1A1 gene of Holstein cows and identified two SNPs out of which AC genotype was associated with heat tolerance and has a potential as genetic marker in future breeding to combat with CC. Dikmen et al. (2013) performed a GWAS for RT during heat stress in Holstein cow and identified SNPs. The largest proportion of SNP variance (0.07–0.44 %) was explained by markers flanking the region between 28,877,547 and 28,907,154 bp on *Bos taurus* autosome (BTA) 24. These SNPs could prove useful in genetic selection and for identification of genes involved in physiological responses to heat stress. Significant QTLs have been identified on chromosome 5 related to stress and anxiety (Tarricone et al. 1995; Roberts et al. 1995; Dai et al. 2009). Thermal stress on bovine mammary development by microarray technique has been evaluated

(Collier et al. 2006). Study revealed an overall upregulation of genes associated with the stress response and protein repair. Four QTLs in pig have been identified with significant effect (Lilja et al. 2000). They are present on chromosomes 2, 6, 8 and 12 and are responsible for induction of IL-2 activity, phagocytic capacity and mitogen induced proliferation. Two significant and two suggestive Marek's disease QTLs were detected in four chromosomal regions, explaining 11–23 % of the phenotypic and 32–68 % of the genetic variation in Marek's disease in poultry (Vallejo et al. 1998). QTLs associated with resistance to avian coccidiosis to GGA1 were mapped by using 119 microsatellite markers (Zhu et al. 2003).

Genetic variation associated with nematodes resistance has been utilised by implementation of marker-assisted breeding value estimation (MA-BVE) using dense maps covering the entire genome (Meuwissen et al. 2001). The interest in the MA-BVE approach is solely in the breeding value of the candidates with the objective to estimate the breeding value with the highest possible accuracy using all phenotypic and genomic information.

25.4 Conclusion

CC adds another layer of uncertainty to the ever-evolving and dynamic livestock sector. Although AnGR and the goods and services rendered by it are affected by direct and indirect effects of CC, it has largely not been integrated in their actual context because of highly concentric focus on present human needs ignoring environmental costs. The lion share of the veritable goldmine of AnGR in the form of many different livestock species and breeds is concentrated in developing and least developed countries, most of which are with the smallholder and pastoralist. It is them who will be most affected by CC.

Undoubtedly resource efficient livestock production will be key to secure the future. Industrial and commercial production will be better able to handle the direct effects of CC through their access to technologies and manipulation of micro-environments. But smallholder and pastoralist livestock production system will face significant challenges in addressing it. In the absence of appropriate, accessible and affordable technologies to counteract CC-induced challenges, the diversity of the production system, AnGR and breed portfolio is likely to be restricted. Further, the inherent structural variability in livestock production along with its differential ability to absorb changes may not allow assimilation of resource-use efficiency at every stratum. This may result in the growing dichotomy between industrial and smallholder livestock production.

In all probability, resource-use efficiency will be measured increasingly through feed conversion efficiency of livestock in immediate and medium terms. This will see altered preference for livestock species as well as breeds. The species and breed portfolio in CC scenario will vary locally as well as regionally. Superior FCR of monogastrics will put them in comparative advantage over cereal-fed ruminants (Hoffmann 2010). However, ruminants may increase in rangelands with sufficient vegetation growth (Seo and Mendelsohn 2008). On the other hand, small ruminants are likely preferred in extensive systems of production (Herrero et al. 2008; Seo and Mendelsohn 2008). The typical outlook of FCR may not help in traditional livestock production; instead, 'human edible return' as suggested by Gill and Smith (2008) may be a better indicator for assessing efficiency. Fertility and longevity of livestock will be more important in the future, and more selection pressure on them along with FCR will be expected. However, key to the climate-resilient livestock production will be the adaptability of the animals to their production environments. This will require careful trade-off between production, productivity and adaptability since they are not favourably related. Although adaptive traits are characterised by low heritability like fertility, significant prominence of fitness traits is expected. This will entail overcoming problems associated with measuring the phenotypes relevant to adaptation and better understanding of its physiology and genetics.

Breeds of livestock species that dominate industrial production have been developed through highly structured breeding programmes and intensive selection for years. Narrow pool of these highly developed animal genetics will continue to catalyse global trade of animal products. As against this, local breeds that predominate traditional livestock production have largely not been placed under any structured breeding and genetic improvement programmes although they have been subjected to differential selection pressures in the form of their ability to survive in harsh production environments and low input. If the common trend of purchasing genetic gain for quick results, through import of *superior* livestock genetics, continues in developing countries instead of developing their own production environment-specific livestock breeds, it will see raising stocks largely not in sync with production environments, thus increasing vulnerability and further marginalization of local and adapted breeds. Of course recent trends of increasing focus on local superior livestock germplasm and its promotion as an alternative to import of *superior* genetics and mutual share may not go unnoticed in many developing countries like India.

Understanding the dynamics of CC and animal production in the *most* comprehensive manner and appropriate modelling to counteract or absorb it shall be the most important step towards ensuring prioritisation of research and developmental goals which shall also help create awareness among all stakeholders including policy planners. Central to the development of climate-resilient animals are characterisation of the AnGR in a broad-based manner and its valuation in the context of its environmental niche and scientific understanding of adaptability. Most tropically adapted breeds that reside in developing countries are largely under-characterised. It shall be an important priority.

Breeding strategies for livestock genetic resources to counter CC impact will not be fundamentally different than what is practised today. Between the choice of matching genetics with environment and vice versa, the norm and practice shall be system specific. Natural stratification of species and breeds of livestock shall be an important guide in the design. Efficient livestock production ensuring diversity of gene pool, fitness for the production environments and optimum fertility that shall also meet sociocultural needs and have low environmental footprint shall be the desirable shape for sustainability. A healthy combination of higher production and productivity with heat resilience, fertility, disease tolerance and challenged nutrition will require flexibility of breeding indices. Irrespective of the scale, GEI may not be ignored.

Large-scale transboundary movement of superior animal genetics and specially considering its relative ease may not match well when cooperation and share of knowledge, expertise and resources are considered with respect to broad-based use of AnGR. A positive change in this regard is desired. Promotion of breed societies will be indispensible, and performance recording of livestock of smallholder production system will be increasingly important for the improvement of AnGR in the CC era.

Although livestock is an important pillar for livelihood, nutritional security and poverty alleviation in most of the developing and poor countries, enabling policies and long-term commitment for its sustainable growth have mostly been missing. Continuation of treating this as an allied sector of agriculture in many parts of the developing world undermining its significant contribution to agricultural GDP and the potential it holds has restricted its growth path and will not help in the long run. A sound policy framework for animal breeding, commitment for long-term investment and close cooperation between stakeholders and partners regionally, nationally and internationally are the need of the hour to ensure that livestock continues to progressively provide diverse goods and services even in the face of looming uncertainties posed by CC.

Acknowledgements The authors are thankful to the Research Fellows Dr. Tukheswar Chutia and Mr. Yoya Vashi for their valuable help in preparing this manuscript.

References

Adams LG, Templeton JW (1998) Genetic resistance to bacterial diseases of animals. Rev Sci Tech Off Int Epiz 17:200–219

Akerfelt MD, Trouillet V, Mezger SL (2007) Heat shock factors at a crossroad between stress and development. Ann N Y Acad Sci 1391:1–13

Albers GA, Gray GD, Piper LR, Barker JS, Le Jambre LF, Barger IA (1987) The genetics resistance and resilience to *Haemonchus contortus* infection in young Merino sheep. Int J Parasitol 17:1355–1363

Ames DR, Ray DE (1983) Environmental manipulation to improve animal productivity. J Anim Sci 57:209–220

Anderson L (2001) Genetic dissection of phenotypic diversity in farm animals. Nat Rev Genet 2:130–138

Barthel R, Feng J, Piedrahita JA, McMurray DN, Templeton JW, Adams LG (2001) Stable transfection of the Bovine NRAMP1 gene into murine RAW264.7 cells: effect on Brucella abortus survival. Infect Immun 69(5):3110–3119

Barton CH, Whitehead SH, Blackwell JM (1995) Nramp transfection transfers Ity/Lsh/Bcg-related pleiotropic effects on macrophage activation: influence on oxidative burst and nitric oxide pathways. Mol Med 1:267–279

Basiricò L, Morera P, Primi V, Lacetera N, Nardone A, Bernabucci U (2011) Cellular thermotolerance is associated with heat shock protein 70.1 genetic polymorphisms in Holstein lactating cows. Cell Stress Chaperones 16(4):441–448

Blench R (1999) Traditional livestock breeds: geographical distribution and dynamics in relation to the ecology of West Africa, ODI working paper 122. Overseas Development Institute, London

Burns BM, Reid DJ, Taylor JF (1997) An evaluation of growth and adaptive traits of different cattle genotypes in a subtropical environment. Aust J Exp Agric 37:399–405

Charoensook R, Gatphayak K, Sharifi AR, Chaisongkram C, Brenig B, Knorr C (2012) Polymorphisms in the bovine HSP90AB1 gene are associated with heat tolerance in Thai indigenous cattle. Trop Anim Health Prod 44(4):921–928

Christensen L, Coughenour MB, Ellis JE, Chen ZZ (2004) Vulnerability of the Asian typical steppe to grazing and CC. Clim Change 63:351–368

Collier RJ, Stiening CM, Pollard BC, VanBaal MJ, Baumgard LH, Gentry PC, Coussens PM (2006) Use of gene expression microarrays for evaluating environmental stress tolerance at the cellular level in cattle. J Anim Sci 84(l):E1–E13

Collier JL, Abdallah MB, Hernandez LL, Norgaard JV, Collier RJ (2007) Prostaglandins A1 and E1 alter heat shock protein 70 (HSP–70) gene expression in bovine mammary epithelial cells. J Dairy Sci 90(1):62

Daetwyler HD, Hickey JM, Henshall JM, Dominik S, Gredler B, van der Werf JHJ, Hayes BJ (2011) Accuracy of estimated genomic breeding values for wool and meat traits in a multi-breed sheep population. Anim Prod Sci 50:1004–1010

Daetwyler HD, Kemper KE, van der Werf JHJ, Hayes BJ (2012a) Components of the accuracy of genomic prediction in a multi-breed sheep population. J Anim Sci 90:3375–3384

Daetwyler HD, Swan AA, vander Werf JHJ, Hayes BJ (2012b) The accuracy from cross-validation of pedigree and genomic predictions of carcass and novel meat quality traits in multi-breed sheep data. Genet Sel Evol 44:33

Dai J, Wang X, Chen Y, Wang X, Zhu J, Lu L (2009) Expression quantitative trait loci and genetic regulatory network analysis reveals that *Gabra2* is involved in stress responses in the mouse. Stress 12(6):499–506

Davies G, Genini S, Bishop SC, Guiffra E (2009) An assessment of opportunities to dissect host genetic variation in resistance to infectious diseases in livestock. Animal 03(03):415–436

de Greef J (2009) Actual standing and perspectives for the sustainable use and development of parasite resistant or tolerant breeds in developed regions: Australia and NZ as an example. In: Presentation, joint FAO/INRA workshop on animal genetic resources and their resistance/tolerance to diseases, with special focus on parasitic diseases in ruminants, Paris

de La Rocque S, Hendrickx G, Morand S (eds) (2008) CC: impact on the epidemiology and control of animal diseases. Rev Sci Tech Off Int Epiz 27:614

Deb R, Sajjanar B, Singh U, Kumar S, Singh R, Gengar G, Sharma A (2014) Effect of heat stress on the expression profile of Hsp90 among Sahiwal (Bos indicus) and Frieswal (Bos indicus × Bos taurus) breed of cattle: a comparative study. Gene 536:435–440

Dikmen S, Cole JB, Null DJ, Hansen PJ (2013) Genome-wide association mapping for identification of quantitative trait loci for rectal temperature during heat stress in Holstein cattle. PloS ONE 8(7):e69202

Dobrinsky JR (2002) Advancements in cryopreservation of domestic animals embryos. Theriogenology 57:285–302

Dobzhansky T (1956) What is an adaptive trait? Am Nat 90(855):337–347

Duchemin SI, Colombani C, Legarra A, Baloche G, Larroque H, Astruc JM, Barillet F (2012) Genomic selection in the French Lacaune dairy sheep breed. J Dairy Sci 95:2723–2733

Elbeltagy AR, Kim ES, Aboul-Naga AM, Rischkowsky B, Rothschild MF (2014) Heat stress in desert sheep and goats: signatures of natural selection and initiation of GWAS. Plant and Animal Genome XXII. San Diego, California, Abstract W431

Fahning MI, Garcia MA (1992) Status of cryopreservation of embryos of domestic animals. Cryobiology 29(1):1–18

FAO (2003) Chapter 1: Introduction and overview. In: Bruinsma J (ed) World agriculture: towards 2015/2030 – an FAO perspective. Earthscan, London, p 432

FAO (2006a) Chapter 3: Livestock's role in climate change and air pollution. In: Steinfeld H, Gerber P, Wassenaar T, Castel V, Rosales M, de Haan C (eds) Livestock's long shadow – environmental issues and options. FAO, Rome, p 390

FAO (2006b) Environmental effects on animal genetic resources. In: Anderson S (ed) CGRFA background study paper no. 28. FAO, Rome, p 20

FAO (2007a) Section E animal genetic resources and resistance to disease. In: Rischkowsky B, Pilling D (eds) The state of the world's animal genetic resources for food and agriculture. FAO, Rome, p 511

FAO (2007b) Global plan of action for animal genetic resources and the interlaken declaration. FAO, Rome

FAO (2009) Status and trends report on animal genetic resources – 2008. CGRFA/WG-AnGR-5/09/Inf. 7. FAO, Rome

FAO (2010a) The state of food and agriculture 2009: livestock in the balance. FAO, Rome

FAO (2010b) Current arrangements for existing national and multi-country storage systems for the conservation of animal genetic resources. CGRFA/WG-AnGR-6/10/Inf.4. FAO, Rome

FAO (2010c) Draft guidelines on phenotypic characterization. CGRFA/WG-AnGR-6/10/Inf.6. FAO, Rome

FAO (2010d) Draft guidelines on molecular genetic characterization. CGRFA/WG-AnGR-6/10/Inf.7. FAO, Rome

FAO (2010e) Draft guidelines for surveying and monitoring of animal genetic resources. CGRFA/WG-AnGR-6/10/Inf.5. FAO, Rome

Fehrenbach E, Niess AM, Veith R, Dickhuth HH, Northoff H (2001) Changes of HSP-72 expression in leukocytes are associated with adaptation to exercise under conditions of high environmental temperature. J Leuckoc Biol 69:747–754. FAO, Rome

Flachowsky G, Brade W (2007) Potentials of reduction of methane emissions in ruminants (in German). Züchtungskunde 79:417–465

Foden W, Mace G, Vié J-C, Angulo A, Butchart S, DeVantier L, Dublin H, Gutsche A, Stuart S, Turak E (2008) Species susceptibility to CC impacts. In: Vié J-C, Hilton-Taylor C, Stuart SN (eds) Wildlife in a changing, The 2008 review of the IUCN red list of threatened species. International Union for Conservation of Nature, Gland

Fontanesi L, Tazzoli M, Russo V, Beever J (2010) Genetic heterogeneity at the bovine KIT gene in cattle breeds carrying different putative alleles at the spotting locus. Anim Genet 41(3):295–303

Frisch JE (1972) Comparative drought resistance of bos indicus and bos taurus cattle in Central Queensland. 1. Relative weights and weight changes of maiden heifers. Aust J Exp Agric Anim Husb 12(56):231–233

Ganguly I, Sharma A, Singh R, Deb SM, Singh DK, Mitra A (2008) Association of microsatellite (GT)n polymorphism at 3′ UTR of NRAMP1 with the macrophage function following challenge with Brucella LPS in buffalo (*Bubalus bubalis*). Vet Microbiol 129:188–196

Gaughan JB, Bonner SL, Loxton I, Mader TL (2009) Effects of chronic heat stress on plasma concentration of secreted heat shock protein 70 in growing feedlot cattle. J Anim Sci 91:120–129

Gerber P, Vellinga T (2009) GHG emissions from animal food chains. Development of a quantification model using life cycle analysis approach. IDS, Berlin

Gill M, Smith P (2008) Mitigating CC: the role of livestock in agriculture. In: Rowlinson P, Steele M, Nefzaoui A (eds) Livestock and global CC 2008, Proceedings international conference. Cambridge University Press, Cambridge, pp 29–30

Gollin D, Van Dusen E, Blackburn H (2008) Animal genetic resource trade flows: economic assessment. Livest Sci 120:248–255

Gorman GM, Park SDE, Hill WE, Meade KG, Coussens PM, Agaba M, Naessens J, Kemp SJ, MacHugh DE (2009) Transcriptional profiling of cattle infected with Trypanosoma congolense highlights gene expression signatures underlying trypanotolerance and trypanosusceptibility. BMC Genomics 10:207. doi:10.1186/1471-2164-10-207

Gouro A, Hamadou S, Soara A, Guerrini L (2008) CC in West Africa: impact on livestock and strategies of adaptation. In: Rowlinson P, Steele M, Nefzaoui A (eds) Proceedings of the international conference livestock and global CC, 17–20 May 2008. BSAS, Hammamet, Tunisia, pp 68–70. Available at www.mashreqmaghreb.org/documents/LGCC_proceedings.pdf

Gowane GR, Arora AL (2010) Performance evaluation of sheep in farmers' flock of eastern semi-arid region of Rajasthan. Indian J Small Rumin 16(1):87–91

Gowane GR, Chopra A, Prince LLL, Paswan C, Arora AL (2010) Estimates of (co)variance components and genetic parameters for body weights and first greasy fleece weight in Bharat merino sheep. Animal 4:425–431

Hall SJG (2004) Livestock biodiversity. Genetic resources for the farming of the future. Blackwell, Oxford, p 264

Hanset R, Dasnoi C, Scalais S, Michaux C, Grobet L (1995) Effets de l'introgression dons le genome Pie´train de l'allele normal aux locus de sensibilite´ a l'halothane. Genet Sel Evol 27:77–88

Hass YD, Calus MPL, Veerkamp RF, Wall E, Coffey MP, Daetwyler HD, Hayes BJ, Pryce JE (2012) Improved accuracy of genomic prediction for dry matter intake of dairy cattle from combined European and Australian data sets. J Dairy Sci 95:6103–6112

Hayes B, Goddard ME (2010) Genome-wide association and genomic selection in animal breeding. Genome 53:876–883

Hayes BJ, Bowman PJ, Chamberlain AJ, Savin K, van Tassell CP, Sonstegard TS, Goddard ME (2009) A validated genome wide association study to breed cattle adapted to an environment altered by CC. PloS ONE 4(8):e6676. doi:10.1371/journal.pone.0006676

Hayes BJ, Lewin HA, Goddard ME (2013) The future of livestock breeding: genomic selection for efficiency, reduced emissions intensity, and adaptation. Trends Genet 29(4):206–214

Herrero M, Thornton PK, Kruska R, Reid RS (2008) Systems dynamics and the spatial distribution of methane emissions from African domestic ruminants to 2030. Agric Ecosyst Environ 126:122–137

Hill WG, Zhang X-S (2009) Maintaining genetic variation in fitness. In: van der Werf J, Graser H-U, Frankham R, Gondro C (eds) Adaptation and fitness in animal populations: evolutionary and breeding perspectives on genetic resource management. Springer, New York, pp 59–82

Hoberg EP, Polley L, Jenkins EJ, Kutz SJ (2008) Pathogens of domestic and free-ranging ungulates: global CC in temperate to boreal latitudes across North America. Rev Sci Tech Off Int Epiz 27(2):511–528

Hoffmann I (2010) CC and the characterization, breeding and conservation of animal genetic resources. Anim Genet 41(1):32–46

Holechek JL (2009) Range livestock production, food, and the future: a perspective. Rangelands 31(6):20–25

Huang L, Mivechi NF, Moskophidis D (2001) Insights into regulation and function of the major stress-induced hsp70 molecular chaperone in vivo: analysis of mice with targeted gene disruption of the hsp70.1 or hsp 70.3 gene. Mol Cell Biol 21:8575–8591

Huson HJ, Sonstegard T, Silverstein J, Sayre B, Woodward-Greene J, Rothschild MF, Nene V, Nagwala FDM, Kemp S, Masiga CW, Garcia JF, Soelkner J, Tassell CV (2013) African goat improvement project: a feed the future initiative harnessing genetic diversity for conservation, disease resistance, and improved productivity. Plant and Animal Genome XXI, San Diego, California, Abstract W416

ICAR/FAO (2000) Case study about the N'Dama breeding programme at the International Trypanotolerance Centre (ITC) in the Gambia, by Dempfle L, Jaitner J. In: Galal S, Boyazoglu J, Hammond K (eds) Developing breeding strategies for lower input animal production environments. Proceedings of a workshop held in Bella, Italy, 22–25 September 1999. ICAR technical series, no. 3. International Committee for Animal Recording, Rome, pp 347–354. Available at http://lprdad.fao.org/cgi-bin/getblob.cgi?sid=-1,50006096

IFAD (2013a) IFAD: a key player in adaptation to CC. Available at www.ifad.org/operations/gef/climate/ifad_adaption.pdf

IFAD (2013b) IFAD: livestock and CC at http://www.ifad.org/lrkm/factsheet/cc.pdf

IPCC (2007) CC 2007: synthesis report. In: Core Writing Team, Pachauri RK, Reisinger A (eds) Contribution of Working Groups I, II and III to the fourth assessment report of the Intergovernmental Panel on CC. IPCC, Geneva, p 104. Available at http://www.ipcc.ch/

Jirimutu et al. (2012) Genome sequences of wild and domestic bactrian camels. Nat Commun 3:1202

Jones PG, Thornton PK (2009) Croppers to livestock keepers: livelihood transitions to 2050 in Africa due to CC. Environ Sci Policy 12:427–437

Khazzaka A, Figwer P, Poirel MT, Serrar M, Franck M (2006) Hsp70 response in pigs is affected by their Halothane genotypes after heat stress. J Therm Biol 31:605–610

King JM (1983) Livestock water needs in pastoral Africa in relation to climate and forage, ILCA research report no. 7. International Livestock Centre for Africa, Addis Ababa

Klip A, Britt BA, Elliott ME, Walker D, Ramlal T, Pegg W (1986) Changes in cytoplasmic free calcium caused by halothane. Role of the plasma membrane and intracellular Ca2+ stores. Biochem Cell Biol 64(11):1181–1189

Krätli S (2007) Cows who choose domestication. Generation and management of domestic animal diversity by WoDaaBe pastoralists (Niger). Institute of Development Studies, Sussex

Lamont SJ, Kaiser M, Bjorkquist A, Fleming D, Rothschild MF, Persia ME, Ashwell C, Schmidt CJ (2013) Effects of thermal conditioning of embryos and heat stress of chicks on physiological responses of diverse chicken genetic lines. Plant and Animal Genome XXI, January 2013, San Diego, CA. Abstract W620

Lilja IE, Wattrang E, Andersson L, Fossum C (2000) Mapping QTL for stress induced alteration in porcine leukocyte number and functions. Anim Genet 31:186–193

Lindquist S (1986) The heat-shock response. Annu Rev Biochem 55:1151–1191

Liu YX, Zhou X, Li DQ, Cui QW, Wang GL (2010) Association of ATP1A1 gene polymorphism with heat tolerance traits in dairy cattle. Genet Mol Res 9(2):891–896

Mader TL, Frank KL, Harrington JA Jr, Hahn GL, Nienbar JA (2009) Potential CC effects on warm-season livestock production in the Great Plains. Clim Change 97:529–541

Mariasegaram M, Chase CC, Chaparro JX, Olson TA, Brenneman RA, Niedz RP (2007) The slick hair coat locus maps to chromosome 20 in Senepol-derived cattle. Anim Genet 38(1):54–59

Matijasevic Z, Snyder JE, Ludlum DB (1998) Hypothermia causes a reversible, p53-mediated cell cycle arrest in cultured fibroblasts. Oncol Res 10:605–610

McManus C, Prescott E, Paludo GR, Bianchini E, Louvandini H, Mariante AS (2008) Heat tolerance in naturalized Brazilian cattle breeds. Livest Sci 120:256–264

Mehla K, Magotra A, Choudhary J, Singh AK, Mohanty AK, Upadhyay RC, Srinivasan S, Gupta P, Choudhary N, Antony B, Khan F (2014) Genome-wide analysis of the heat stress response in Zebu (Sahiwal) cattle. Gene 553:505–507

Meuwissen TH, Hayes BJ, Goddard ME (2001) Prediction of total genetic value using genome-wide dense marker maps. Genetics 157:1819–1829

Mishra AK, Arora AL, Kumar S, Kumar S, Singh VK (2007) Improving productivity of Malpura breed by crossbreeding with prolific Garole sheep in India. Small Rumin Res 70:159–164

Mohanarao GJ, Mukherjee A, Banerjee D, Gohain M, Dass G, Brahma B, Datta TK, Upadhyaya RC, Deb S (2013) HSP70 family genes and HSP27 expression in response to heat and cold stress in vitro in peripheral blood mononuclear cells of goat (Capra hircus). Small Rumin Res 116:94–99

Monin G, Larzul C, Le Roy P, Culioli J, Mourot J, Rousset-Akrim S, Talmant A, Touraille C, Sellier P (1999) Effects of the halothane genotype and slaughter weight on texture of pork. J Anim Sci 77:408–415

Morgan JA, Milchunas DG, LeCain DR, West M, Mosier AR (2007) Carbon dioxide enrichment alters plant community structure and accelerates shrub growth in the shortgrass steppe. Proc Natl Acad Sci U S A 104:14724–14729

Morimoto RI (1998) Regulation of the heat shock transcriptional response: cross talk between a family of heat shock factors, molecular chaperones, and negative regulators. Genes Dev 12:3788–3796

Mujibi FD, Bishop ER, Fevre E, Thomas L, Plastow G, Rothschild MF (2014) Signatures of adaptive selection in indigenous pigs: implications for African swine fever (ASF). Plant Anim Genome XXII:605

Naskar S, Gowane GR, Chopra A, Paswan C, Prince LLL (2012) Genetic adaptability of livestock to environmental stresses. In: Lal R, Sejian V, Naqvi SMK, Ezeji T, Lakritz J (eds) Environmental stress and amelioration in livestock production. Springer, Berlin/Heidelberg, pp 317–378

Ohnishi T, Wang X, Ohnishi K, Takahashi A (1998) p53- dependent induction of WAF1 by cold shock in human glioblastoma cells. Oncogene 16:1507–1511

Olson TA, Lucena C, Chase CC Jr, Hammond AC (2003) Evidence of a major gene influencing hair length and heat tolerance in *Bos taurus* cattle. J Anim Sci 81:80–90

Otterbein LE, Choi AM (2000) Heme oxygenase: colors of defense against cellular stress. Am J Physiol Lung Cell Mol Physiol 279:L1029–L1037

Page TJ, Sikder S, Yang L, Pluta L, Wolfinger RD, Kodadek T, Thomas RS (2006) Genome-wide analysis of human HSF1 signaling reveals a transcriptional program linked to cellular adaptation and survival. Mol Biosyst 2:627–639

Parsell DA, Lindquist S (1993) The function of heat-shock proteins in stress tolerance: degradation and reactivation of damaged proteins. Annu Rev Genet 27:437–496

Patir H, Upadhyay RC (2007) Interrelationship between heat shock protein 70 (HSP70) and lymphocyte proliferation in thermal exposed buffalo heifers. Ital J Anim Sci 6(2):1344–1346

Perry BD, Randolph TF, McDermott JJ, Sones KR, Thornton PK (2002) Investing in animal health research to alleviate poverty. International Livestock Research Institute (ILRI), Nairobi, p 148

Pilling D, Hoffmann I (2011) CC and animal genetic resources for food and agriculture – state of knowledge, risks and opportunities. FAO CGRFA background study paper no. 53. Available at http://www.fao.org/docrep/meeting/022/mb386e.pdf

Pinedo PJ, Buergelt CD, Donovan GA, Melendez P, Morel L, Wu R, Langaee TY, Rae DO (2009) Candidate gene polymorphisms (BoIFNG, TLR4, SLC11A1) as risk factors for paratuberculosis infection in cattle. Prev Vet Med 91:189–196

Pirkkala L, Nykänen P, Sistonen L (2001) Roles of the heat shock transcription factors in regulation of the heat shock response and beyond. FASEB J 15:1118–1131

Prayaga KC, Barendse W, Burrow HM (2006) Genetics of tropical adaptation. 8th world congress on genetics applied to livestock production, 13–18 August 2006, Belo Horizonte, Brazil

Pryce JE, Daetwyler HD (2011) Designing dairy cattle breeding schemes under genomic selection: a review of international research. Anim Prod Sci 52:107–114

Pryce JE, Arias J, Bowman PJ, Davis SR, Macdonald KA, Waghorn GC, Wales WJ, Williams YJ, Spelman RJ, Hayes BJ (2012) Accuracy of genomic predictions of residual feed intake and 250-day body weight in growing heifers using 625,000 single nucleotide polymorphism markers. J Dairy Sci 95:2108–2119

Rathore JS (2004) Drought and household coping strategies: a case of Rajasthan. Indian J Agric Econ 59:689–708

Roberts AJ, Finn DA, Phillips TJ, Belknap JK, Keith LD (1995) Genetic analysis of the corticosterone response to ethanol in BxD recombinant inbred mice. Behav Neurosci 109(6):1199–1208

Rogers DJ, Randolph SE (2006) CC and vector-borne diseases. Adv Parasit 62:345–381

Ron M, Weller JI (2007) From QTL to QTN identification in livestock–winning by points rather than knock-out: a review. Anim Genet 38:429–439

Rothschild MF, Plastow GS (2014) Applications of genomics to improve livestock in the developing world. Livest Sci. http://dx.doi.org/10.1016/j.livsci.2014.03.020i

Rowlinson P (2008) Adapting livestock production systems to CC – temperate zones. In: Rowlinson P, Steele M, Nefzaoui A (eds) Proceedings of the international conference livestock and global CC, 17–20 May 2008. BSAS, Hammamet, Tunisia, pp 61–63. Available at www.mashreq-maghreb.org/documents/LGCC_proceedings.pdf

Santana MHA, Utsunomiya YT, Neves HHR, Gomes RC, Garcia JF, Fukumasu H, Silva SL, Oliveira GA, Alexandre PA, Leme PR, Brassaloti RA, Coutinho LL, Lopes TG, Meirelles FV, Eler JP, Ferraz JBS (2014) Genome-wide association analysis of feed intake and residual feed intake in Nellore cattle. BMC Genet 15:21–28

Sarge KD, Murphy SP, Morimoto RI (1993) Activation of heat shock gene transcription by heat shock factor 1 involves oligomerization, acquisition of DNA-binding activity, and nuclear localization and can occur in the absence of stress. Mol Cell Biol 13:1392–1407

Scheарf B (ed) (2003) World watch list for domestic animal diversity. FAO, Rome

Schena M, Shalon D, Heller R, Chai A, Brown PO, Davis RW (1996) Parallel human genome analysis:

microarray-based expression monitoring of 1000 genes. Proc Natl Acad Sci U S A 93:10614–10619

Schwerin M, Maak S, Kalbe C, Fuerbass R (2001) Functional promoter variants of highly conserved inducible hsp70 genes significantly affect stress response. Biochem Biophys Acta 1522:108–111

Schwerin M, Maak S, Hagendorf A, Lengerken G, Seyfert HM (2002) A 3′UTR variant of the inducible porcine HSP70.2 gene affects mRNA stability. Biochem Biophys Acta 1578:90–94

Seo S, Mendelsohn R (2006) The impact of CC on livestock management in Africa: a structural Ricardian analysis. CEEPA discussion paper no. 23, Centre for Environmental Economics and Policy in Africa, University of Pretoria

Seo SN, Mendelsohn R (2007) An analysis of livestock choice: adapting to CC in Latin American farms. World Bank policy research working paper, p 4164

Seo SN, Mendelsohn R (2008) Measuring impacts and adaptations to CC: a structural Ricardian model of African livestock management. Agric Econ 38:151–165

Shinde AK, Gowane GR, Naqvi SMK (2013) Commercial sheep farming. Central Sheep and Wool Research Institute, Avikanagar

Sidahmed A (2008) Livestock and CC: coping and risk management strategies for a sustainable future. In: Livestock and global CC conference proceeding, May 2008, Tunisia

Singh D, Swarnkar CP, Sushi K, Prince LLL, Arora AL (2009) Performance of Avikalin sheep selected for resistance to Haemonchus contortus. J Vet Parasitol 23(1):23–27

Singh S, Kushwaha BP, Nag SK, Bhattacharya S, Gupta PK, Mishra AK, Singh A (2012) Assessment of enteric methane emission of Indian livestock in different agro-ecological regions. Curr Sci 102(7):1017–1027

Sodhi M, Mukesh M, Kishore A, Mishra BP, Kataria RS, Joshi BK (2013) Novel polymorphisms in UTR and coding region of inducible heat shock protein 70.1 gene in tropically adapted Indian zebu cattle (*Bos indicus*) and riverine buffalo (*Bubalus bubalis*). Gene 527:606–615

Sonna LA, Fujita J, Gaffin SL, Lilly CM (2002) Invited review: effects of heat and cold stress on mammalian gene expression. J Appl Physiol 92:1725–1742

Steinfeld H, Wassenaar T, Jutzi S (2006) Livestock production systems in developing countries: status, drivers, trends. Rev Sci Tech Off Int Epiz 25(2):505–516

Sudaryanto T, Rusastra IW, Seodjana TD (2001) The impact of economic crisis on livestock industry in Indonesia. Paper provided by International Agricultural Trade Research Consortium in its series international trade in livestock products symposium, 18–19 January 2001, Auckland, New Zealand. Available at http://ageconsearch.umn.edu/bitstream/14539/1/cp01su01.pdf

Tarricone BJ, Hingtgen JN, Belknap JK, Mitchell SR, Nurnberger JI Jr (1995) Quantitative trait loci associated with the behavioural response of BxD recombinant inbred mice to restraint stress: a preliminary communication. Behav Genet 25(5):489–495

Thornton PK (2010) Livestock production: recent trends, future prospects. Philos Trans R Soc B 365:2853–2867

Thornton P, Herrero M (2008) CC, vulnerability and livestock keepers: challenges for poverty alleviation. In: Rowlinson P, Steele M, Nefzaoui A (eds) Livestock and global CC, proceedings, international conference. Cambridge University Press, Cambridge, pp 21–24

Vallejo RL, Bacon LD, Liu HC, Witter RL, Groenen MAM, Hillel J, Cheng HH (1998) Genetic mapping of quantitative trait loci affecting susceptibility to Marek's disease virus induced tumors in F2 intercross chickens. Genetics 148:349–360

Van den Bossche P, Coetzer JAW (2008) CC and animal health in Africa. Rev Sci Tech Off Int Epiz 27(2):551–562

Vidal SM, Malo D, Vogan K, Skamene E, Gros P (1993) Natural resistance to infection with intracellular parasites: isolation of a candidate gene for *Bcg*. Cell 73:469–485

Vidal S, Tremblay ML, Govoni G, Gauthier S, Sebastiani G, Malo D, Skamene E, Olivier M, Jothy S, Gros P (1995) The *Ity*/*Lsh*/*Bcg* locus: natural resistance to infection with intracellular parasites is abrogated by disruption of the Nramp1 gene. J Exp Med 182:655–666

West JW (2003) Effects of heat-stress on production in dairy cattle. J Dairy Sci 86:2131–2144

Wiggans GR, Vanraden PM, Cooper TA (2011) The genomic evaluation system in the United States: past, present, future. J Dairy Sci 94:3202–3211

Williams RW, Strom RC, Goldowitz D (1998) Natural variation in neuron number in mice is linked to a major quantitative trait locus on chr 11. J Neurosci 18(1):138–146

Williams AG, Audsley E, Sandars DL (2006) Determining the environmental burdens and resource use in the production of agricultural and horticultural commodities. Main report. Defra research project IS0205. Cranfield University and Defra, Bedford. Available at: http://www2.defra.gov.uk/research/project_data/More.asp?I=IS0205&SCOPE=0&M=CFO&V=SRI#Docs

Winter A, Alzinger A, Ruedi F (2007) Assessment of the gene content of the chromosomal regions flanking bovine DGAT1. Genomics 83:172–180

Zhang YJ, Hong FZ (2009) Carbon sequestration in the grasslands of China. Technical and policy issues. FAO workshop. The role of grassland carbon sequestration in the mitigation of CC: technical and policy issues. FAO, Rome

Zhang X, Du H, Li J (2002) Single nucleotide polymorphism of chicken heat shock protein (HSP70) gene. 7th world congress on genetics applied to livestock production, France, Montpellier

Zhu JJ, Lillehoj HS, Allen PC, Van Tassell CP, Sonstegard TS, Cheng HH, Pollock D, Sadjadi M, Min W, Emara M (2003) Mapping quantitative trait loci associated with resistance to coccidiosis and growth. Poult Sci 82:9–16

Zwald NR, Weigel KA, Fikse WF, Rekaya R (2003) Identification of factors that cause genotype by environment interaction between herds of Holstein cattle in seventeen countries. J Dairy Sci 86(3):1009–1018

Part VI

Research and Development Priorities

Climate Change Impact on Livestock Sector: Visioning 2025

26

Cadaba S. Prasad and Veerasamy Sejian

Abstract

Climate change and climate change mitigation will bring about major structural change in the agriculture, forestry, and other land use sectors. With effective global action, climate change mitigation would become the more important force for change. In agricultural and animal production, to control and decrease emission of harmful greenhouse gases (GHGs) have become important in environmental protection. The contributions to global warming by ruminant livestock are by and large through enteric CH_4 production. Hence while aiming at sustainable livestock production, it is imperative to concentrate on reduction strategies for enteric methane production. The enteric methane emission reduction strategies can be grouped under three broader headings including management, nutritional, and other molecular strategies. The application of a single strategy would not help and may need a combination of strategies to address mitigation based on the agroecosystems, the production systems, and the resources available with the farmer. While measures to reduce the growth of GHG emissions are an important response to the threat of climate change, adaptation to climate change in addition to mitigation will also form a necessary part of the response. Promotion of sustainable livestock production will be vital to ensure that the impact of climate change is minimized on the livestock farmers. This will involve rearing of animals which are more sturdy, heat tolerant, disease resistant, and relatively adaptable to the adverse climatic stress conditions. Livestock has potential to strengthen resilience to

---

C.S. Prasad (✉)
ICAR-National Institute of Animal Nutrition
and Physiology, Adugodi, Hosur Road, Bangalore,
Karnataka 560030, India
e-mail: cadaba_prasad@yahoo.co.in

V. Sejian
Animal Physiology Division, ICAR-National Institute
of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_26, © Springer India 2015

climate change, as livestock production systems tend to be more resilient than crop-based systems. In developing a strategy for adapting to climate change, one key challenge is dealing with uncertainty. The challenge for governments and agricultural industry stakeholders is to deal with these uncertainties through further research and the development of policies and farm management approaches that are flexible enough to deal effectively with a range of potential climate change outcomes.

Keywords
Adaptation • Breeding • Climate change • Heat tolerance • Livestock and resilience

26.1 Introduction

Climate change represents one of the greatest environmental, social, and economic threats facing the planet today (IPCC 2013). In developing countries, climate change will have a significant impact on the livelihoods and living conditions of the poor. It is an impediment to the attainment of the Millennium Development Goals (MDGs) and progress in sustainable development. Increasing temperatures and changing rainfall patterns reduce access to food and impact regions, farming systems, households, and individuals in varying ways. Additionally changed trade patterns and energy policies have the potential to exacerbate the negative effects of climate change on some of these systems and groups. Thus, analyses of the biophysical and socioeconomic factors that determine exposure, adaptation, and the capacity to adapt to climate change are priority areas so that policymakers can make more informed decisions (IPCC 2001, 2007).

While measures to reduce the growth of greenhouse gas (GHG) emissions are an important response to the threat of climate change, adaptation to climate change in addition to mitigation will also form a necessary part of the response. In this context, adaptation refers to strategies that act to reduce the adverse impacts of climate change. Developing adaptation strategies is therefore an important part of ensuring that countries are well prepared to deal with any negative impacts that may occur as a result of climate change. Given limited resources, adaptation strategies must target those populations most vulnerable to global change and equip them with the tools and incentives that will enable them to do so. Adaptation to climate variability has been an ongoing necessity, more so, for the agricultural sector. Existing strategies to manage climate variability provide opportunities for addressing the challenges of future climate change.

26.2 Importance of Minimizing Climatic Change on Animal Husbandry

Climate change and climate change mitigation will bring about major structural change in the agriculture, forestry, and other land use sectors. With effective global action, climate change mitigation would become the more important force for change. A rising carbon price will alter the cost of land management practices and commodities, depending on their emission profiles. Domestic food production in many developing countries will be at immediate risk of reductions in agricultural productivity due to crop failure, livestock loss, severe weather events, and new patterns of pests and diseases (FAO 2006). Climate change could disrupt ocean currents, which would have serious ramifications on the availability of fish, a major protein source.

Farmers in developing countries possess lesser options to adapt to and effectively manage these risks due to the higher proportion of small-scale and subsistence farms, poorly developed infrastructure, and lesser access to capital, technology, and market (Evenson 1999; Easterling et al. 2007). These impacts, together with the considerable increases in population and food demand expected in developing countries, could lead to an increase in global food prices (Deressa et al. 2005).

In agricultural and animal production, to control and decrease emission of harmful gases (GHGs) has become important in environmental protection. It should be noted that certain gases released in agriculture/animal husbandry production, such as methane, carbon dioxide, nitrous oxide, and ammonia, directly affect global climate change which influences the development of social economy by acting on agriculture, animal husbandry, and water resources. If the warming of global climate is continually accelerated, it is possible that further increase is likely to influence occurrence of flood and drought. Because of the pressure on land and water coupled with increased demand of agriculture and pasture, the shortage of water will become serious and the quantity and quality of herbage will largely decline. The increase of temperature will lead to the decline in the yield of crops resulting in decreased forage for livestock thereby decreasing animal production and reproduction performance to different degrees. Climate change will also influence etiologic bacteria and parasites in livestock. Therefore, in order to avoid threats to global environment and prevent it from further deterioration, it is vital that immediate strategies to control the density of greenhouse gases in the atmosphere are taken on priority.

26.3 Sustenance of Livestock Production and Mitigation of Climate Change

Promotion of sustainable livestock production will be vital to ensure that the impact of climate change is minimized on the livestock farmers. This will involve rearing of animals which are more sturdy, heat tolerant, disease resistant, and relatively adaptable to the adverse climatic stress conditions. In such a situation, some of the indigenous breeds are able to cope much better than the crossbred, as crossbreds containing higher exotic inheritance exhibit problems in adapting when compared to indigenous breeds because of their acclimatization to different agroecological systems.

Relatively, there is a lot of basic knowledge on the interaction between heat stress and livestock production, reproduction, and health traits. The implementation of the knowledge to maintain the welfare of animals maintained under extensive management systems is difficult because of objective limitations to monitor heat stress and economic compulsions in applying measures to ameliorate. From welfare point of view, ideally the animals should be raised in the zone of optimal thermal well-being. However, these would be almost impracticable goal to attain in dominant grazing system of the world. The following recommendations are general rules that can be applied under extensive conditions: (1) provision of shade/shelter in areas where typical ambient temperature during summer exceeds above than normal, (2) provision of adequate water (it is recommended that the distance between watering spot and grazing area be such that grazing animals are able to visit the water spot at least once a day), and (3) provision of balanced feed with micronutrients to address heat and oxidative stress. There are substantial environmental benefits associated with sustainable livestock production. In extensive system of rearing, generally, sustainable livestock production is pasture based and is offered little or no supplemental feed.

26.4 Significance of Improving the Adaptive and Resilience Capacity of Livestock to Climate Change

Changes in rainfall and seasonal patterns are already being experienced in many parts of the world, including Indian subcontinent, creating problems for vulnerable farmers and other land users in securing their livelihoods and increasing the risks they face. The frequency and intensity of extreme climatic events such as heat waves and erratic heavy rainfall, as well as the long-term chronic effects of higher temperatures, are set to increase. The effects of these climatic changes will become even more pronounced in the future, particularly in sub-Saharan Africa where livelihoods and ecosystems are highly sensitive to changes in climate.

Livestock has potential to strengthen resilience to climate change, as livestock production systems tend to be more resilient than crop-based systems. This chapter also discusses a number of innovative social, technical, and management interventions that might be helpful to increase the resilience of livestock production systems to climate change. However, substantial controversy exists about the short-term and long-term effectiveness of a number of them. This will require more in-depth analyses over the coming years. Strengthening resilience in the livestock sector relies on building the adaptive capacity of livestock keepers, and it is necessary to take an ambitious approach to address the fundamental determinants of capacity. Four dimensions of adaptive capacity are:

- Ability to make informed assessment of imminent threats
- Ability to make an informed choice, from a range of options, about the best response measure under different production systems
- Being capable of deploying the preferred option (skills, money, infrastructure)
- Access to implement this option (policy, governance, rights)

To address the above, adaptive strategies would be:

- Production adjustments
- Breeding strategies
- Livestock management system
- Science and technology development
- Development of early-warning system
- Capacity building of livestock keepers
- Policy framework and changes
- Market responses

26.5 Strategic Plans for Meeting the Challenges of Climate Change

(a) Identification and characterization for genes to adapt to drought and heat stress
(b) Developing germplasms with greater tolerance to climatic variability
(c) Reducing risks to pastoralists by improved rangeland management
(d) Fostering community-based development plans that increase local capacity to comanage natural resources
(e) Developing resilient crop-livestock production systems through better soil and water management and higher water-use efficiency
(f) Managing crop rotations that sequester carbon conserve water and maintain soil fertility
(g) Improving feed resources that reduce greenhouse gas emissions
(h) Building scenarios and models to determine trade-offs between development and climate change (e.g., optimizing on-farm water allocation)
(i) Conducting livelihood analyses that include strategies to cope with unpredictable ecosystems and climate variability and change
(j) Enabling policy and institutional options to promote the uptake of technologies that enhance the capacity of communities to adapt to climate change

26.6 Strategies to Reduce GHG Emission and to Improve Livestock Production Under Changing Climatic Scenario

The ways and means by which sustainable livestock production can be achieved under changing climatic conditions are:

- Producing forage on-site without the use of energy-intensive inputs including fertilizers, herbicides, and fuels and drying and storing feed generally lower the embodied energy in livestock feed.

- When feeding native hay and grains that are produced locally, the energy required for transportation is reduced further due to shorter distances between the feed source and the animal farm.
- Since fossil fuels are primary sources of greenhouse gas emissions such as CO_2, using fewer energy inputs usually reduces emissions as well.
- Providing livestock with access to pasture forage improves the ecological balance between forage and livestock.
- Distributing manure and urine on the pasture also reduces methane emissions from manure slurry.
- Proper soil and pasture management can also mitigate the release of emissions. Under certain soil conditions, N_2O emissions are released from the soil through a process called denitrification. An excessive buildup of manure and urine (nitrogen, ammonium) in water-saturated soils can lead to denitrification and the release of N_2O, a greenhouse gas 310 times more powerful than CO_2. Rotating animals through pastures and moving feeding, watering, and shade areas will help spread the manure and urine more uniformly and may help decrease N_2O emissions from pasture soils.

The contributions to global warming by ruminant livestock are by and large through enteric CH_4 production. Hence while aiming at sustainable livestock production, it is imperative to concentrate on reduction strategies for enteric methane production (Sirohi and Michaelowa 2007). The enteric methane emission reduction strategies can be grouped under three broader headings including managemental, nutritional, and other molecular strategies. Any reduction strategies must be confined to the following general framework such as development priority, product demand, infrastructure, livestock resource, and local resources. The most attractive emission mitigation projects must balance the needs in all of these areas, so that no one factor creates a constraint on continued improvement in production efficiency and resultant CH_4 emission reductions (Sejian et al. 2011). Within this framework, CH_4 emission mitigation options for enteric fermentation can encompass a wide range of activities across these areas. However, underlying these activities must be specific options for improving the production efficiency of livestock. Without these options, CH_4 emissions cannot be reduced.

The total GHG and methane emissions over the years would increase considerably as shown in Figs. 26.1 and 26.2 below.

A similar trend in methane emissions could also be seen requiring immediate ameliorative measures to control.

Several approaches including dietary, chemical, and biological interventions are available or on the anvil, and each method could have its merits and demerits.

The application of a single strategy would not help and may need a combination of strategies to address mitigation based on the agroecosystems, the production systems, and the resources available with the farmer. However, the feed-based strategy appears to hold promise as it could be much easier to modify diets and feeding practices. Figure 26.3 describes the various approaches for enteric methane reduction, while Fig. 26.4 describes the comparative efficacy of different approaches for in vivo methane reduction.

26.7 Adaptation Measures to Be Undertaken to Improve Livestock Production Under Changing Climatic Scenario

Projections for 2050 suggest an increase in both global mean temperatures and weather variability, including precipitation. This will clearly affect the type and location of agricultural production worldwide. The entire patterns of production and livelihoods could be transformed. Many countries will be able to adapt and some may even benefit by being able to grow new crops. But poorer communities and those living in fragile lands, such as deltas and low-lying

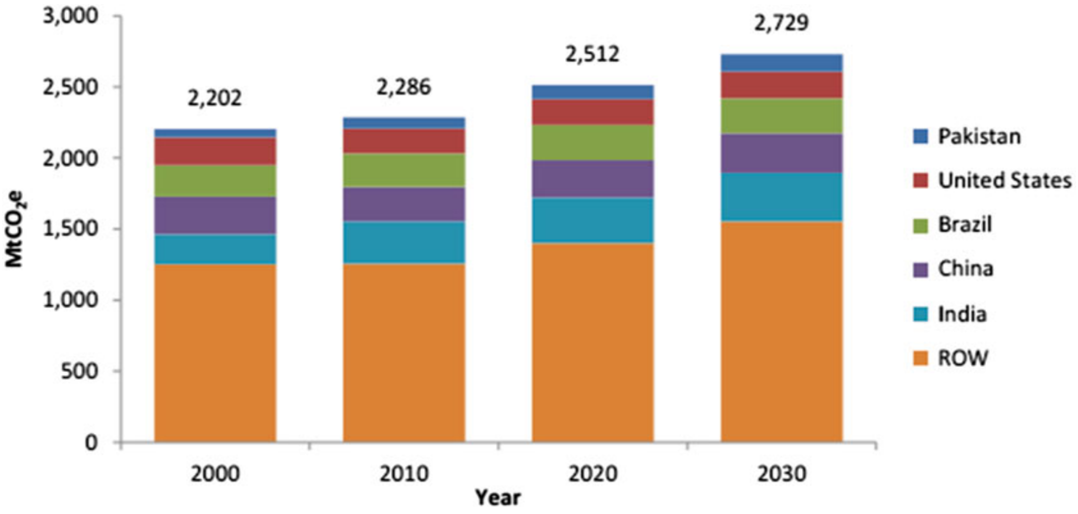


Fig. 26.1 Total GHG emissions and projections for the livestock sector: 2000–2030

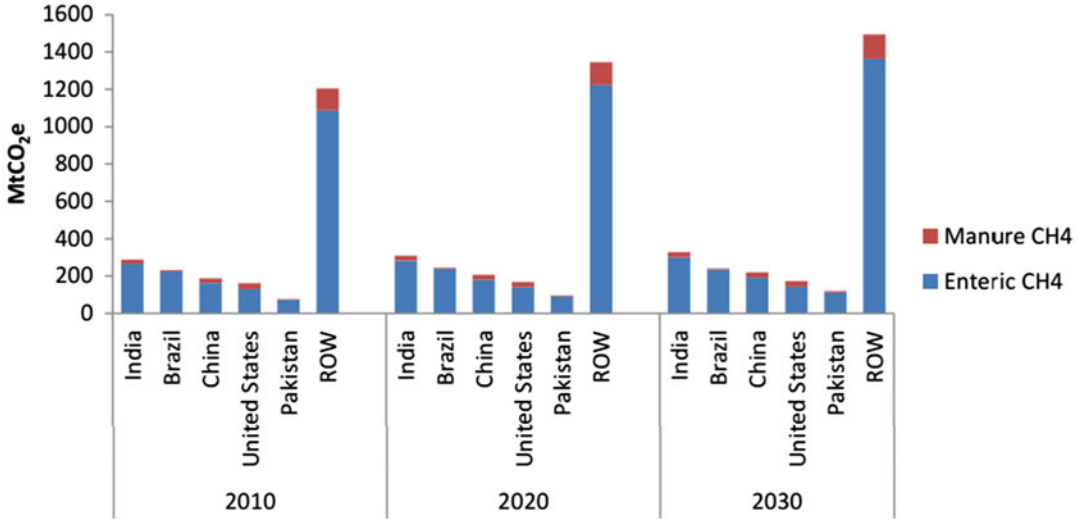


Fig. 26.2 Methane emission projections for the livestock sector: 2010–2030

coasts, may be exposed to greater risks (Kabubo-Mariara 2005, 2007, 2008). This makes adaptation vitally important. It also confirms just how key global cooperation will be in meeting adaptation needs in the years ahead (Calvosa et al. 2009).

Broadly speaking, at the national, regional, or local level, the new strategies consist of a displacement of livestock into areas where natural resources are available. At the local level, new feeding approaches are used, leading to the adoption of either new feeds or other forms of rangeland management. There are a number of initiatives of adaptation to climate change on a regional or national scale. Be they regional or national, the strategies proposed to respond to

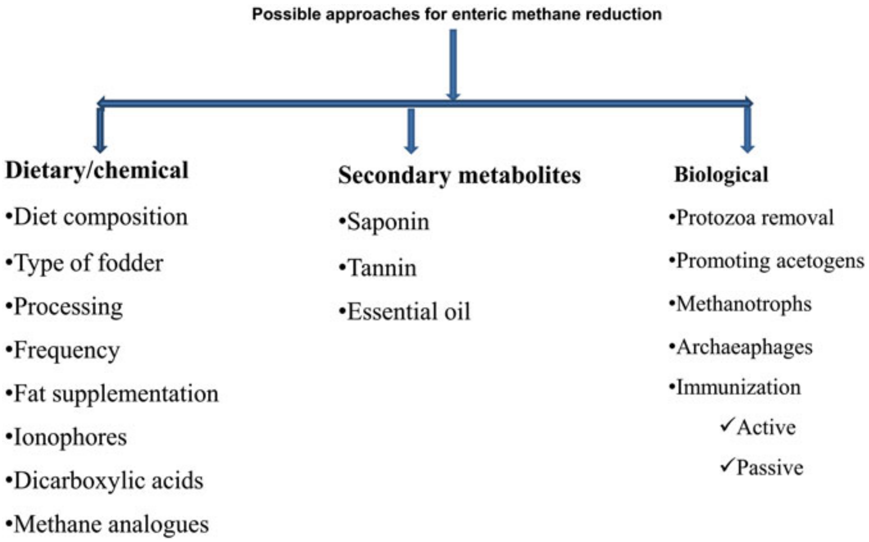


Fig. 26.3 Different possible approaches for enteric methane reduction

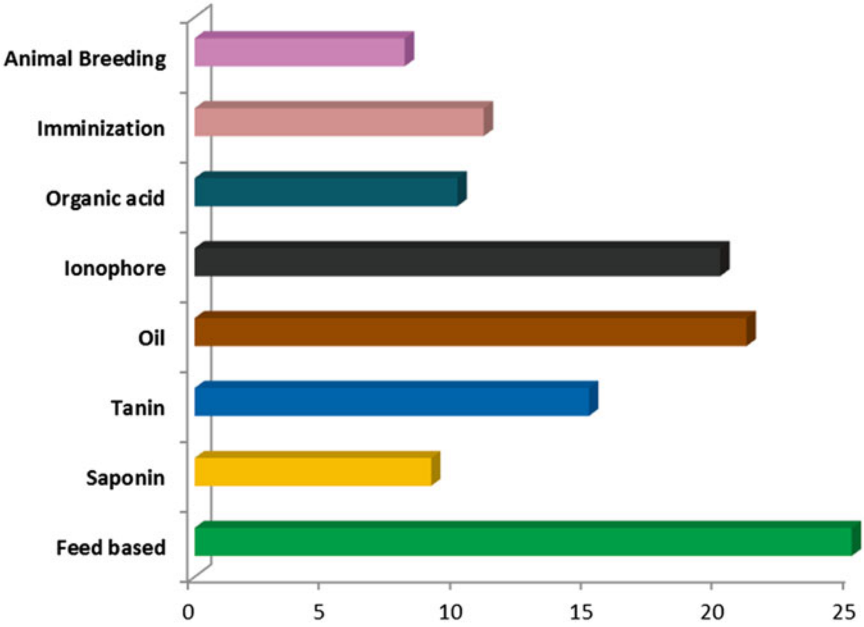


Fig. 26.4 Comparative efficacy of different approaches for in vivo methane reduction

climate change are not specific to livestock, even in arid and subarid eco-regions where livestock is an important part of the economy and very often is the sector most affected by climate change. With regard to regional initiatives, these are at the stage of design and strategy development rather than concrete proposals ready for implementation (Calvosa et al. 2009).

National actions are envisaged by the states under the United Nations Framework Convention on Climate Change. These include the National Communication Programs for climate change and the National Adaptation Programs for Action (NAPA). In fact, under these two frameworks, the states have limited their actions to doing a vulnerability analysis and an inventory of measures for adaptation and mitigation without advocating to appropriate actions relevant to national agro-climatic conditions and traditional livestock practices (Nordhaus 1998; Quiggin 2007).

Different Livestock Adaptation Options to Sustain Production

- Developing and promoting drought-tolerant and early-maturing crop species
- The adoption of improved animal breeds and grass/legume seed stock with increased resilience to projected climate conditions
- Adapting annual production cycle to better match feed production
- Adopting integrated disease surveillance response systems and emergency preparedness to prevent, mitigate, and respond to epidemic
- Strengthening meteorological services to provide time series weather and climate forecast/information early-warning systems
- Promoting and strengthening aquaculture, poultry raising, and the like as alternative livelihood options
- Developing and promoting guidelines for using herbal and alternative medicine
- Increasing agriculture extension activities for wide dissemination of knowledge about climate change impact
- Reducing livestock density

26.7.1 Technological Interventions to Meet the Climate Change Challenge

- Conserving genetic resources: This requires better characterization of breeds, production environments, and associated knowledge, the compilation of more complete breed inventories, improved mechanisms to monitor and respond to threats to genetic diversity, more effective in situ and ex situ conservation measures, genetic improvement programs targeting adaptive traits in high output and performance traits for developing countries in their management of animal genetic resources, and wider access to genetic resources and associated knowledge.
- Projections suggest that further selection for breeds with effective thermoregulatory control will be needed. This calls for the inclusion of traits associated with thermal tolerance in breeding indices and more consideration of genotype-by-environment interactions (GxE) to identify animals most adapted to specific conditions. Selections for heat tolerance based on temperature-humidity index (THI) in genetic evaluation models are promising. The significance of including molecular markers like heat shock proteins (HSPs) and marker-assisted selection in such breeding programs offers huge scope for developing the most appropriate breed which can survive and reproduce normally in specific agroecological zone.
- Similarly breeding animals for low residual feed intake (RFI) which is a heritable trait would be beneficial to use the available feed resources judiciously.
- A variety of technologies can be used to deal with the effects of short-term heat waves, including shading or sprinkling to reduce excessive heat loads. Improved farmhouse microclimate management through the use of thermal insulating construction materials and modern ventilation systems to protect livestock from extreme conditions and increase productivity.
- Improved pasture management by matching stocking rates to pasture production and integrating pasture improvement to increase feed value.

26.7.2 Challenges While Formulating Breeding Programs Under Changing Climate Scenario

Breeding for improved performance has become a technology-intensive exercise; the technologies and skills required present a bias toward certain breeds and production systems. Similarly, while GxE is the measure of choice for assessing variability of breed performance and adaptation across different environments, there are several caveats related to its wide application:

- Limited breeds: GxE to identify animals most adapted to specific conditions are available only for very few breeds as per international genetic evaluation programs. Routine GxE assessments are not available for other breeds or species.
- Limited countries: Researches pertaining to breeding for adaptation to climate change are currently in practice only in developed countries. GxE effects are more pronounced in tropical countries.
- Limited production systems: International genetic evaluation programs are mostly confined to high-input production systems and often do not differentiate between environments within countries. Such programs should address between grazing and confined dairy herds, especially those in extensive, hot areas, semi-intensive to intensive.
- Demanding data quality and analysis: Only a small percentage of national herds are usually used for progeny testing. Electronic data capture which increasingly forms the basis of genetic evaluations is mostly prevalent in large herds; in future even smaller herds will be needed for progeny testing. Adaptation traits are more difficult to study and to record, have lower heritability and higher levels of nonadditive genetic variation and phenotypic variance, and are more susceptible to GxE than production traits.
- Economic constraints: There are no breeding programs in developed countries that target developing country environments. As only a relatively small amount of genetic material is sold to developing countries, commercial breeders find it hard to justify specific breeding programs for such environments.

26.7.3 Supporting Adaptive Capacities

Adaptive capacity, at individual, community, or national levels, is poorly understood. However, there are risks inherent in externally driven determination of risks and opportunities for adaptation. Top-down and externally driven approaches have often been harmful to development in the past, and it is critical to develop a broader understanding of the determinants of adaptive capacity. The ability to adapt may consist of a number of fundamental attributes that are relevant across a range of threats.

26.7.3.1 Improving the Assessment of Threats

This can enable farmers and planners to react appropriately and rapidly. This requires better access to information and greater capacity to interpret information and understand the implications of a given threat. At a local level, this requires training and awareness, improved understanding between farmers and extension workers, and investment in information infrastructure. At the national level, greater investment may be required to improve meteorological data collection and dissemination so that information is available regularly and reliably.

26.7.3.2 Capability to Adopt the Chosen Strategy

This relies to a large extent on the core livelihood assets: human, social, physical, financial, and natural capital. In more practical terms, to be capable of deploying a preferred adaptation option, people need particular skills, resources, and infrastructure. Many of the basic capabilities of livestock keepers are weak, leading to their underdevelopment and contributing to their vulnerability to climate change and other threats. Training is important to develop these capabilities, as is access to financial services and markets.

26.7.3.3 Freedom to Implement the Chosen Strategy

These cut across policy, governance, and rights. At a local level, farmers need secure property rights, strong and equitable local institutions, and functioning legal systems. They also need government to put in place supportive policies, to relax policy disincentives, and to effectively implement key policies. Important policy gaps include forward and backward linkages, natural resource governance and tenure, gender issues, legitimizing local organizations, and the regulation and protection of transhumance routes. Freedom to adapt can also be constrained by cultural and societal norms, which must be taken into consideration by embracing appropriate participative and empowering approaches to adaptive development.

26.7.3.4 Enabling Informed Choice

Livestock keepers and advisors/planners do not necessarily require the development of new choices. Many adaptation options are already known, and it is important to ensure that farmers and planners can make use of the options available to them. This requires the building of human capabilities through education, skill development, and improved extension services and through better access to information sources. Collaborative research is required where adaptation options still need to be developed to ensure that both endogenous and exogenous knowledge is considered.

26.8 Conclusion

Climate change is one additional factor affecting the already highly dynamic livestock sector. However, due to its slow but long-term effect and more pressing current needs such as increasing demand for animal products, climate change is not yet fully on the radar screen of the livestock community. It will increase the need for resource-efficient livestock production and may thus intensify current trends with a growing dichotomy between livestock kept for livelihoods by smallholders and pastoralists and those kept for commercial production. The direct effects of climate change depend very much on the production and housing system, resulting in a buffered effect for the high-output breeds in confined systems.

Scientific research can help the livestock sector in the battle against climate change. All animal scientists must collaborate closely with colleagues of other disciplines, first with agronomists, then physicists, meteorologists, engineers, economists, etc. The effort in selecting animals that up to now has been primarily oriented toward productive traits must be oriented toward adaptability to heat stress. In this way, molecular biology could allow to directly achieve genotypes with the necessary phenotypic characteristics. Research must continue developing new techniques of cooling systems such as thermo-isolation, concentrating more than in the past on techniques requiring low energy expenditure. New indices that are more complete than THI to evaluate the climatic effects on each animal species must be developed, and weather forecast reports must also be developed with these indices to inform the farmers in advance. Above all to negate the climate change or in any case not to let the climate negate livestock systems, researchers must be aware of technologies of water conservation.

Adaptation to climate change is an integral part of agricultural production now and will become more important in the future as the impacts of climate change become more evident. In developing a strategy for adapting to climate change, one key challenge is dealing with uncertainty. Significant uncertainty relates to the nature and extent of regional climate change impacts, impacts across agricultural industries, and impacts over time. The challenge for governments and agricultural industry stakeholders is to deal with these uncertainties through further research and the development of policies and farm management approaches that are flexible enough to deal effectively with a range of potential climate change outcomes.

References

Calvosa C, Chuluunbhaatar D, Fara K (2009) Livestock and climate change. Thematic paper. International fund for Agricultural Development (IAFD), Paolo di no, Rome, Italy. pp 1–19

Deressa T, Hassan R, Poonyth D (2005) Measuring the economic impact of climate change on South Africa's sugarcane growing regions. Agrekon 44(4):524–542

Easterling WE, Aggarwal PK, Batima P, Brander KM, Erda L, Howden SM, Kirilenko A, Morton J, Soussana JF, Schmidhuber J, Tubiello FN (2007) Food, fibre and forest products. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Climate change 2007: impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 273–313

Evenson RE (1999) Global and local implications of biotechnology and climate change for future food supplies. Proc Natl Acad Sci U S A 96(11):5921–5928

FAO (Food and Agriculture Organization of the United Nations) (2006) Livestock a major threat to the environment: remedies urgently needed. Available: http://www.fao.org/newsroom/en/news/2006/1000448/index.html

IPCC (2001) Technical summary: contribution of Working Group I to the Third Assessment Report. Inter governmental Panel on Climate Change, January 2001

IPCC (2007) Climate change 2007: the physical science basis, summary for policy makers. Contribution of Working Group I to the Fourth Assessment Report of Intergovernmental Panel on Climate Change. http://www.ipcc.ch

IPCC (Intergovernmental Panel on Climate Change) (2013) Impacts, adaptation and vulnerability. http://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-TS_FGDall.pdf

Kabubo-Mariara J (2005) Herders response to acute land pressure under changing property rights: some insights from Kenya. Environ Dev Econ 10(1):67–85

Kabubo-Mariara J (2007) Poverty and rural livelihoods in Kenya: evidence from a semi-arid region. In: Tisdell C (ed) Poverty, poverty alleviation and social disadvantage: analysis, case studies and policies. Serials Publications, Vol III, Part VII, Chapter 56

Kabubo-Mariara J (2008) Climate change adaptation and livestock activity choices in Kenya: an economic analysis. Nat Resour Forum 32:131–141

Nordhaus WD (1998) Revised estimates of the impacts of climate change. p 18, http://www.econ.yale.edu/~nordhaus/homepage/impacttables20122998.PDF

Quiggin J (2007) Drought, climate change and food prices in Australia, report for the Australian Conservation Foundation, www.afconline.org.au/articles/news

Sejian V, Lal R, Lakritz J, Ezeji T (2011) Measurement and prediction of enteric methane emission. Int J Biometeorol 55:1–16

Sirohi S, Michaelowa A (2007) Sufferer and cause: Indian livestock and climate change. Clim Change 85:285–298

Conclusions and Researchable Priorities

27

Veerasamy Sejian, Raghavendra Bhatta,
John Gaughan, Lance Baumgard, Cadaba S. Prasad,
and Rattan Lal

Abstract

Given that the livestock production system is sensitive to climate change and at the same time itself a contributor to the phenomenon, climate change has the potential to be an increasingly formidable challenge to the development of the livestock sector in the world. This chapter provides the salient findings established by various researchers in their field of specialization and also elaborates on the future research priorities that are available before the researchers in the field of climate change and livestock production. In the changing climatic scenario, apart from high ambient temperature, air movement, solar radiation, wind speed, and relative humidity are other critical attributes of the climatic variables that hamper livestock production. The direct effects on livestock production are primarily mediated through increased temperature, altered photoperiod, and changes in rainfall pattern. The indirect effects on livestock production are mediated through sudden disease outbreaks, less feed and water availability, and low grazing lands. There are different adaptive mechanisms by which livestock respond to fluctuations of climatic changes including physiological, blood biochemical, neuroendocrine, cellular, and molecular

---

V. Sejian
Animal Physiology Division, ICAR-National Institute of Animal Nutrition and Physiology, Adugodi,
Hosur Road, Bangalore, Karnataka 560030, India
e-mail: drsejian@gmail.com

R. Bhatta • C.S. Prasad
ICAR-National Institute of Animal Nutrition and Physiology, Adugodi, Hosur Road, Bangalore,
Karnataka 560030, India

J. Gaughan
Animal Science Group, School of Agriculture and Food Sciences, The University of Queensland,
Gatton, QLD 4343, Australia

L. Baumgard
Department of Animal Science,
Iowa State University, Ames, IA 50011, USA

R. Lal
Carbon Management and Sequestration Center, School of Environment and Natural Resources, The Ohio State University, Columbus, OH 43210, USA

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1_27, © Springer India 2015

mechanisms of adaptation, respectively. Globally, the livestock sector contributes 18 % of global GHG emissions. Hence, understanding of GHG emissions by sources and removal by sinks in animal agriculture is critical to take appropriate mitigation and adaptation strategies and to estimate and develop inventory of GHGs. The chapter also signifies that considerable research efforts are needed to modify the existing shelter design to make them more suitable for the current climate change scenario. The chapter also calls for multidisciplinary approach to develop suitable technological interventions to cope up to climate change for the ultimate benefit of livestock farmers who rely heavily on livestock resources for their livelihood security. If one attempts improving livestock production under the changing climate condition, research efforts are needed to develop strategies encompassing adaptation, mitigation, and amelioration strategies simultaneously, apart from strengthening the existing extension system.

Keywords
Breeding • Epigenetics • LCA • Heat tolerance • Simulated heat stress model • Shelter design

27.1 Conclusions

The introductory chapter provides the overall vision of the book. It presents an insight of the impact of climate change on livestock production and its amelioration. Further, it addresses the role of livestock in climate change and its mitigation. There are two chapters (Chaps. 2 and 3) in the first part of this book. This part particularly addresses in detail the greenhouse gas (GHG) emission and climate change and also the general principles governing GHG emission and carbon (C) stock accounting. Chapter 3 focuses on different sources of GHG emission from the agriculture sector in particular and their key mitigation strategies. These chapters highlight three broad anthropogenic sources of GHG emission from agriculture including energy use and management of land- and livestock-related emissions. Among these sources, globally, the livestock sector contributes 18 % of global GHG emissions. Chapter 3 signifies that an understanding of GHG emissions by sources and removal by sinks in agriculture is critical to take appropriate mitigation and adaptation strategies and to estimate and develop inventory of GHGs. It also highlights the significance of improving the efficiency of agricultural production to meet global food supply demands and to decrease impact of agriculture on climate change.

Part II of this book deals with the climate change impact on livestock production and reproduction. These multifold impacts of climate change on livestock production are presented in Chaps. 4, 5, 6, 7, 8, and 9 and cover this aspect with detailed description on both direct and indirect impacts of climate change on livestock production. The direct effects on livestock production are primarily mediated through increased temperature, altered photoperiod, and changes in rainfall pattern. The indirect effects on livestock production are mediated through sudden disease outbreaks, less feed and water availability, and low grazing lands. Chapter 4 addresses the impact of climate change on livestock production and reproduction. It elaborates the impact of climate change on growth and milk and meat production and highlights the impact on reproductive processes. Chapter 5 deliberates the effect of thermal stress as the key factor in reducing animal production and negatively impacting health and development during postnatal life. It also deals with the global impact of heat stress on livestock production and its subsequent economic and food security issues and reiterates that the importance of heat stress on livestock production must not be overlooked. Both heat and cold stresses compromise animal production by directly altering metabolism and the hierarchy of nutrient utilization. A prerequisite to understanding thermal stress adaptation is an appreciation for the physiological and metabolic adjustments responsible for altered postabsorptive metabolism in livestock species during periods of inadequate nutrient intake. These altered metabolic adaptations due to heat stress are described pertaining to carbohydrate, protein, and lipid metabolic pathways. During heat stress exposure, animal productivity is compromised due to reduced feed intake (FI), an altered metabolic profile, and gastrointestinal integrity perturbations. On the contrary, cold stress-induced performance reductions are primarily a result of enhanced thermogenesis required to maintain homeothermy.

Chapter 6 describes the impact of climate change on both the quality and quantity of water resources and signifies the importance of water for agricultural activities and forecasts climate change to be the most crucial factor influencing the quality and quantity of water resources. It signifies that water requirements differ with breeds and elaborates the adaptive mechanisms in terms of changes in behavioral, blood biochemical, and endocrine responses as exhibited by livestock to cope up to deprived water resources. It also emphasizes that water deprivation in rumen plays a vital role in maintaining homeostasis in adapted animals and states that variability and distribution of water can aggravate the competition between livestock and other farming sectors. Thus, strategies have to be developed to improve water use efficiency by conservation of diversified production system in different locations. Chapter 7 describes the impact of climate change on feed and pasture availability for livestock by altering the herbage growth and composition. It highlights that parameters such as atmospheric carbon dioxide concentrations, temperature, precipitation, and ozone are the primary factors influencing the quality and quantity of pasture available for livestock. In addition, climate change alters the composition of pastures by altering the ratio of grasses to legumes apart from influencing the herbage quality, with changing concentrations of water-soluble carbohydrates and N for the dry matter yields. It also emphasizes that greater incidences of drought and rainfall may also offset the dry matter yield and lead to nitrogen leaching, respectively. The impact of environmental stresses on grasslands and rangelands, along with key farm-level adaptations (e.g., changing planting dates and associated decisions to match evolving growing seasons and improving cultivar tolerance to high temperature, drought conditions, and elevated CO_2 levels), is also discussed. The other adaptation strategies include matching stocking rates with pasture production, adjusting herd and water point management to altered seasonal and spatial patterns of forage production, managing diet quality, more effective use of silage, pasture seeding and rotation, fire management to control woody thickening, using more suitable livestock breeds or species, migratory pastoralist activities, and a wide range of biosecurity activities to monitor and manage the spread of pests, weeds, and diseases.

Chapter 8 in Part II deals with impact on livestock disease occurrences and emphasizes that climate change and livestock diseases are a relatively neglected area of research and signify the importance of such studies to prevent huge production loss because of the sudden outbreaks of livestock diseases. It also highlights the significance of studying the zoonotic diseases and accentuates the importance of modeling to predict and prepare for countering climate change-related livestock diseases. Thus, different models discussed include environmental niche modeling, epidemiological modeling using R_0 map, and teleconnection modeling. The chapter emphasizes an urgent need to consider the entangled linkages between ecosystems, society, and health of animals and humans. The need of elaborated scenarios of livestock diseases linked to climate change and variability, which necessitates developing and improving the recording of livestock diseases, is also discussed. The significance of incorporating climate-mediated physiological responses into the programs that manage breeding genetic diversity is also presented. Chapter 9 addresses the different adaptive mechanisms exhibited by the domestic livestock to cope up to the adverse environmental condition that arises due to climate change. The authors of this particular chapter rationalized that climatic change is a common phenomenon in the arid and semiarid region of the world, where more than 75 % of the populations of livestock are reared currently. Discussions in Chap. 9 vividly indicate that apart from high ambient temperature, air movement, solar radiation, wind speed, and relative humidity are other critical attributes of the climatic variables that hamper livestock production. As a result, the authors of Chap. 9 signified the importance of studying the influence of multiple environmental factors simultaneously influencing livestock production in the changing climatic condition. It is imperative, therefore, that researchers aiming at improving livestock production under the changing climatic conditions should also address the effects of multiple stresses simultaneously rather than studying heat stress alone. In addition, authors of Chap. 9 elaborately discussed different adaptive mechanisms by which livestock respond to fluctuations of climatic changes including physiological, blood biochemical, neuroendocrine, cellular, and molecular mechanisms of adaptation, respectively. They further highlighted the importance of developing suitable mitigation strategies to sustain livestock production under the changing climate scenario.

Part III of this book covers in detail the role of livestock in climate change. This part comprises of six chapters (Chaps. 10, 11, 12, 13, 14, and 15) dealing in detail the sources and sinks of GHG that emerge from livestock and livestock-related activities that contribute to climate change/global warming. This particular chapter provides an overview of the current state of knowledge concerning global warming with special reference to contribution from livestock resources. The authors of this particular chapter emphasize the contribution of livestock to climate change through emissions of carbon dioxide, methane, and nitrous oxide into the atmosphere. While direct GHG emissions from livestock refer to emissions from enteric fermentations in livestock, urine excretion, and microbial activities in manure, indirect GHG emissions are those not directly derived from livestock activities but from manure applications on farm crops, production of fertilizer for growing crops used for animal feed production, and processing and transportation of refrigerated livestock products. Other indirect emissions include deforestation, desertification, and release of carbons from cultivated soils due to expansion of livestock husbandry. It was concluded that from the global warming perspectives, assessing the contribution of livestock and its production systems in relation to GHG emissions using the life cycle assessment (LCA) approach is very crucial. They assumed that this will facilitate better understanding of the sector's impacts, taking into account the differences across production systems and species, and the development of effective design and mitigation options.

Chapter 11 of Part III describes in detail the process of enteric fermentation and methanogenesis in ruminant livestock. Rumen fermentation is the process by which the food particles are digested in rumen to release the end product of digestion, the volatile fatty acids. The authors of Chap. 11 conclude that the metabolic pathways involved in volatile fatty acid (VFA) production are strictly linked to methane emission because hydrogen is actively produced during the fermentation of structural carbohydrates and it is rapidly metabolized by methanogens, in order to maintain the optimal thermodynamic condition for the metabolism of the microbial consortium in the rumen. Further, the chapter addresses in detail the relationship between hydrogen, VFA, and methane production. Chapter 12 of this volume deals with enteric methane under different feeding systems of livestock rearing. This chapter in particular signifies the importance of methane to global warming by highlighting its superior global warming potential as compared to carbon dioxide. Further, Chap. 12 described different livestock rearing systems and identified intensive, extensive, and semi-intensive systems to be the commonly identified livestock rearing systems in most of the countries rearing livestock. This chapter further highlights the different factors that influence enteric methane emission in different livestock feeding systems. In addition, the authors of Chap. 12 suggested suitable mitigation strategies that may be followed to curtail enteric methane production under different feeding systems.

Chapter 13 of this volume signifies the importance of developing suitable methane estimation methodologies from individual ruminant animals as well as the entire herd/flock. The authors of this chapter urged the need for such methodological developments to counter global warming as well as to prevent feed inefficiency which otherwise would occur as a result of enteric methane production. Further, these authors opined that developing methane estimation methodologies might pave way for developing suitable mitigation strategies. In addition, these efforts will help to test the mitigation strategies for their applicability. Chapter 13 addresses in detail both in vivo and in vitro methane estimation methodologies for ruminant animals. Discussion in Chap. 13 vividly indicated the advantages and disadvantages of each methane estimation methodologies currently being in use. Important in vivo techniques that were discussed in detail in this chapter include open- and closed-circuit respiration chambers, open-circuit hood systems, sulfur hexafluoride (SF_6) tracer, polythene tunnel system, methane/carbon dioxide ratio, GreenFeed, infrared (IR) thermography, laser methane detector, and intraruminal gas measurement device. Furthermore, in Chap. 13 authors described the in vitro gas technique (IVGT) that estimates the methane emissions from different dairy rations. However, the authors of this chapter opined that selection of the most appropriate technique for methane estimation depends on the cost, species, accuracy of the technique, maintenance, and environment of the ruminant.

A new theme of research, signifying the use of metagenomics approaches in understanding the rumen function and establishing the rumen microbial diversity in the rumen, is discussed in Chap. 14. The authors of this chapter highlighted that the metagenome of the rumen is considered a determining factor for the efficiency of the particular digestive metabolism of ruminants as well as the accompanying environmental problems. These authors signified the importance of scientific research pertaining to gene signature and biological fingerprinting of microorganisms present in ruminants. This chapter suggests that the recent advances in the ruminant gut microbiology and genomics offer new opportunities to conduct a more holistic research to establish the function of rumen ecology. The authors of this chapter emphasized the significance of applying the metagenomics concept for providing an insight into the functional dynamics of the ruminomics database which apart from achieving the major goal of rumen ecosystem may also help to identify the microbial communities' function and interaction among these microbes as well as with the host. The final chapter of Part III (i.e., Chap. 15) addresses in detail the various opportunities and challenges for carbon trading from the livestock sector. The author of this chapter denoted that such attempts in the livestock sector are in nascent stage, largely confined to animal waste management projects not taking into account the emissions from enteric fermentation. This chapter discusses the potential of generating carbon credits by improving the feed fermentation efficiency through nutritional interventions and increasing the productivity of animals through breeding and other long-term management strategies. However, the author opined that while targeting carbon trading from the livestock sector, there are several challenges for the stakeholders including socioeconomic, institutional, and technical for implementing such mitigation strategies.

Part IV of this volume covers methane mitigation strategies in livestock both from enteric fermentation and from manure management. This part consists of six chapters (Chaps. 16, 17, 18, 19, 20, and 21) covering in detail methane mitigation strategies including manipulation of rumen microbial ecosystem, plant secondary metabolites, ration balancing, alternate hydrogen sink, and modeling. Chapter 16 of this part covers in detail the manipulation of rumen microbial ecosystem for reducing enteric methane emission in ruminant livestock. This chapter describes in detail the process of rumen methanogenesis and highlights the importance of understanding the relationship between methane-producing microbes with others. The authors of Chap. 16 identified three broad approaches for inhibiting the process of methanogenesis including plant secondary metabolites, microbial intervention, and chemical inhibitors. Further, the authors of this chapter discussed their results on rumen microbial manipulation and its significance on reducing enteric methane production based on their in vitro and in vivo experiments. In addition, these authors concluded that long-term feeding trials are needed to establish whether these feed supplements can provide sustained efforts in methane inhibition for a prolonged period without adaptation of the microbes. Further, they opined that the animals fed these feed supplements should not have any adverse effect on the quality and acceptability of the livestock products. Chapter 17 of Part III deals with the impact of plant secondary metabolites (PSM) on enteric methane reduction. The author of this chapter concluded that there are many naturally occurring compounds that appear to have anti-methanogenic properties, such as tannins, saponins, and essential oils. The author emphasized that researchers are actively engaged in evaluating the potential of these plant secondary constituents as natural means of modifying ruminal fermentation. Further, the author reported the methane reduction potential of PSM including tannins, saponins, and essential oils based on both in vivo and in vitro experiments in ruminant species. Based on the discussion in Chap. 17, the author concluded that although PSM look very promising in suppressing enteric methane emissions in ruminants, results are not consistent in several studies primarily due to great variations in chemical composition of phytochemicals, doses, and feed composition.

Chapter 18 deals with yet another new theme of research, by employing ration balancing technique in improving production efficiency as well as reducing enteric methane emission in ruminant livestock. The authors of Chap. 18 signified the importance of using ration balancing technique for improving both feed conversion efficiency and milk production. Further, it was concluded that ration balancing can be very effective in reducing enteric methane emission in ruminant livestock. Discussions in Chap. 18 lucidly indicate that ration balancing can inhibit methane emission by acting as electron sink as well as by altering the microbial nitrogen supply. Chapter 19 of this volume deals with alternate H sink as one of the primary mechanisms for reducing methanogenesis in ruminant livestock. The authors of this particular chapter signified the importance of reducing methane emission in order to reduce global warming/climate change as compared to other GHGs primarily due to its high global warming potential and a short half-life. Based on their discussion in Chap. 19, the prospects of some emerging approaches to redirect metabolic H_2 away from methanogenesis which may serve as potential alternate sink for H_2 in rumen for conserving the energy were addressed. Further, the alternate H_2 sink as a potential methane reduction strategy by the process of sulfate and nitrate reduction, reductive acetogenesis, and propionogenesis was targeted.

Chapter 20 of Part IV is very important for this volume as it is the sole chapter to address in detail the GHG emission from manure management and its mitigation strategies. The author of Chap. 20 apart from describing the different sources of GHG emission from livestock manure also highlighted the importance of studying ammonia (NH_3) emissions as it contributes to global warming when it is converted to nitrous oxide. Therefore, Chap. 20 targets reduction of GHG as well as ammonia from livestock manure. This chapter specified the mitigation strategies for reducing GHG and ammonia emission from livestock manure based on diet manipulation, manure storage techniques, using additives, manipulating the pH of manure, using chemical inhibitors covering manure storage, anaerobic treatment, and incorporation to soil. Additionally, Chap. 20 also deals with several novel mitigation strategies including manure management to produce value-added products and bioenergy and life cycle analysis to improve productivity and effective use of resources apart from reducing GHG emissions. The final chapter of Part IV (i.e., Chap. 21) of this volume addresses the significance of modeling of GHGs in livestock farms to predict GHG emission and to develop suitable mitigation strategies for the sector. The author of Chap. 21 concluded that computer simulation provides a cost-effective and an efficient method of estimating GHG emissions from dairy farms apart from paving way for developing suitable GHG mitigation strategies. Based on discussions in Chap. 21, the author concluded that it is very difficult to conduct research trials to ascertain the effects of multiple changes on production, economics, and GHG emissions from a dairy production system and further explained that such an attempt would be highly expensive and time consuming. Therefore, the author of Chap. 21 signified the importance of using whole farm models with short-term studies for its validation and confessed that such an attempt would prove to be an attractive alternative for curtailing GHG from livestock farms. Further the author of Chap. 21 emphasized that in simulating the whole farm production process, the integrated farm system model (IFSM) allows for the evaluation and comparison of alternative agronomic, feeding, manure storage, and disposal strategies in terms of production, profitability, and nutrient cycling. In addition, these models also account for the use of fossil fuels used in the production process.

The Part V of this volume covers in detail the various adaptation strategies to improve livestock production under the changing climate scenario. This part is covered in five chapters (Chaps. 22, 23, 24, 25, and 26) addressing the various adaptation, mitigation, and amelioration strategies to counter climate change impact on livestock. Chapter 22 provides an overview on climate change adaptation, mitigation, and amelioration strategies to sustain livestock production. The authors in this chapter concluded that while efforts to mitigate the impact of livestock on climate change are of real concern, simultaneous efforts pertaining to reducing the already existing impact of climate change on livestock production are also equally important. The authors addressed in detail the different adaptation strategies including developing less sensitive breeds, improving water availability, improving animal health, promoting women empowerment, developing various policy issues, establishing early warning systems, and developing suitable capacity-building programs for different stakeholders. Further, they provided a detailed overview on different methane mitigation strategies. The salient mitigation strategies addressed in the chapters were management strategies, nutritional intervention, manipulation of rumen microbial ecosystem, PSM, immunization for reducing enteric methane mitigation, and modeling. In addition, the authors in this chapter highlighted the relevance of various amelioration strategies that are needed to be implemented to sustain livestock production under the changing climate scenario. The various amelioration strategies that were discussed here are physical protection, ideal housing requirements, nutritional intervention, disease surveillance measures, advanced reproductive technologies, and developing breeding program to identify thermotolerant genes in livestock. Finally, they concluded that all three strategies, i.e., adaptation, mitigation, and amelioration strategies, should be implemented simultaneously if one aims at improving livestock production under the changing climate scenario.

Chapter 23 deals in detail shelter designs for different livestock species from climate change perspectives. The authors suggested that considerable efforts are needed to modify the existing shelter design to make them more suitable for the current climate change scenario. These authors suggested that the major shelter design considerations for livestock in the climate change scenario should be thermal stress alleviation, methane mitigation, and space requirement optimization. The chapter focuses on housing requirements for cattle, sheep, goat, pig, rabbit, and poultry to cope up to the existing changing climatic conditions. It was concluded that creation of suitable shelter designs for livestock will ensure food security, reduce stress, and help in carbon recycling. In addition, they emphasized the importance of developing innovative, integrated, and self-sufficient shelter designs for climate change adaptation of animal agriculture and opined that such an attempt is possible only through multidisciplinary approaches. They signified the importance of developing an integrated housing system by highlighting their research findings on the recently developed innovative integrated housing model with goat, rabbit, poultry, and fodder production. This chapter specially targets developing strategies to improve livestock reproduction under the changing climate scenario. Chapter 24 is about various strategies that are available to improve reproduction in the changing climate scenario. Here various management strategies including ideal shelter design and nutritional interventions to reduce the impact of climate change on livestock reproduction were discussed. Special emphasis was given to describe the body condition score technique as one of the important tools to optimize reproductive efficiency in livestock species that gives economically viable returns to livestock farmers. Further, this chapter highlights the importance of developing advanced reproductive technologies including improving follicular dynamics, hormone interventions to improve reproductive cyclicity in animals, timed artificial insemination, embryo transfer, and genetic selection and production of progenies of desired sex to augment reproductive efficiency of livestock. Finally, the authors concluded that if one attempts to improve livestock reproduction in the changing climate, a combination of heat stress ameliorative measures including nutritional management, shelter management, and advanced reproductive strategies is required for harvesting rich dividends.

Chapter 25 of Part V deals with nutritional interventions to sustain livestock production in the changing climate scenario. The authors here particularly discussed in detail the different nutritional strategies that may be implemented to improve the productivity of livestock species under the changing climate scenario. The final chapter of Part V (i.e., Chap. 26) of this volume deals with strategies to improve livestock genetic resources to cope up to the changing climatic scenario. Here, the authors describe various challenges associated with improving animal genetic resources from the climate change perspectives. Further, they emphasized the significance of developing suitable breeding programs involving components of thermotolerance, production and feed efficiency, and disease tolerance and resistance. In addition, the significance of conserving the indigenous germplasms to plan for the future of developing thermotolerant breed was highlighted. Finally, in Chap. 26 it was concluded that it is high time genetic tools are developed involving identification of genes associated with climate change and calls for concerted efforts among multidisciplinary research groups in attainting this milestone by using the emerging technologies to shape up the future of livestock breeding.

The final part of this volume (i.e., Part VI) describes research and development priorities that are required for sustaining livestock production under the changing climate scenario. Chapter 27 signifies the importance of forecasting climate change impact on the livestock sector by 2025. The authors concluded that such a vision can help researchers to plan appropriate preventive strategies for the future that may be a handful to tackle the climate change issues. The authors concluded that such an attempt of visualizing climate change impact on livestock production by 2025 warrants concerted efforts from researchers to develop suitable adaptation and mitigation strategies to sustain livestock production in the changing climate. Apart from this, the authors of Chap. 27 also highlighted the significance of developing policy issues to support researchers involved in research pertaining to climate change and livestock production. The authors of this chapter call for a multidisciplinary approach to develop suitable technological interventions to cope up to climate change and emphasized strengthening extension activities in disseminating such knowledge for the ultimate benefit of livestock farmers who rely heavily on livestock resources for their livelihood security.

27.2 Future Researchable Priorities

Changes in climate and climate variability will affect livestock production systems in all parts of the world and will inevitably impact the 1.3 billion people whose livelihoods are wholly or partially dependent on livestock. At the same time, livestock production is a major contributor to GHG emissions. Therefore, livestock keepers will have to mitigate emissions as well as adapt to the changing climate. The immediate need for livestock researchers aiming to counter climate change impact on livestock production is to understand the biology of climate change impact response components in deep as well as the measures of animal well-being. This will give the researchers a basis for predicting when an animal is under stress or distress and in need of attention. The future research needs for ameliorating heat stress in livestock are to identify strategies for developing and monitoring appropriate measures of heat stress; assess genetic components, including genomics and proteomics of heat stress in livestock; and develop alternative management practices to reduce heat stress and improve animal well-being and performance. Substantial efforts are also needed to identify specific genes associated with tolerance and sensitivity to heat stress. Continued research for evaluating genomic and proteomic approaches to improve reproductive performance and nutritional status of heat-stressed animals is also warranted. Further researches are required to quantify the genetic antagonism between adaptation and production traits to evaluate the potential selection response. With the development of molecular biotechnologies, new opportunities are available to characterize gene expression and identify key cellular responses to heat stress. These new tools enable scientists to improve the accuracy and the efficiency of selection for heat tolerance. Epigenetic regulation of gene expression and thermal imprinting of genome could also be an efficient method to improve thermal tolerance.

27.2.1 Future Strategies for Improving Livestock Production Under the Changing Climate Scenario

If one attempts improving livestock production under the changing climate condition, research efforts are needed to develop strategies encompassing adaptation, mitigation, and amelioration strategies simultaneously, apart from strengthening the existing extension system. Strategies in isolation may not yield results, and hence, combined research efforts are needed to develop strategies covering all aspects of climate change and livestock production. Figure 27.1 describes the future researchable priorities for the livestock sector aiming to sustain livestock production under the changing climate scenario.

27.2.1.1 Adaptation Strategies

The primary focus in adaptation strategies is on developing suitable technological intervention at different stages of livestock production cycle. These technologies should be essentially farmer friendly and cost-effective. Thorough understanding of local resources available and the valuable experiences of local farmers must form the bases for the development of such technologies to ensure easy adoption by the local farmers. For self-sustaining livestock production, economic and eco-friendly nutritional strategies such as search for newer unconventional feeds including herbal and microbial feed additives, organic mineral supplements for better bioavailability, and improved health and production of designer livestock products by modifying the rumen microbes using conventional and advanced biotechniques should be taken up. Newer feed supplements for domesticated animals ensuring their health, immunity, and productivity should be considered. Research efforts to identify specific diets for different disease conditions of livestock also should be developed. Considerable research efforts are also needed to conserve water resources for improving livestock productivity under the changing climate scenario. Water conservation for livestock produc-

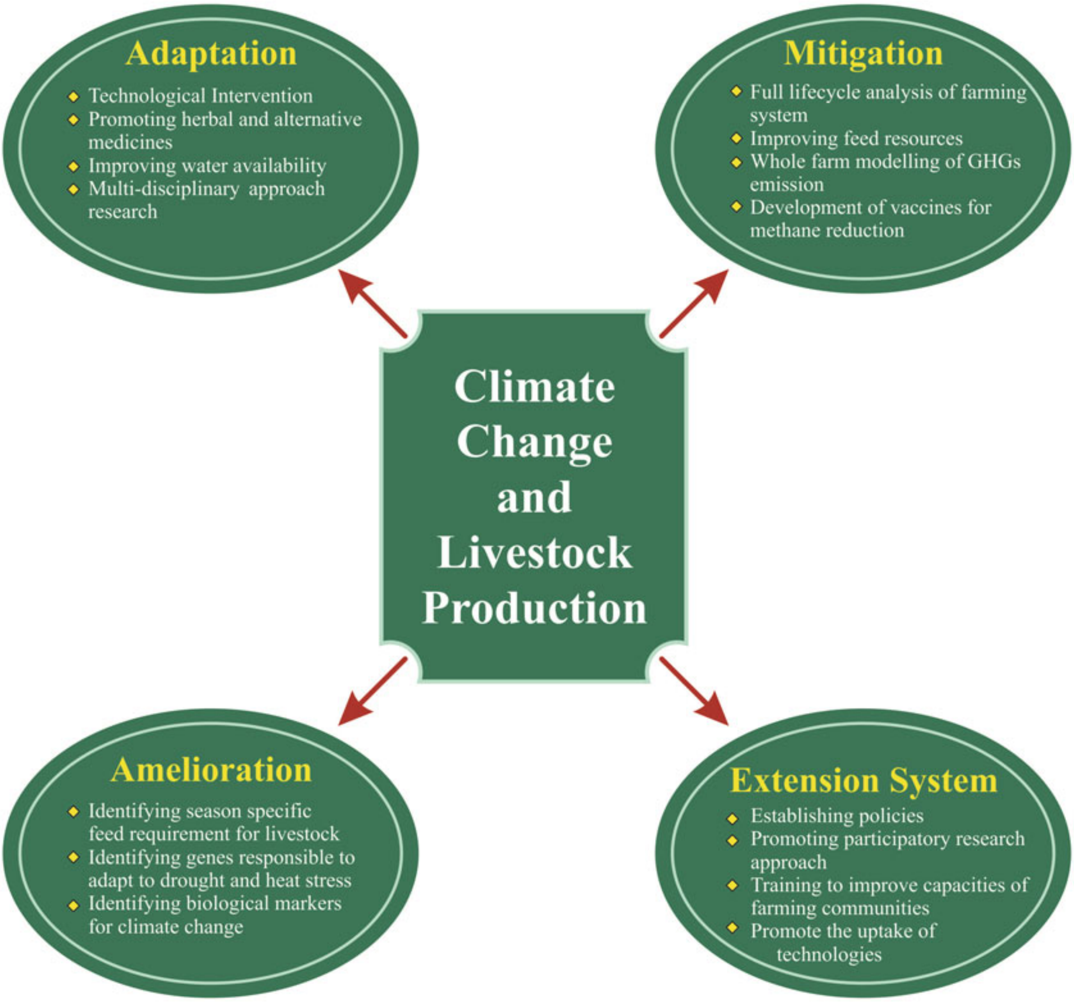


Fig. 27.1 Future researchable priorities for sustaining livestock production in the changing climate scenario

tion in changing climate is relatively a neglected research area, and emphasis should be given to develop such research projects with primary focus on themes including integrating climate adaptation measures in the activities of sustainable use of water resources, enhancing groundwater recharging mechanisms, constructing livestock watering points, and integrating climate adaptation measures in activities supporting sustainable use of water resources.

27.2.1.2 Mitigation Strategies

Considerable research efforts are still needed for mitigating the livestock-related GHG emissions. The primary focuses of such efforts need to concentrate in further refining the LCA models, and other integrated farm system models address mitigation strategies at national/international level. The LCA offers an approach that can relate the emission during the whole production chain to multiple products, irrespective of where in the chain the product boundaries are placed. Improving feed resources for efficient livestock production and diverting research efforts to develop vaccines for enteric methane reduction are some of the other research priorities targeted at mitigating livestock-related GHG emission. There are new needs for further concerted research on methane emission by livestock and its mitigation. For instance, there are several novel and advanced CH_4 mitigation options, including the addition of probiotics, acetogens, bacteriocins, archaeal viruses, organic acids, and plant extracts to the diet, as well as immunization, and genetic selection of animals. Although these new strategies are promising, more research is needed to validate their effectiveness in vivo in reducing CH_4 production in dairy animals. In addition, it is essential to improve the efficacy of current strategies both economically for livestock production and increasing their capacity to limit emissions. Vaccine development against methanogens is promising and calls for concerted research efforts if this strategy is to become a reality. The development of biomarkers to identify low-CH_4-emitting animals or low-CH_4-producing bacteria also merits further investigation. Future developments in the area of modeling must include any improved understanding of the underlying rumen biology. Furthermore, the need to develop simpler and more accurate models that are compatible with current trends in computer technology cannot be overemphasized.

27.2.1.3 Amelioration Strategies

The priority focus of developing ameliorative strategies should be to prevent economic losses incurred due to environmental stresses on livestock productivity. Reducing heat stress in livestock requires multidisciplinary approaches which emphasize animal nutrition, housing, and health. It is important to understand the livestock responses to the environment and analyze them, in order to modify nutritional and environmental management, thereby improving animal comfort and performance. Identifying season-specific feed requirement for livestock offers huge scope for future research. Such research efforts can ensure economically viable returns by reducing the impact of weather parameters on livestock production. Management alternatives, such as the strategic use of wind protection and bedding in the winter or sprinklers and shade in the summer, need to be considered to facilitate livestock cope with adverse conditions. In addition to these changes, manipulation of diet energy density and intake may also be beneficial for livestock challenged by environmental conditions. Another research area which needs due attention is to develop suitable markers for heat and drought stress for livestock. Given the fact of technological advancement, consorted research efforts are also needed to develop new biological markers to identify climate change impact on livestock production and reproduction. Additionally, socioeconomic status, technological tools, and financial infrastructure have pivotal roles in modifying environmental stress response. The ameliorative measures, to be incorporated, are therefore strongly driven by socioeconomic and environmental factors.

27.2.1.4 Strengthening Extension Systems

Establishing an effective extension system is very crucial for disseminating the importance of climate change and livestock production research. Efforts are needed for initiating public awareness and education program on protecting animals from environmental extremes. An extension system should assist the government in developing suitable policies to support the adaptation and mitigation strategies for climate change. Efforts are also needed to strengthen support system for producers through the distribution of inputs and the dissemination of technological knowledge. One of the crucial points for success of climate change adaptation and mitigation program is to promote participatory research approach involving different stakeholders including the ultimate target groups of small and marginal farmers. Capacity-building programs are other important activities of a good extension system that ensures training of manpower for effective implementation of strategies developed for climate change adaptation. Increasing awareness, education, and training for farmers is very crucial for the success of any development program. Considerable efforts are also needed for implementing awareness-creation programs about the effects of GHG emissions, climate change, and natural environment among the farming community to ensure preparedness of those communities to tackle climate change-associated natural calamities. In addition, the extension system should also

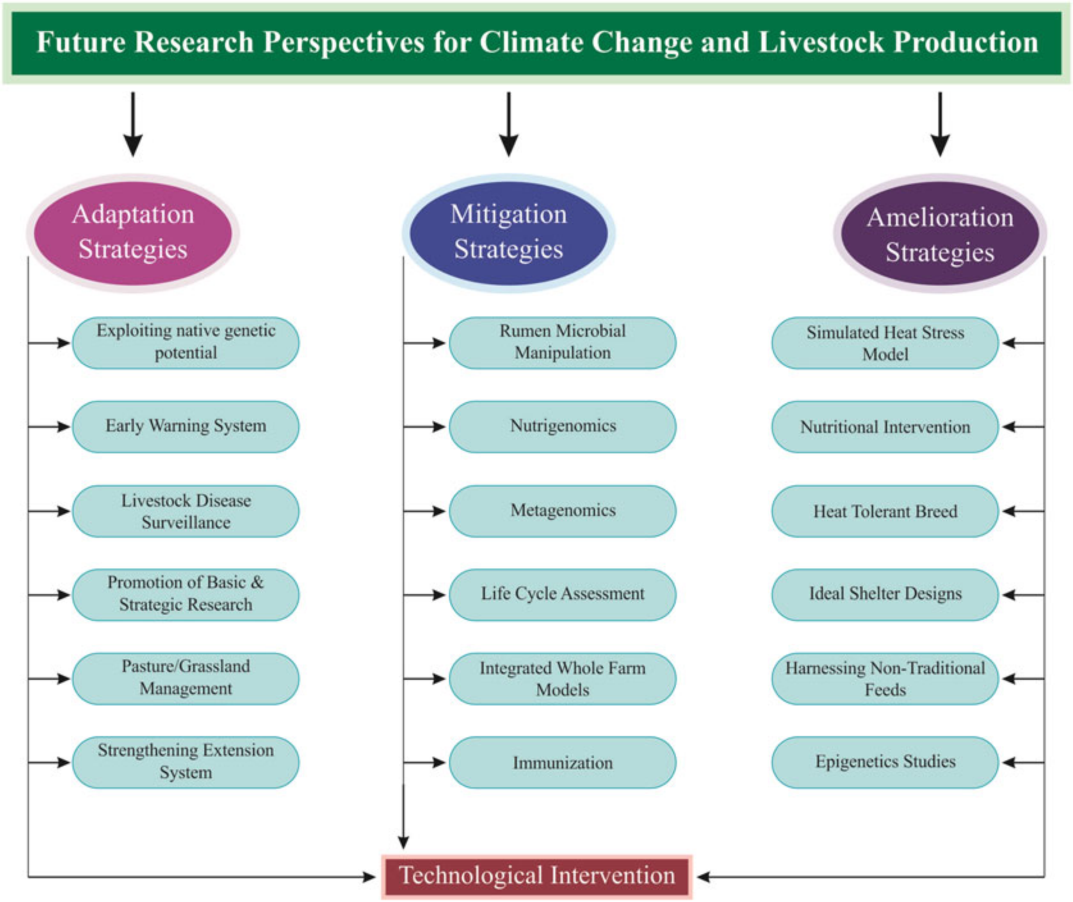


Fig. 27.2 Researchable priorities for climate change adaptation, mitigation, and amelioration strategies in the livestock sector

support crop and animal production by acquiring and distributing agricultural materials, developing income-generating activities in different regions, and promoting animal vaccination camps for successfully sustaining the livestock production under the changing climate scenario.

27.2.2 Other Researchable Priorities

There are in vogue several future priorities that offer ample scope for research pertaining to climate change impact on livestock production. Figure 27.2 describes in detail the various researchable priorities for studying climate change adaptation, mitigation, and amelioration strategies specific to the livestock sector.

27.2.2.1 Technological Interventions to Meet the Climate Change Challenge

Greater emphasis should be given for identification and distribution of indigenous technical knowledge for reducing vulnerability and adaptation to climate change. Technological intervention is needed to protect rich animal genetic diversity. This will enable to characterize the breeds for genetic improvement programs targeting adaptive traits in high-output and performance traits. A variety of technologies can be used to deal with the effects of short-term heat waves, including shading or sprinkling to reduce excessive heat loads. Access to these technologies and to capital will determine the ability of producers to protect their herds from the physiological stress of climate change. The use of multispecies and multi-breed herds is one strategy that many traditional livestock farmers use to maintain high diversity in on-farm niches and to buffer against climatic and economic adversities. Breeding for climate change adaptation and mitigation offers huge scope for technological interventions to develop breeds with high thermotolerant ability. Environment-specific breeding programs are necessary to breed for special adaptability. Selection for heat tolerance in high-output breeds based on rectal temperature measurements and inclusion of a temperature-humidity index (THI) in genetic evaluation models are promising. Research must continue on developing new techniques of cooling systems such as thermo-isolation, concentrating more than in the past on techniques requiring low energy expenditure. New indices that are more complete than THI to evaluate the climatic effects on each animal species must be developed, and weather forecast reports must also be developed with these indices, to inform the farmers in advance. Above all to beat the climate change or in any case not to let the climate beat livestock systems, researchers must be very aware of technologies of water conservation.

27.2.2.2 Exploiting the Genetic Potential of Native Breeds

We need to concentrate not only on breeds that may be of immediate value in current production systems but at the same time will have to consider on the potential long-term benefit of preserving unique allelic diversity across the local breeds that may not have immediate commercial concerns. Strong investments are now needed to expand efforts to identify and preserve the unique traits in our native germplasm. Several molecular tools are now available to identify valuable traits in our indigenous breeds. This pool of information will be crucial in maintaining and increasing productivity in times to come. Adaptation research, particularly for developing and upscaling strategies to cope with climate change, is an important area that needs prime attention. The elucidation of molecular basis of thermotolerance in native breeds and comparing with other livestock species would be key in developing strategies to minimize the effect of heat stress on productivity.

27.2.2.3 Nutritional Research

The development of nutritional strategies to manage heat stress in dairy animals is one of the priority areas of research in livestock adaptation to climate change. Applications of new informations through functional and nutrigenomics studies promise to revolutionize the way agriculturalists and animal scientists think about livestock production. These new information will provide vital clues for studies involving complex metabolic interactions that dictate fertility and influence reproductive efficiency. Applications of molecular technology will provide new ways to evaluate reproductive potential and the basic physiological mechanisms that limit reproductive performance. These technologies will also provide new tools for managing and monitoring livestock fertility. Nutrigenomics studies are becoming important as we acquire an understanding of the relationship between nutrition, genetics, and fertility. These sciences can provide new tools that can be used to more clearly understand how nutritional management can be applied to address disease, performance, and fertility limitations in livestock. Further, research efforts are needed to find the nutritional requirement of stressed animals in the rapidly changing climate scenario. These studies are required to have a clear understanding of these associations at a mechanistic level to fully exploit the potential of nutritionally manipulated production and reproduction in livestock. It is hoped that this approach will be valuable in gaining a thorough understanding of adjusting the nutrient requirements to deal with existing environments and will therefore aid in developing rational managerial decisions to optimize productivity in livestock farms.

27.2.2.4 Early Warning Systems

Predicting and forecasting extreme events are a crucial component for preparedness and response to climate change-associated uncertainties. Efforts are needed to strengthen meteorological services to provide timely weather and climate forecast/information early warning systems (EWS). The primary focus of EWS should be to reduce risks to farmers arising from drought, extreme weather events, and pests and disease outbreaks. The components of EWS should include risk mapping; monitoring and forecasting of weather events and pests and disease outbreaks; system of disseminating information through alerts to producers, municipal officials, and the population at large; and adoption of appropriate methods to respond to these alerts. All efforts need to be taken to work in coordination with other international organizations that are directly involved in climate change and environment change issues. Disaster relief programs include (1) incorporation of an early warning system in the animal relief communities, (2) conduction of joint disaster trainings and exercises with animal protection experts, and (3) incorporation of animal shelter and veterinary clinics to protect livestock against strong wind and earthquake, (4) some information system for disaster management, and (5) disaster recording facility.

27.2.2.5 Livestock Disease Surveillance Measures

On the basis of all aspects about climate change impact on livestock diseases, our planet is likely to face several problems with the livestock productivity. The scientific community and related organizations pertaining to livestock research should take steps ahead to reduce losses from climate disaster to ensure global livestock related food security. A clear futuristic program should be executed to overcome this in the long run. We need to design a global strategy to assist members to reduce/prevent adverse effects of climate and environment changes on animal disease and production. Efforts are needed to conduct mass vaccination programs in the event of sudden outbreaks of diseases. The disease-control program should have provision of trained manpower and resources to implement disease-control strategies in the event of an outbreak. Regular surveillance will provide up-to-date information about changes in pathogen populations. Laboratory and field research will help illuminate how climate change influences pathogen characteristics, and models will help researchers and producers predict and plan for pathogen threats. A nationwide network of research facilities and a history of groundbreaking pathogen research demand cross-field partnerships internationally and nationally. Surveillance of infectious diseases should be increased, and special emphasis must be given for vector-borne and viral diseases where threat of climate change epidemiology is highest. On a global scale, improved disease surveillance and monitoring systems should be implemented with use of geographic information systems (GIS), and modern veterinary and animal health production systems are required to be followed. We can use GIS by which we can both monitor the level of stress and how our climate is changing and monitor the spread of disease. Predictive modeling systems need to be developed to predict the probability of an outcome. Furthermore, laboratory and field research will also help researchers and producers predict and plan for pathogen threats.

27.2.2.6 Rumen Manipulation to Improve Nutrient Utilization

Efforts to beneficially manipulate rumen should differ from country to country primarily due to the differences in type and quantity of feed availability. Efforts need to be made primarily to identify and quantify the enzyme and microbial profile most suited for fiber degradation in the rumen. Once we have identified the most appropriate microbial consortium, efforts need to be made in creating that consortium by selective stimulation of microbes by different feed additives so that optimum level of productivity could be achieved with the feed resources available at farm-gate level. Simultaneously efforts should also be made for exploring the poorly understood microbial diversity in the rumen to better understand the mechanism of energy extraction from poor quality fibrous feeds.

27.2.2.7 Metagenomics and Other Advanced Strategies to Mitigate Methane Emission

Integrated research involving animal, plant, microbe, and nutrient level strategies might offer a long-term solution in methane mitigation. Developing strategies to mitigate methane emissions by manipulating methane-producing microbes in the guts of ruminants through metagenomics approaches offers huge scope. At the animal level, genetic selection is an area of research with the best chance of finding a solution. At the microbe level, vaccination and probiotics are the promising approaches for future research. Advances brought about through rumen metagenomics projects and the utilization of new technologies will broaden our understanding of the mechanisms involved in methanogenesis and other metabolic hydrogen-consuming and hydrogen-releasing processes that will help find new targets for mitigation. Research pertaining to manipulation of methane-producing microbes in the guts of ruminant animals is the need of the hour. Metagenomics offers huge scope to establish the interrelationship among the rumen-residing microbes. This may help to understand the hidden intricacies of rumen methanogenesis. Although new research efforts are in place with respect to application of metagenomics in understanding rumen microbiology, still there are lots of scopes for improvement. It is also important to assess the scope for the application of breeding and genetics along with metagenomics tools to reduce methane emission from the livestock system, while maintaining or improving animal well-being, food safety, quality, and biodiversity. It is therefore inevitable to understand the genetic components of unique characters of our native livestock species and create mechanisms to better exploit them in response to changing environmental conditions.

27.2.2.8 Developing Complete Life Cycle Assessment Models

With the global demand for animal-sourced foods expected to double by 2050, the implications of GHG emissions will be profound. The contributions from animal agriculture to global GHG emissions will therefore increase in importance unless more effective and climate-friendly systems are adopted. Life cycle assessment (LCA) is an appropriate and proven methodology to quantify the environmental impact of a product through the product chain. At the same time, this tool can efficiently be used to identify hot spots and, thereby, improvement options in relation to environmental impacts associated with a certain product. LCA has been the primary focus of researchers currently to reduce the impact of GHG emission from livestock farms; however, there are still scopes for fine-tuning these models to make them more appropriate for curtailing GHG emission. Further refinement in LCA models is required to make it suitable to various production systems which can act as an ideal tool for developing potential mitigation options related to livestock farm. Therefore, considerable research efforts are needed to further refine the existing LCA models.

27.2.2.9 Significance of Whole Farm Modeling

Livestock undoubtedly will be the priority focus of attention as the global community seeks to address the challenge of climate change. The magnitude of the discrepancy among estimates illustrates the need to provide the climate change community and policy makers with accurate emissions estimates and information about the link between animal agriculture and climate. Improving the global estimates of GHG attributed to livestock systems is of paramount importance. This is not only because we need to define the magnitude of the impact of livestock on climate change, but also we need to understand their contribution relative to other sources. Estimates of GHG emission through experiments under different production systems are practically impossible. Growing awareness of global warming and its continuous negative impact on the agricultural production system demands immediate mitigation strategies to curtail such emissions. In this context, simulation models offer greater scope to predict accurately the GHG emission in farms as a whole. Such information will enable effective mitigation options to be designed to reduce emissions and improve the sustainability of the livestock sector while continuing to provide livelihoods and food for large population.

27.2.2.10 Significance of Basic and Strategic Research

To achieve superior and healthy livestock productivity, physiological responses, genes, and allele mining associated with abiotic stress tolerance and immune competence under natural and controlled climatic stress conditions in livestock adaptation, facilitation and amelioration of stress via newer-generation biotechnological approaches are important areas which need research attention. Application of gene-based physiological strategies and exploration of applied molecular biology to improve the livestock resilience for climate change are the need of the hour, and considerable research efforts are needed to augment animal production and performance in farm animals under the changing climate scenario.

27.2.2.11 Simulated Heat Stress Models to Different Species

In the current global perspective on climate change, it is essential to understand the effect of environmental changes on the organism as well as the adaptive mechanisms in their arsenal to combat them. However, only the summer season cannot offer sufficient time to conduct all the research activities and identify solutions. Hence, in order to quickly cope up to the climate change scenario, such research needs to be done round the year. Climate chambers are the only solution to overcome this drawback as it offers enough opportunity to conduct controlled environmental stress-related studies on livestock throughout the year. But the majority of studies involving climatic chambers have used a constant temperature as heat stress model for livestock. However, under field condition, livestock species are not subjected to a constant heat. Hence, it is essential to conduct climatic chamber studies involving simulation of natural heat stress as that would occur in the natural environment based on the climographs of the study location. The latter types of stress models will be more meaningful while attempting to study the impact of heat stress on livestock production. There is a general lack of simulation models for assessing adaptation of livestock. Keeping this in view, a lot of research attempts are needed to develop a heat stress simulation model suitable for different species of livestock to observe their impact on production and adaptation. Such studies would be more meaningful from ethical perspectives and further would be ideal for establishing mitigation strategies as it simulates the natural environmental conditions.

27.2.2.12 Genetic Development of Heat-Resistant Breeds

There are clear genetic differences in resistance to heat stress. Tropically adapted breeds experience lower body temperatures during heat stress than non-adapted breeds. Even in non-adapted breeds, it is probably possible to perform genetic selection for heat resistance. There are specific genes that could be selected which confer increased thermoregulatory ability. It may be possible to identify genes that control cellular resistance to elevated temperature. The superior fertility of tropically adapted breeds during heat stress is due to their better thermoregulation ability during heat stress. However, certain tropically adapted breeds are also more resistant to elevated temperature at the cellular level. Identification of those genes responsible for enhanced cellular resistance to heat shock may allow these genes to be transferred into thermally sensitive breeds through conventional or transgenic breeding techniques to produce an animal whose oocytes and embryos have increased resistance to elevated temperature. The present scenario calls for mining of the genetic resources for identifying the genes/genomic regions associated with thermoregulation and adaptive biology and develops further functional gene resource for native livestock with inherent thermotolerant ability as a model for better understanding of thermoregulation pathways/molecular mechanism of heat stress. A strong foundation for exploitation of molecular markers may be in place for selection of animals with superior adaptive ability.

27.2.2.13 Improving Pasture and Fodder Availability

The use of indigenous and locally adapted fodder grasses as well as the selection and multiplication of crop varieties and races adapted or resistant to adverse conditions will ensure adequate availability of fodder for the livestock. The selection of crops and cultivars tolerant to stresses (e.g., high temperature, drought, flooding, high salt content) as well as resistance to insect pests and diseases helps to utilize the genetic variability in new crop varieties to cope with climate change. There are many fodder crop species already in use with wide range of climatic adaptation, and one crop can be substituted for another to suit the climate. The first priority in breeding would be the screening and development of the vast amount of material already available to develop a robust range of cultivars of each species. It would be prudent to increase collection and screening of more material of forages already in use so that, as change happens, the material will be available to develop cultivars adapted to new conditions. The plant breeders have to play a key role to convert the climate change challenge into an opportunity. Stay-green genotypes possess higher leaf chlorophyll content at all stages of development and more photosynthetically active leaves. A range of traits are being developed in crop and pasture species to help farmers adapt to the impacts of climate change. Similarly, the biotechnologists have greater responsibility in the development of varieties with these improved characteristics.

27.2.2.14 Harnessing Nontraditional Feeds

The worldwide discussion on climate change based on the reported data and evidences of shift in environmental parameters, human health, crop, and livestock production warrants well-thought policies and tested technological innovations to manage the unfavorable outcomes. It is estimated that by 2050, the world needs to feed an additional two billion people and requires 70 % more meat and milk. The increasing future demand for livestock products due to increase in income, population, and urbanization will impose a great demand on feed resources. Sustainability of feed production systems is being threatened due to biophysical factors such as land, soil, and water scarcity, food-fuel-feed competition, and frequent climatic vagaries. One of the immediate answers for sustainable livestock development is the efficient use of available feed resources by expansion of the feed resource basket through research, technology adoption, extension, reduction in wastage, and efficient recycling. Strategies for strengthening the feed/fodder base should focus on regional availability and suitability of potential resources depending on the existing cropping and livestock system. The use of certain nontraditional feed stuffs avoids dependency on conventional ingredients. Perception of end users about the technology and their involvement in technology assessment is a key to successful adoption. Local milk unions, Krishi Vigyan Kendras, organized livestock farms, and village-level self-help groups should act as subcenters of technology transfer and harness benefits of innovation. These efforts should be part of developing climate-resilient management strategies to sustain and improve livestock production.

27.2.2.15 Livestock Shelter Design from Climate Change Perspectives

Livestock need to be protected from extreme changes in climate. Suitable shelter or housing that matches with climatic conditions and type of production system needs to therefore be provided if livestock are to produce optimally. Efforts are needed to develop housing systems ideal to the prevailing agroecological zones. The traditional housing system will not serve the purpose in the changing climatic condition. Therefore, consorted efforts are needed from site selection to construction of housing and the type of housing should match the production systems. The housing site should be a well-drained area and on a floor 1–1.5 m above the ground should the area be waterlogged or prone to flooding. While designing an animal house, the important factors that are to be considered are agroecological condition, local farmer’s opinion, and utilizing low-cost indigenous materials. Further, cost of construction, ease of cleaning, proper ventilation and drainage, and adequate lighting are important aspects to be considered in designing an animal house. The role of extension services is very crucial, and the extension specialists should understand their role that correct housing plays an important role in improving overall animal productivity and advise farmers/pastoralists accordingly.

27.2.2.16 Genomics Tools to Establish Thermotolerance

With the technological advancement, it is possible to identify genes involved in key regulatory/metabolic pathways for thermal resistance/sensitivity using genomic advancements such as whole genome arrays, RNA sequencing, next-generation sequencing (NGS), and whole transcriptome analysis, in different native breeds of livestock. Genome-wide association studies are needed to detect panel of DNA markers associated with the sensitivity of production (milk/meat) and reproduction (semen quality/fertility) traits to heat stress and other environmental stresses. This will aid in selecting animals for high production/reproduction capacity under anticipated climate change scenarios. The identified SNPs can potentially be utilized as markers to screen the variation in animal response (resistance/sensitivity) to heat stress. Once these are validated, they can be utilized in the breeding programs. Such efforts will provide the possibility to introgress desirable genes/alleles and drift herds toward superior tolerant ability against environmental stresses. Efforts are also equally needed to systematically assess and record phenotypes related to adaptive traits in response to different environmental stresses in breeds of livestock to undertake accurate phenotype-genotype association studies in livestock in the current climate change scenario.

27.2.2.17 Studying the Epigenetics of Livestock Adaptation

The DNA methylation and histone modifications are important for the coordinated transcription, replication, and repair process. In all those complex cellular events, cross-talk between DNA methylation and histone modifications may help to maintain correct and ordered recruitment of protein factors onto chromatin for coordinated function. Therefore, deregulation of cross-talk(s) can lead to aberrant outcomes of important biological processes in living cells. The study of epigenetic variation is expected to be an attractive challenge during the next decade. Efforts should focus on proving that DNA methylation (DNAm) marks contribute to variation of traits of interest in the livestock populations. Subsequently, research efforts should focus on the development of technology to detect DNAm on individuals in an affordable manner.

27.2.3 Closing Remarks

Given that the livestock production system is sensitive to climate change and at the same time itself a contributor to the phenomenon, climate change has the potential to be an increasingly formidable challenge to the development of the livestock sector in the world. Responding to the challenge of climate change requires formulation of appropriate adaptation and mitigation options for the sector. Livestock population is expected to increase tremendously over the next few years, and hence, developing an authentic database for GHG inventory is important for studying the future impacts of livestock to climate change. Strategies which are cost-effective, improve productivity, and have no potential negative effects on livestock production hold a greater chance of being adopted by farmers/producers.

In order to make progress along a sustainable development path under the changing climate scenario, more research into alternative models that address the double challenge of food and environmental security is vital. Innovative research is essential to meet the challenge of growing more food for the ever-growing world population on limited land, with less energy and other scarce resources. At the same time, efforts should also be made for improving soil fertility and ecosystems resilience capacity as well as exploring all possibilities for mitigating climate change effects. The development of the “omic” sciences, nanotechnology, robotics, and other technologies is an important component of meeting the challenge. In order to achieve these multiple goals, we need to improve the response capacity of the agriculture knowledge system by promotion of cutting-edge research to produce more with less input and to encourage more systems-oriented research to better understand key issues in terms of functioning and criticality. More investment in these types of research is needed, and a better integration and coordination of research efforts have to be highlighted by establishing more cross-border programs. Economic evaluation of adaptation technologies, appraisal of farmers' responses under different resource conditions, and change in regional, national, and international policies relating to farm-level adaptation and assessment of the investment requirements for coping with the challenges of climate change are some critical areas in which research efforts in social sciences need to be intensified. Immediate and far-reaching changes in current animal agriculture practices and consumption patterns are essential to mitigate adverse climatic effect on livestock production. Indigenous knowledge is an integral part of the culture and history of a local community. We need to learn from local communities to enrich the development process. Understanding the genetic regulation of cutaneous evaporative heat loss and determining the role of heat shock factors (HSF) in coordinating cellular metabolism, thermotolerance, and genetic regulation of nutrient partitioning during thermal stress need special attention for further research. Considering the understanding of homeorhetic regulation of thermoregulation and advancement of technological innovations, it looks very promising to mitigate climatic stress to livestock in the changing climate scenario. This will ultimately lead to sustainable security to livestock production and food and health security to human beings. However, as physiological phenomenons are very precisely and finely adjusted to maintain interior milieu of the body, any irrational modulation may disturb the physiological mechanism of the body. Therefore, it will require utmost care and vigilance as well as keeping pace with scientific developments.

Abbreviations

Ac-CoA	Acetyl-coenzyme-A
AD	Anaerobic digester
ADF	Acid detergent fiber
AERs	Adverse Event Reporting System
AFCS	Accounting for Forest Carbon Stocks
AFOLU	Agriculture Forestry and Other Land Use
AGRI	Animal Genetic Resources of India
AHS	African horse sickness
AI	Artificial insemination
AIV	Avian influenza virus
AnGR	Animal Genetic Resources
AR5	IPCC Fifth Assessment Report
ATP	Adenosine triphosphate
BAT	Best Available Technique
BCM	Bromochloromethane
BCS	Body condition scoring
bLS	Backward Lagrangian stochastic
BOD	Biochemical oxygen demand
bST	Bovine somatotropin
BTA	Bos taurus autosome
BW	Body weight
C3 cycle	Calvin cycle
C4 cycle	Hatch and Slack pathway
CAAS	Chinese Academy of Agricultural Science
CAPRI	Common Agricultural Policy Regionalized Impact
CAR	Climate Action Reserve
CBMs	Carbohydrate-binding modules
CBP	Calvin-Benson photosynthetic cycle
CBP	*C*apacity Building Program
CC	Climate change
CCN	Cloud-condensation nuclei
CCX	Chicago Climate Exchange
CDM	Clean Development Mechanism
CEFM	Cattle Enteric Fermentation Model
CER	Certified Emission Reduction
CF	Crude fibre
CFCl$_3$	Chloroflurocarbon
CFCs	Chlorofluorocarbons
CGIAR	Consultative Group on International Agricultural Research
CH$_4$	Methane
CHCl$_3$	Hydrofluorocarbon
CIDR	Controlled Intravaginal Drug Releasing Device
CL	Corpus luteum
CLAs	Conjugated linoleic acids
CO	Carbon monoxide
CO$_2$	Carbon dioxide
CO$_2$e	CO$_2$ equivalent
COD	Chemical oxygen demand
COP	Conference of Parties
COX-2	Cyclooxigenase-2
CP	Crude protein
CS	Cold stress
CSA	Climate smart agriculture
CSIRO	Commonwealth Scientific and Industrial Research Organization
CT	Condensed tannin
DAD-IS	Domestic Animal Diversity Information System
DAGRIS	Domestic Animal Genetic Information System
DCD	Dicyandiamide
DE	Digestible energy
DFM	Direct-fed microbials

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1, © Springer India 2015

DHA	Docosahexanoic acid
DM	Dry matter
DMI	Dry matter intake
Dw	Dwarfism
EEA	European Environment Agency
EF	Emission factors
EGTs	Environmental gene tags
EMEP	Evaluation of the Long-Range Transmission of Air Pollutants in Europe
ENM	Environmental niche modelling
ENSO	El Nino Southern Oscillation
EO	Essential oils
EPA	Environmental Protection Agency
ET	Embryo transfer
ETS	Emissions trading scheme
ETT	Embryo transfer technology
EU	European Union
EUETS	European Union Emission Trading System
EWE	Extreme weather events
EWS	Early Warning Systems
F	Frizzle
FAA	Free fatty acids
FACE	Free-air carbondioxide enrichment
FAD	Ferridoxin adenosine dinucleotide
FADH	Ferridoxin adenosine dinucleotide phosphate
FAO	Food and Agricultural Organization
FCE	Feed conversion efficiency
FCM	Fat corrected milk
FCR	Feed conversion ratio
FEC	Faecal worm egg counts
FFA	Free fatty acid
FI	Feed intake
FID	Flame ionization detector
FMD	Foot-and-mouth disease
FOLU	Forestry and other land use changes
FPCM	Fat and protein corrected milk
FSH	Follicle stimulating hormone
GAINS	Greenhouse gas and air pollution interactions and synergies
GDP	Gross domestic product
GE	Gross energy
GEBVs	Genomic estimated breeding values
GEI	Genotype environment interaction
GH	Growth hormone
GHG	Greenhouse gas
GHGF	Greenhouse gas emission footprint
GHGI	Greenhouse gas inventory
GHGs	Greenhouse gases
GHs	Glycoside hydrolases
GI	Gastrointestinal
GIS	Geographic Information System
GLEAM	Global Livestock Environmental Assessment Model
GnRH	Gonadotrophin releasing hormone
GOS	Galacto-oligosaccharide
GPX	Glutathione peroxidase
GS	Genomic selection
GSH	Glutathione
GWAS	Genome-Wide Association Study
GWP	Global warming potential
GxE	Genotype-by-environment interactions
H_2	Hydrogen
H_2O_2	Hydrogen peroxide
H_2S	Hydrogen sulfide
Hb	Haemoglobin
hCG	Human chorionic gonadotrophin
HFC	Hydrofluorocarbon
HO-1	Heme oxygenase-1
HPA	Hypothalamo-pituitary-adrenal axis
HPU	Heat producing unit
HS	Heat shock
HS	Heat stress
HSFs	Heat shock factors
HSP	Heat shock protein
HT	Hydrolyzable tannin
HW	Hardy Weinberg
IFAD	International Fund for Agricultural Development
IFN	Interferon
IFSM	Integrated farm system model
IGF-1	Insulin like growth factor-1
ILRI	International Livestock Research Institute
IMAGE	Integrated Model to Assess the Global Environment
IMPACT	International Model Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change

IR	Infrared
IT	Information technology
IVGPT	In vitro gas production technique
IVP	In vitro embryo production
IWRM	Integrated water resources management
JI	Joint implementation
KP	Kyoto Protocol
LCA	Life cycle assessment
LH	Luteinizing hormone
LLS	Livestock's long shadow
LMD	Laser methane detector
LPG	Liquefied petroleum gas
LPS	Lipopolysaccharide
LUCF	Land-use change and forestry
LUD	Livestock unit density
LULUCF	Land-use, land-use change and forestry
MA-BE	Marker assisted breeding value estimation
MAS	Marker assisted selection
MB	Methanogenic bacteria
mcrA	Methyl coenzyme M reductase gene
ME	Metabolizable energy
MEI	Multivariate ENSO Index
MFR	Methane-furan coenzyme
MGRAST	Metagenome rapid annotation system tools
MOET	Multiple ovulation and embryo transfer
MPP	Methane production potential
MRV	Measurement, reporting and verification
N	Nitrogen
N_2O	Nitrous oxide
NAD	Nicotinamide adenosine dinucleotide
NADH	Nicotinamide adenine dinucleotide hydrate
NADP	Nicotinamide adenosine dinucleotide phosphate
NAMA	Nationally Appropriate Mitigation Actions
NAPA	National Adaptation Programs for Action
NBAGR	National Bureau of Animal Genetic Resources
ND	Newcastle Disease
NDDB	National Dairy Development Board
NDF	Neutral detergent fiber
NEFA	Non-esterified fatty acid
NGS	Next generation techniques
NH_3	Ammonia
NH_3-N	Ammoniacal nitrogen
NH_4^+	Ammonium
NMVOC	Non-methane volatile organic compounds
NO	Nitric oxide
NO_2^-	Nitrite
NO_2	Nitrogen dioxide
NO_3^-	Nitrate
NOAA	National Oceanic and Atmospheric Administration
NOx	Nitrogen oxides
NP	Nitrooxypropanol
NPL	National Physical Laboratory
NPN	Non-protein nitrogen
Nramp1	Natural resistance associated macrophage protein 1
NRC	National Research Council
NSC	Non-structural carbohydrates
O_2	Oxygen
O_3	Ozone
°C	Centigrade
OIE	World Organization for Animal Health
OM	Organic matter
OPU	Ovum pick up
OTC	"Over-the-counter" market
OTUs	Operational taxonomic units
PBMC	Peripheral blood mononuclear cells
PCV	Packed cell volume
PEM	Polioencephalomalacia
PFCs	Per fluorocarbons
PFTN	Pair-fed thermal neutral
PGA1	Prostaglandin A1
PGF2α	Prostaglandin F2α
PGH	Prostaglandin-H_2
PMSG	Pregnant mare serum gonadotropin
ppm	Parts per million
PPR	Peste des petits ruminants
PR	Pulse rate
PRID	Progesterone impregnated intravaginal device
PSM	Plant secondary metabolites
PSS	Porcine stress syndrome

PTGS2	Prostaglandin endoperoxidase synthase 2
PUFA	Polyunsaturated fatty acids
PVC	Polyvinyl chloride
QD	Quality data
QTL	Quantitative trait locus
RATC	Resistance to antibiotics and toxic compounds
RBP	Ration balancing programme
RCC	Reinforced cement concrete
RCP	Representative concentration pathways
REDD	Reduced emissions from deforestation and degradation
RFI	Residual feed intake
RFID	Radio frequency identification
RH	Relative humidity
ROS	Reactive oxygen species
RR	Respiration rate
RT	Rectal temperature
RVF	Rift Valley fever
SC	Structural carbohydrates
SCP	Single cell protein
SF5CF3	Trifluoromethyl sulphur pentafluoride
SF_6	Sulphur hexafluoride
SFA	Saturated fatty acids
SIMS	Sustainable and Integrated Management Systems
SNF	Solid not fat
SNPs	Single nucleotide polymorphisms
So_2	Sulfur dioxide
SOC	Soil organic carbon
SOD	Superoxide dismutase
SOM	Soil organic matter
SOV	Superovulation
SPEED	Sustainably Priced Energy Enterprise Development
SRB	Sulfate reducing bacteria
SRES	Special Report on Emissions Scenarios
SRI	System of Rice Intensification
T_3	Tri-ido-thryronine
T_4	Thyronine
TAN	Total ammoniacal nitrogen
TBA	Tannin bioassay
TCC	Thermochemical conversion
TDN	Total digestible nutrients
TDS	Total dissolved solids
Tg	Teragram
THI	Temperature Humidity Index
TKN	Total Kjeldahl nitrogen
TN	Thermal neutral
TNZ	Thermo-neutral zone
TS	Total solids
UNCCD	United Nations Convention to Combat Desertification
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	US Environmental Protection Agency
VERs	Verified (or Voluntary) Emission Reductions
VFA	Volatile fatty acid
VFI	Voluntary feed intake
VOC	Volatile organic compounds
VS	Volatile solids
WBCSD	World Business Council for Sustainable Development
WHO	World Health Organization
WMO	World Meteorological Organization
WRI	World Resources Institute
WSC	Water soluble carbohydrates

Glossary

Acclimatisation A long-term adaptive physiological adjustment which results in an increased tolerance to continuous or repeated exposure to complex climatic stressors (normally produced under field conditions).

Acid Detergent Fibre The ADF value refers to the cell wall portions of the forage that are made up of cellulose and lignin. These values are important because they relate to the ability of an animal to digest the forage. ADF is related to forage digestibility (energy) and is used to calculate forage total digestible nutrients (TDN) or net energy (NE) for hay, haylage and corn silage.

Adaptation (Biological) The morphological, anatomical, physiological, biochemical and behavioural characteristics of the animal which promote welfare and favour survival in a specific environment.

Adaptation (Genetic) The heritable animal characteristic alterations which favour survival of a population in a particular environment. This may involve evolutionary changes over many generations (selected by nature) or acquiring specific genetic properties (selection by man).

Adaptation (Physiological) The capacity and process of adjustment of the animal to itself, to other living material and to its external physical environment.

Adaptation Adaptation is the evolutionary process whereby an organism becomes better able to live in its habitat or habitats.

Adverse Event Reporting System It refers to a computerised information database designed to support the US Food and Drug Administration's (FDA) post-marketing safety surveillance programme for all approved drug and therapeutic biologic products. FDA receives some adverse event and medication error reports directly from health care professionals (such as physicians, pharmacists, nurses and others) and consumers (such as patients, family members, lawyers and others). AERS is a useful tool for FDA, which uses it for activities such as looking for new safety concerns that might be related to a marketed product, evaluating a manufacturer's compliance to reporting regulations and responding to outside requests for information.

Agriculture Forestry and Other Land Use Is a term from the 4th assessment report of the Intergovernmental Panel on Climate Change (IPCC) describing a category of activities which contribute to anthropogenic greenhouse gas (GHG) emissions. Used in national greenhouse gas inventories, the AFOLU category combines two previously distinct sectors LULUCF (Land Use, Land-Use Change and Forestry) and Agriculture. AFOLU accounts for more than 30 % of total anthropogenic GHG emissions.

Ambient Temperature Ambient temperature simply means 'the temperature of the surroundings' or temperature of the immediate environment.

Ammonia A colourless gas with a characteristic pungent smell, which dissolves in water to give a strongly alkaline solution.

Ammoniacal Nitrogen Is a measure for the amount of ammonia, a toxic pollutant often found in landfill leachate and in waste products,

V. Sejian et al. (eds.), *Climate Change Impact on Livestock: Adaptation and Mitigation*,
DOI 10.1007/978-81-322-2265-1, © Springer India 2015

such as sewage, liquid manure and other liquid organic waste products. It can also be used as a measure of the health of water in natural bodies such as rivers or lakes or in man-made water reservoirs. The term is used widely in waste treatment and water purification systems.

Anaerobic Digester Anaerobic digester is an airtight, oxygen-free container that is fed an organic material, such as animal manure or food scraps. A biological process occurs to this mixture to produce methane gas, commonly known as biogas. Anaerobic digesters provide a variety of environmental and public health benefits including greenhouse gas abatement, organic waste reduction, odour reduction and pathogen destruction.

Animal Genetic Resources of India An information system on Animal Genetic Resources of India covering all domestic livestock and poultry species information. The database is designed such that it can store information on all aspects of animal resources in an integrated form. This database has the facility to store district-wise information on animal resources with respect to population, infrastructure, production, farms, semen availability, vaccine production, import and export and also on breed description.

AR5 (IPCC Fifth Assessment Report) AR5 provides a clear and up-to-date view of the current state of scientific knowledge relevant to climate change. It consists of three Working Group (WG) reports and a Synthesis Report (SYR) which integrates and synthesises material in the WG reports for policymakers. The SYR will be finalised on 31 October 2014.

Artificial Insemination Is the deliberate introduction of sperm into a female's uterus or cervix for the purpose of achieving a pregnancy through in vivo fertilisation by means other than sexual intercourse. It is a fertility treatment.

Backward Lagrangian Stochastic This is one of the methods by which methane is estimated. This provides an efficient method for calculating dispersion of methane from area sources.

Best Available Technique Is a term applied with regulations on limiting pollutant discharges with regard to the abatement strategy. Similar terms are *best available techniques*, *best practicable means* or *best practicable environmental option*. The term constitutes a moving target on practices, since developing societal values and advancing techniques may change what is currently regarded as 'reasonably achievable', 'best practicable' and 'best available'.

Biochemical Oxygen Demand Is the amount of dissolved oxygen needed by aerobic biological organisms in a body of water to break down organic material present in a given water sample at certain temperature over a specific time period. The BOD value is most commonly expressed in milligrams of oxygen consumed per litre of sample during 5 days of incubation at 20 °C and is often used as a robust surrogate of the degree of organic pollution of water.

Bioclimatology The branch of climatology which deals with the relations of climate with animals and plants.

Biometeorology Biometeorology is an interdisciplinary science studying the interactions between atmospheric processes and living organisms—plants, animals and humans. The most important question that biometeorology answers is: *How does weather and climate impact the well-being of all living creatures?* This would include reproduction, population fluctuations and general health of the organism community.

Body Condition Scoring An assessment of relative proportions of muscle and fat in farm animals. The assessment is made by the palpation of the amount of tissue cover between the points of the hip, over the transverse processes of the lumbar vertebrae, the cover over the ribs and the pin bones below the tail to determine the thickness of fat cover in these areas.

Bovine Somatotropin Is a peptide hormone produced by the cow's pituitary gland. Like other hormones, it is produced in small quantities and is used in regulating metabolic processes.

Bromochloromethane It is a heavy low-viscosity liquid with refractive index 1.4808. The Environment Protection Agency describes it as a substance that depletes the ozone layer.

C3 Cycle (Calvin Cycle) Is a series of biochemical redox reactions that take place in the stroma of chloroplasts in photosynthetic organisms. It is also known as the light-independent reactions. It uses the energy from short-lived electronically excited carriers to convert carbon dioxide and water into organic compounds that can be used by the organism (and by animals that feed on it). This set of reactions is also called *carbon fixation*.

C4 Cycle (Hatch and Slack Pathway) Is one of the three biochemical mechanisms used in carbon fixation. It is named for the 4-carbon molecule present in the first product of carbon fixation in the small subset of plants known as C_4 plants, in contrast to the 3-carbon molecule products in C_3 plants.

Capacity Building Programme It refers to the training of different stakeholders associated with climate change adaptation. It is very crucial for the successful implementation of adaptation strategies. CBP should address in detail the basic understanding of climate change science, climate change impacts on biodiversity and ecosystems and implication for conservation and sustaining eco-services and strategies for assessing vulnerability and adaptation.

Carbon Dioxide Is a naturally occurring chemical compound composed of two oxygen atoms each covalently double bonded to a single carbon atom. It is a gas at standard temperature and pressure and exists in the Earth's atmosphere in this state, as a trace gas at a concentration of 0.04 % (400 ppm) by volume, as of 2014. It is the gas which is the single largest contributor to global warming.

Carbon Monoxide Is a colourless, odourless and tasteless gas that is slightly less dense than air. It is toxic to humans and animals when encountered in higher concentrations, although it is also produced in normal animal metabolism in low quantities and is thought to have some normal biological functions. In the atmosphere, it is spatially variable and short lived, having a role in the formation of ground-level ozone.

Cattle Enteric Fermentation Model Is a spreadsheet-based model used to calculate methane emissions from cattle enteric fermentation based on a 'rolling herd' population characterisation that tracks cattle energy demand through different growth stages. These energy demands are then correlated with methane production based on diet and animal characteristics. The CEFM is based on the IPCC Good Practice Guidance Tier 2 approach (IPCC 2000).

Certified Emission Reduction These are a type of emissions unit (or carbon credits) issued by the Clean Development Mechanism (CDM) Executive Board for emission reductions achieved by CDM projects and verified by a DOE under the rules of the Kyoto Protocol.

Chemical Oxygen Demand Is used to indirectly measure the amount of organic compounds in water. Most applications of COD determine the amount of organic pollutants found in surface water (e.g. lakes and rivers) or waste water, making COD a useful measure of water quality. It is expressed in milligrams per litre (mg/L) also referred to as ppm (parts per million), which indicates the mass of oxygen consumed per litre of solution.

Chicago Climate Exchange Was North America's only voluntary, legally binding greenhouse gas (GHG) reduction and trading system for emission sources and offset projects in North America and Brazil. It employed independent verification, included six GHGs, and traded GHG emission allowances from 2003 to 2010. The companies joining the exchange committed to reducing their aggregate emissions by 6 % by 2010. CCX had an aggregate baseline of 680 million metric tons of CO_2 equivalent.

Chinese Academy of Agricultural Science Is a national agricultural research institution undertaking China's agricultural research and development in both basic and applied sciences as well as new and advanced application technology. CAAS plays an important role in solving the fundamental and strategic technological issues in agriculture and rural economic development, training advanced researchers, integrating agriculture with science and technology and developing agricultural science and technology exchanges and cooperation.

Chlorofluorocarbon Is an organic compound that contains only carbon, chlorine and fluorine, produced as a volatile derivative of methane, ethane and propane. The most common representative is dichlorodifluoromethane (R-12 or Freon-12). Many CFCs have been widely used as refrigerants, propellants (in aerosol applications) and solvents. Because CFCs contribute to ozone depletion in the upper atmosphere, the manufacture of such compounds has been phased out under the Montreal Protocol, and they are being replaced with other products such as HFCs and CO_2.

Clean Development Mechanism Is one of the flexibility mechanisms defined in the Kyoto Protocol (IPCC 2007) that provides for emissions reduction projects which generate Certified Emission Reduction units which may be traded in emissions trading schemes. The CDM is defined in Article 12 of the Protocol and is intended to meet two objectives: (1) to assist parties not included in Annex I in achieving sustainable development and in contributing to the ultimate objective of the United Nations Framework Convention on Climate Change (UNFCCC), which is to prevent dangerous climate change, and (2) to assist parties included in Annex I in achieving compliance with their quantified emission limitation and reduction commitments (greenhouse gas (GHG) emission caps).

Climate Action Reserve The Climate Action Reserve is a national offsets programme focused on ensuring environmental integrity of GHG emissions reduction projects to create and support financial and environmental value in the US carbon market. It does this by establishing high-quality standards for quantifying and verifying GHG emissions reduction projects, overseeing independent third party verification bodies, issuing carbon credits generated from such projects and tracking the credits over time on a transparent, publicly accessible system. These standards not only ensure the environmental integrity of using offsets but they also bring credibility and efficiencies to the carbon market by creating a trusted and valuable commodity.

Climate Change Is a significant and lasting change in the statistical distribution of weather patterns over periods ranging from decades to millions of years. Climate change may be limited to a specific region or may occur across the whole Earth. It refers to changes in measures of climate such as temperature and rainfall for a given area persisting for an extended period, typically decades or longer. Climate change can involve cooling or warming. Climate change may result from natural factors (e.g. changes in the sun’s energy, volcanic eruption), natural processes within the climate system (e.g. changes in ocean circulation) and human activities (e.g. burning of fossil fuels, agriculture).

Climate Smart Agriculture Is an approach to develop the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change.

Climate The long-term (some 30 years) average condition of the meteorological variable in a given region. The pattern or cycle of weather conditions such as temperature, wind, rain, snowfall, humidity and clouds, including extreme or occasional ones, over a large area, averaged over many years.

Climatography A thorough, quantitative description of climate, particularly with reference to the tables and charts which show the characteristic values of climatic elements at a station or over an area.

Climatology The scientific study of climate and presentation of climatic data (climatography), analysis of the causes of differences of climate (physical climatology) and the application of climatic data to the solution of specific design or operational problems (applied climatology).

CO_2 Equivalent Measures for describing how much global warming a given type and amount of greenhouse gas may cause, using the functionally equivalent amount or concentration of carbon dioxide (CO_2) as the reference. It is the concentration of CO_2 that would cause the same level of radiative forcing as a given type and concentration of GHGs. Examples of such greenhouse gases are methane, perfluorocarbons and nitrous oxide. CO_2e is expressed as parts per million by volume, ppmv.

Cold Stress Is one of the types of environmental stresses where livestock are exposed as a result of changing climate. It is a response of the body to cold temperatures resulting from heat loss from a portion of the body, such as the feet, hands, limbs or head.

Common Agricultural Policy Regionalized Impact Is a success story of an economic model developed by European Commission research funds. Operational since almost a decade, it supports decision making related to the Common Agricultural Policy based on sound scientific quantitative analysis. CAPRI is only viable due to its Pan-European network of researchers which based on an open source approach tender together for projects, develop and maintain the model, apply it for policy impact assessment, write scientific publications and consult clients based on its results.

Commonwealth Scientific and Industrial Research Organisation Australia's national science agency and one of the largest and most diverse research agencies in the world.

Condensed Tannin Are polymers formed by the condensation of flavans. They do not contain sugar residues.

Consultative Group on International Agricultural Research Is an international organisation which funds and coordinates research into agricultural crop breeding with the goal of 'reducing rural poverty, increasing food security, improving human health and nutrition, and ensuring more sustainable management of natural resources'. It does this through a network of 15 research centres known as the CGIAR Consortium of International Agricultural Research Centres.

Controlled Intravaginal Drug-Releasing Device This device is used in livestock for the synchronisation of estrus. They are T-shaped devices with a silicone-coated nylon core. The silicone coating is impregnated with progesterone. CIDRs are inserted intravaginally using a specialised applicator. The flexible wings collapse for facilitated insertion and expand once placed appropriately within the vagina. The expansion of the wings retains its position; CIDRs have very high retention rates that may exceed 97 %. A thin nylon tail remains exteriorised and is used for removal. Once inserted, CIDRs provide slow-release administration of progesterone, which artificially extends the luteal phase. Plasma progesterone levels rapidly increase upon insertion and remain relatively consistent while in place. Following CIDR removal, progesterone levels decrease rapidly. Occasionally, vaginal irritation may occur. This is normal and does not impact the effectiveness of the device or the animal's performance.

Corpus Luteum Is a temporary endocrine structure in female mammals that is involved in the production of relatively high levels of progesterone and moderate levels of estradiol and inhibin A. It is coloured as a result of concentrating carotenoids (including lutein) from the diet and secretes a moderate amount of estrogen to inhibit further release of gonadotropin-releasing hormone (GnRH) and thus secretion of luteinising hormone (LH) and follicle-stimulating hormone (FSH).

Crude Fibre A measurement of fibre content. Also known as Weende cellulose, it is the insoluble residue of an acid hydrolysis followed by an alkaline one. This residue contains true cellulose and insoluble lignin. It is also used to assess hair, hoof or feather residues in animal by-products.

Crude Protein Is the approximate amount of protein in foods that is calculated from the determined nitrogen content by multiplying by a factor (as 6.25 for many foods and 5.7 for wheat) derived from the average percentage of nitrogen in the food proteins and that may contain an appreciable error if the nitrogen is derived from nonprotein material or from a protein of unusual composition.

Cyclooxigenase-2 Officially known as prostaglandin-endoperoxide synthase (PTGS), is an enzyme that is responsible for the formation of important biological mediators called prostanoids, including prostaglandins, prostacyclin and thromboxane.

Digestible Energy Is the gross energy of feed minus the gross energy of faeces. Therefore, this energy system takes into account the digestibility of feed and gives a useful measure of the energy the animal may be able to use.

Direct-Fed Microbials Are feed additives that contain microbial species that are considered to be nonpathogenic normal flora. A probiotic is defined as 'a live microbial feed supplement which beneficially affects the host by improving its intestinal microbial balance'. Probiotics are also referred to as 'direct-fed microbials'. The US Food and Drug Administration (FDA) defines direct-fed microbials as 'products that are purported to contain live (viable), naturally occurring microorganisms (bacteria/or yeast)'.

Domestic Animal Diversity Information System It is a communication and information tool for implementing strategies for the management of animal genetic resources (AnGR). It provides the user with searchable databases of breed-related information and images, management tools and a library of references, links and contacts of Regional and National Coordinators for the Management of Animal Genetic Resources. It provides countries with a secure means to control the entry, updating and accessing of their national data.

Domestic Animal Genetic Information System Is a web-based electronic source of information on selected indigenous farm animal genetic resources (breeds/ecotypes of cattle, sheep, goats, chicken and pigs) with options to extend it further to cover geese, turkey and ducks. DAGRIS is an information system designed to facilitate the compilation, organisation and dissemination of information on the origin, distribution, diversity, present use and status of indigenous farm animal genetic resources from past and present research results in an efficient way. The underlying concept is that such information provides the necessary basis for developing breed improvement as well as conservation programmes.

Dry Matter Intake Refers to feed intake excluding its water content.

Dry Matter This refers to the dry portion of animal feed. A substance in the feed, such as a nutrient or toxin, can be referred to on a dry matter basis to show its level in the feed (e.g. ppm). Considering nutrient levels in different feeds on a dry matter basis (rather than an as-is basis) makes a comparison easier because feeds contain different percentages of water.

Early Warning Systems Is a major element of disaster risk reduction. It prevents loss of life and reduces the economic and material impact of disasters. To be effective, early warning systems need to actively involve the communities at risk, facilitate public education and awareness of risks, effectively disseminate messages and warnings and ensure there is constant state of preparedness. A complete and effective early warning system is more than about supporting the prediction of catastrophic environment events; it supports four main functions, spanning knowledge of the risks faced through to preparedness to act on early warning. These four functions are risk analysis, monitoring and warning, dissemination and communication and a response capability.

El Niño Southern Oscillation Refers to the effects of a band of sea surface temperatures which are anomalously warm or cold for long periods of time that develops off the western coast of South America and causes climatic changes across the tropics and subtropics. The 'Southern Oscillation' refers to variations in the temperature of the surface of the tropical eastern Pacific Ocean and in air surface pressure in the tropical western Pacific. The two variations are coupled: the warm oceanic phase, El Niño, accompanies high air surface pressure in the Western Pacific, while the cold phase, *La Niña*, accompanies low air surface pressure in the Western Pacific.

Embryo Transfer Technology Is a technique by which embryos are collected from a donor female and are transferred to recipient females, which serve as surrogate mothers for the remainder of pregnancy. Embryo transfer techniques have been applied to nearly every species of domestic animal and to many species of wildlife and exotic animals, including humans and non-human primates.

Embryo Transfer Refers to a step in the process of assisted reproduction in which embryos are placed into the uterus of a female with the intent to establish a pregnancy. The objective of embryo transfer is to facilitate conception following fertilisation from the in vitro fertilisation procedure.

Emission Factors Is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere with an activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant divided by a unit weight, volume, distance or duration of the activity emitting the pollutant (e.g. kilograms of particulate emitted per megagram of coal burned). Such factors facilitate estimation of emissions from various sources of air pollution. In most cases, these factors are simply averages of all available data of acceptable quality and are generally assumed to be representative of long-term averages for all facilities in the source category.

Emissions Trading Scheme Is a market-based approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. A central authority (usually a governmental body) sets a limit or *cap* on the amount of a pollutant that may be emitted. The limit or cap is allocated or sold to firms in the form of emissions permits which represent the right to emit or discharge a specific volume of the specified pollutant. Firms are required to hold a number of permits (or allowances or *carbon credits*) equivalent to their emissions. The total number of permits cannot exceed the cap, limiting total emissions to that level. Firms that need to increase their volume of emissions must buy permits from those who require fewer permits.

Environmental Gene Tags Are short DNA sequences used to characterise and distinguish microbial environments. EGT include fragments or complete sequences of genes that are important to survive in specific environmental condition and hence are present in the genomes of many microbes of one environment and lower or even non-present in another. The frequency of all EGT sequences in the whole genomic content of a specific environment is used as a fingerprint that characterises the environmental adaptation of microbes.

Environmental Niche Modelling Refers to the process of using computer algorithms to predict the distribution of species in geographic space on the basis of a mathematical representation of their known distribution in environmental space (= realised ecological niche). The environment is in most cases represented by climate data (such as temperature and precipitation), but other variables such as soil type, water depth and land cover can also be used. These models allow for interpolating between a limited number of species occurrences, and they are used in several research areas in conservation biology, ecology and evolution.

Environmental Protection Agency Is an agency of the US federal government which was created for the purpose of protecting human health and the environment by writing and enforcing regulations based on laws passed by Congress. The agency conducts environmental assessment, research and education. It has the responsibility of maintaining and enforcing national standards under a variety of environmental laws, in consultation with state, tribal and local governments.

Essential Oils Is a concentrated hydrophobic liquid containing volatile aroma compounds from plants. Essential oils are also known as volatile oils, ethereal oils, aetherolea or simply as the ‘oil of’ the plant from which they were extracted, such as oil of clove. These oils are used as one of the primary means of nutritional strategies to reduce enteric methane emission.

European Environment Agency Is an agency of the European Union (EU). Its task is to provide sound, independent information on the environment. It is a major information source for those involved in developing, adopting, implementing and evaluating environmental policy and also the general public. The EEA is governed by a management board composed of representatives of the governments of its 33 member states, a European Commission representative and two scientists appointed by the European Parliament, assisted by a committee of scientists.

European Monitoring and Evaluation Programme It is a programme for international cost sharing of a monitoring programme which forms the backbone for review and assessment of relevant air pollution in Europe in the light of agreements on emission reduction. EMEP has three main components: collection of emission data for SO2, NOx, VOCs and other air pollutants; measurement of air and precipitation quality; and modelling of atmospheric dispersion.

European Union Emission Trading System This refers to the first large greenhouse gas emissions trading scheme in the world and remains the biggest. It was launched in 2005 to combat climate change and is a major pillar of EU climate policy.

Extreme Weather Events This includes unusual, severe or unseasonal weather, weather at the extremes of the historical distribution—the range that has been seen in the past. Often, extreme events are based on a location's recorded weather history and defined as lying in the most unusual 10 %. In recent years some extreme weather events have been attributed to human-induced global warming, with studies indicating an increasing threat from extreme weather in the future.

Faecal Worm Egg Counts Is a count of the number of worm eggs in a sample of faeces. It is used to monitor the worm burden; the results are presented as 'eggs per gram' (epg) of faeces. The number of eggs is an indication of the number of adult worms in the gut.

Feed Conversion Efficiency Also known as feed conversion efficiency (FCE), is a measure of an animal's efficiency in converting feed mass into increased body mass.

Flame Ionisation Detector Is a scientific instrument that measures the concentration of organic species in a gas stream. It is frequently used as a detector in gas chromatography. Standalone FIDs can also be used in applications such as landfill gas monitoring and fugitive emissions monitoring in stationary or portable instruments.

Follicle-Stimulating Hormone Is a hormone found in animals. It is synthesised and secreted by gonadotrophs of the anterior pituitary gland. FSH regulates the development, growth, pubertal maturation and reproductive processes of the body. FSH and luteinizing hormone (LH) act synergistically in reproduction.

Food and Agricultural Organization It is an agency of the United Nations that leads international efforts to defeat hunger. Serving both developed and developing countries, FAO acts as a neutral forum where all nations meet as equals to negotiate agreements and debate policy. FAO is also a source of knowledge and information and helps developing countries and countries in transition modernise and improve agriculture, forestry and fisheries practices, ensuring good nutrition and food security for all.

Foot-and-Mouth Disease Is an infectious and sometimes fatal viral disease that affects cloven-hoofed animals, including domestic and wild bovids. The virus causes a high fever for 2 or 3 days, followed by blisters inside the mouth and on the feet that may rupture and cause lameness.

Free Fatty Acids Nonesterified fatty acids, released by the hydrolysis of triglycerides within adipose tissue. Free fatty acids can be used as an immediate source of energy by many organs and can be converted by the liver into ketone bodies. They are ubiquitous if minor components of all living tissues. In animals, much of the dietary lipid is hydrolysed to free acids before it is absorbed and utilised for lipid synthesis.

Free-Air Carbon Dioxide Enrichment A method used by ecologists and plant biologists that raises the concentration of CO_2 in a specified area and allows the response of plant growth to be measured. Measuring the effect of elevated CO_2 using FACE is a better way of estimating how plant growth will change in the future as the CO_2 concentration rises in the atmosphere. FACE also allows the effect of elevated CO2 on plants that cannot be grown in small spaces (e.g. trees) to be measured.

Frizzle Is a curled-feather type of chicken plumage common to certain breeds of domestic chicken.

Galacto-oligosaccharide Belongs to the group of prebiotics. Prebiotics are defined as non-digestible food ingredients that beneficially affect the host by stimulating the growth and/or activity of beneficial bacteria in the colon. GOS occurs in commercial available products such as food for both infants and adults.

Genome-Wide Association Study Is an examination of many common genetic variants in different individuals to see if any variant is associated with a trait. GWAS typically focus on associations between single-nucleotide polymorphisms (SNPs) and traits like major diseases.

Genomic Selection Is a form of marker-assisted selection in which genetic markers covering the whole genome are used so that all quantitative trait loci (QTL) are in linkage disequilibrium with at least one marker. This approach has become feasible thanks to the large number of single-nucleotide polymorphisms (SNP) discovered by genome sequencing and new methods to efficiently genotype large number of SNP.

Genotype-by-Environment Interactions Is the phenotypic effect of interactions between genes and the environment. Gene–environment interaction is exploited by plant and animal breeders to benefit agriculture. For example, plants can be bred to have tolerance for specific environments, such as high or low water availability. The way that trait expression varies across a range of environments for a given genotype is called its norm of reaction.

Geographic Information System Is a system designed to capture, store, manipulate, analyse, manage and present all types of geographically referenced data. The acronym GIS is sometimes used to mean geographical information science or geospatial information studies; these latter terms refer to the academic discipline or career of working with geographic information systems. In the simplest terms, GIS is the merging of cartography, statistical analysis and database technology.

Global Livestock Environmental Assessment Model Produces estimates of the GHG emissions of the livestock industry by livestock type, farming system and location using data from the 2006 IPCC Guidelines for National GHG Inventories.

Global Warming Potential Is a relative measure of how much heat a greenhouse gas traps in the atmosphere. It compares the amount of heat trapped by a certain mass of the gas in question to the amount of heat trapped by a similar mass of carbon dioxide.

Global Warming Global warming refers to an increase in average global temperature which in turn causes climate change. Solar radiation in the form of light waves passes through the atmosphere; most of this radiation is absorbed by the Earth and radiated back into space in the form of infrared waves. Part of the infrared waves is trapped by the atmosphere making the Earth just warm enough to be livable. But because of too much GHGs that thicken the atmosphere, most if not all of the infrared waves are now trapped making the Earth warmer.

Glutathione Peroxidase Is the general name of an enzyme family with peroxidase activity whose main biological role is to protect the organism from oxidative damage. The biochemical function of glutathione peroxidase is to reduce lipid hydroperoxides to their corresponding alcohols and to reduce free hydrogen peroxide to water.

Glutathione Is an important antioxidant in plants, animals, fungi and some bacteria and archaea, preventing damage to important cellular components caused by reactive oxygen species such as free radicals and peroxides.

Gonadotrophin-Releasing Hormone Is a trophic peptide hormone responsible for the release of follicle-stimulating hormone (FSH) and luteinizing hormone (LH) from the anterior pituitary. GnRH is synthesised and released from neurons within the hypothalamus.

Greenhouse Effect The greenhouse effect is the process by which radiative energy leaving a planetary surface, like the Earth, is absorbed by some atmospheric gases, called greenhouse gases (GHGs). The GHGs transfer this energy to other components of the atmosphere, and it is re-emitted in all directions, including back down towards the surface.

Greenhouse Gas and Air Pollution Interactions and Synergies This model provides a consistent framework for the analysis of co-benefits reduction strategies from air pollution and GHG sources. It addresses health and ecosystem impacts of particulate pollution, acidification, eutrophication and tropospheric ozone. Simultaneously, the GAINS model considers GHG emission rates and the associated value per ton of CO_2e. Historic emissions of air pollutants and GHGs are estimated for each country based on information collected by available international emission inventories and on national information supplied by individual countries. The GAINS model assesses emissions on a medium-term time horizon, and emission projections are specified in 5-year intervals through the year 2030. Options and costs for controlling emissions are represented by several emission reduction technologies.

Greenhouse Gas Emission Footprint Refers to the amount of GHG that is emitted during the creation of products or services. It is expressed in units of GHG warming potential (GGWP) and is generated by products or services.

Greenhouse Gas Inventory Is a type of emission inventory that is developed for a variety of reasons. Scientists use inventories of natural and anthropogenic (human-caused) emissions as tools when developing atmospheric models. Policymakers use inventories to develop strategies and policies for emissions reductions and to track the progress of those policies. And, regulatory agencies and corporations rely on inventories to establish compliance records with allowable emission rates. Businesses, the public, and other interest groups use inventories to better understand the sources and trends in emissions. Unlike some other air emission inventories, greenhouse gas inventories include not only emissions from source categories but also removals by carbon sinks. These removals are typically referred to as carbon sequestration.

Greenhouse Gas Is a gas in an atmosphere that absorbs and emits radiation within the thermal infrared range. This process is the fundamental cause of the greenhouse effect. The primary GHGs in the Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide and ozone. GHGs greatly affect the temperature of the Earth; without them, the Earth's surface would average about 33 °C colder, which is about 59 °F below the present average of 14 °C (57 °F).

Gross Domestic Product Is defined as 'an aggregate measure of production equal to the sum of the gross values added of all resident institutional units engaged in production (plus any taxes, and minus any subsidies, on products not included in the value of their outputs)'. Estimates are commonly used to measure the economic performance of a whole country or region but can also measure the relative contribution of an industry sector.

Gross Energy Is the energy released as heat when a compound undergoes complete combustion with oxygen in a bomb calorimeter.

Growth Hormone Also known as somatotropin or somatropin, is a peptide hormone that stimulates growth, cell reproduction and regeneration in humans and other animals. It is a type of mitogen which is specific only to certain kinds of cells. Growth hormone is a 191-amino acid, single-chain polypeptide that is synthesised, stored and secreted by somatotropic cells within the lateral wings of the anterior pituitary gland.

Haemoglobin Is the iron-containing oxygen-transport metalloprotein in the red blood cells of all vertebrates as well as the tissues of some invertebrates. Haemoglobin in the blood carries oxygen from the respiratory organs (the lungs or gills) to the rest of the body (i.e. the tissues) where it releases the oxygen to burn nutrients to provide energy to power the functions of the organism in the process called metabolism.

Heat Shock Factors Is the name given to transcription factors that regulate the expression of the heat shock proteins. These activators bind specifically to Heat Shock sequence Elements (HSE) throughout the genome whose consensus sequence is a tandem array of three oppositely oriented 'AGAAN' motifs or a degenerate version thereof.

Heat Shock Protein Is a class of functionally related proteins involved in the folding and unfolding of other proteins. Their expression is increased when cells are exposed to elevated temperatures or other stress. This increase in expression is transcriptionally regulated. The dramatic upregulation of the heat shock proteins is a key part of the heat shock response and is induced primarily by heat shock factor (HSF).

Heat Shock It refers to the effect of subjecting a cell to a higher temperature than that of the ideal body temperature of the organism from which the cell line was derived.

Heat Stress It can be defined as a group of conditions due to overexposure to or overexertion in excess environmental temperature. The condition includes heat cramp, heat exhaustion and heat stroke.

Heme Oxygenase-1 Is an enzyme that catalyses the degradation of heme. This produces biliverdin, iron and carbon monoxide.

Homeostasis Homeostasis refers to this tendency to maintain a balanced or constant internal state that is optimal for functioning. Animals have a specific 'balanced' or 'normal' body temperature. When there is a problem with the internal functioning of the animal body, this temperature may increase, signalling an imbalance. As a result, the body attempts to solve the problem and restore homeostasis for normal body temperature.

Human Chorionic Gonadotrophin Is a glycoprotein hormone produced during pregnancy that is made by the developing embryo after conception and later by the syncytiotrophoblast.

Hydrofluorocarbon It refers to any of several organic compounds composed of hydrogen, fluorine and carbon. HFCs are produced synthetically and are used primarily as refrigerants. They became widely used for this purpose beginning in the late 1980s, with the introduction of the Montreal Protocol, which phased out the use of chemicals such as halons and chlorofluorocarbons (CFCs) that contribute to the depletion of the Earth's ozone layer. However, while HFCs have an ozone depletion potential of zero, they are potent GHG, and thus their manufacture and use became increasingly regulated in the twenty-first century.

Hydrogen Sulphide Is a colourless gas with the characteristic foul odour of rotten eggs; it is heavier than air, very poisonous, corrosive, flammable and explosive. Hydrogen sulphide often results from the bacterial breakdown of organic matter in the absence of oxygen, such as in swamps and sewers; this process is commonly known as anaerobic digestion. H_2S also occurs in volcanic gases, natural gas, and some well waters. The human body produces small amounts of H_2S and uses it as a signalling molecule.

Hydrogen Is a chemical element with chemical symbol H and atomic number 1. With an atomic weight of 1.00794 u, hydrogen is the lightest element on the periodic table. Its monatomic form (H) is the most abundant chemical substance in the universe, constituting roughly 75 % of all baryonic mass.

Hypothalamo-Pituitary-Adrenal Axis Is a complex set of direct influences and feedback interactions among the hypothalamus, the pituitary gland and the adrenal glands. It is also known as stress axis which controls the stress-relieving pathway.

In Vitro Embryo Production It represents the third generation of techniques aimed at a better control of animal reproduction. This technique involves four major steps: oocyte collection, oocyte in vitro maturation (IVM), in vitro fertilisation (IVF) and in vitro development of the resulting embryos (IVD).

In Vitro Gas Production Technique This is a commonly used technique to quantify GHG emission through different feed stuffs under in vitro condition. This technique will provide information that is relevant to the interpretation of nutritional values of feedstuffs and/or animal response and/or animal impacts on the environment.

Information Technology Is the application of computers and telecommunications equipment to store, retrieve, transmit and manipulate data, often in the context of a business or other enterprise. Several industries are associated with information technology, including computer hardware, software, electronics, semiconductors, internet, telecom equipment, e-commerce and computer services.

Infrared Invisible radiant energy, electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 700 nm (frequency 430 THz) to 1 mm (300 GHz).

Insulin-Like Growth Factor-1 IGF-1 is a hormone similar in molecular structure to insulin. It plays an important role in growth and continues to have anabolic effects in adult animals.

Integrated Farm System Model Is a simulation tool for evaluating and comparing economic and environmental effects of alternative management scenarios on representative farms.

Integrated Model to Assess the Global Environment Is an ecological–environmental model framework that simulates the environmental consequences of human activities worldwide. It represents interactions between society, the biosphere and the climate system to assess sustainability issues such as climate change, biodiversity and human wellbeing. The objective of the IMAGE model is to explore the long-term dynamics and impacts of global changes that result from interacting demographic, technological, economic, social, cultural and political factors.

Integrated Water Resources Management It is a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Intergovernmental Panel on Climate Change Is a scientific intergovernmental body first established in 1988 by two United Nations organisations, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP), and later endorsed by the United Nations General Assembly through Resolution 43/53. Its mission is to provide comprehensive scientific assessments of current scientific, technical and socioeconomic information worldwide about the risk of climate change caused by human activity, its potential environmental and socioeconomic consequences and possible options for adapting to these consequences or mitigating the effects.

International Fund for Agricultural Development Is a specialised agency of the United Nations dedicated to eradicating rural poverty in developing countries. It was established as an international financial institution in 1977 as one of the major outcomes of the 1974 World Food Conference. Seventy-five per cent of the world's poor live in rural areas in developing countries, yet only 4 % of official development assistance goes to agriculture.

International Livestock Research Institute It works to improve food security and reduce poverty in developing countries through research for better and more sustainable use of livestock. ILRI is a member of the CGIAR Consortium which works for a food-secure future.

International Model Policy Analysis of Agricultural Commodities and Trade Is a representation of a competitive world agricultural market for 30 crop and livestock commodities, including cereals, soybeans, cotton, roots and tubers, meats, milk, eggs, oils, sugar/sweeteners, fruits/vegetables and fish. It is specified as a set of 115 countries and regions within each of which supply, demand and prices for agricultural commodities are determined. The country and regional agricultural submodels are linked through trade, a specification that highlights the interdependence of countries and commodities in global agricultural markets. The model uses a system of supply and demand elasticities incorporated into a series of linear and nonlinear equations, to approximate the underlying production and demand functions.

Joint Implementation It refers to a programme under the Kyoto Protocol that allows industrialised countries to meet part of their required cuts in GHG emissions by paying for projects that reduce emissions in other industrialised countries.

Kyoto Protocol It is an international treaty that sets binding obligations on industrialised countries to reduce emissions of GHGs. The UNFCCC is an environmental treaty with the goal of preventing dangerous anthropogenic (i.e. human-induced) interference of the climate system. It recognises that developed countries are principally responsible for the current high levels of GHG emissions in the atmosphere as a result of more than 150 years of industrial activity and places a heavier burden on developed nations under the principle of 'common but differentiated responsibilities'. There are 192 parties to the convention: 191 states (including all the UN members except Andorra, Canada, South Sudan and the United States) and the European Union.

Land Use, Land-Use Change and Forestry Is defined by the United Nations Climate Change Secretariat as 'A greenhouse gas inventory sector that covers emissions and removals of greenhouse gases resulting from direct human-induced land use, land-use change and forestry activities'. LULUCF has impacts on the global carbon cycle, and as such, these activities can add or remove carbon dioxide (or, more generally, carbon) from the atmosphere, influencing climate. LULUCF has been the subject of two major reports by the Intergovernmental Panel on Climate Change (IPCC). Additionally, land use is of critical importance for biodiversity.

Laser Methane Detector It is an innovative portable detector that allows methane gas to be detected from a distance. This enables easy access to hard-to-reach locations, such as elevated piping or locked premises, and helps keep the operator away from potential leak sources.

Life Cycle Assessment It is a technique to assess environmental impacts associated with all the stages of a product's life from cradle to grave (i.e. from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance and disposal or recycling).

Lipopolysaccharides Are large molecules consisting of a lipid and a polysaccharide composed of O-antigen, outer core and inner core joined by a covalent bond; they are found in the outer membrane of gram-negative bacteria and elicit strong immune responses in animals.

Liquefied Petroleum Gas It refers to a flammable mixture of hydrocarbon gases used as a fuel in heating appliances, cooking equipment and vehicles. It is increasingly used as an aerosol propellant and a refrigerant, replacing chlorofluorocarbons in an effort to reduce damage to the ozone layer. When specifically used as a vehicle fuel, it is often referred to as autogas.

Livestock's Long Shadow It is a United Nations report, released by the Food and Agriculture Organization of the United Nations (FAO) on 29 November 2006 that aims to assess the full impact of the livestock sector on environmental problems, along with potential technical and policy approaches to mitigation.

Luteinizing Hormone It is a hormone produced by gonadotroph cells in the anterior pituitary gland. In females, an acute rise of LH ('LH surge') triggers ovulation and development of the corpus luteum. In males, where LH had also been called interstitial cell-stimulating hormone (ICSH), it stimulates Leydig cell production of testosterone. It acts synergistically with FSH.

Marker-Assisted Selection Is a process whereby a marker is used for indirect selection of a genetic determinant or determinants of a trait of interest.

Metabolisable Energy The net energy available to an animal after the utilisation of some energy in the processes of digestion and absorption and the loss of some of the material as being undigested or indigestible.

Methane Production Potential Is the volume of methane biogas produced during anaerobic degradation in the presence of bacteria of a sample initially introduced, expressed under normal conditions of temperature and pressure (CNTP: 0 °C, 1,013 hPa).

Methane Is a chemical compound with the chemical formula CH4 (one atom of carbon and four atoms of hydrogen). It is the simplest alkane and the main component of natural gas. The relative abundance of methane makes it an attractive fuel, though capturing and storing it may pose challenges due to its gaseous state found at normal conditions. In its natural state, methane is found both below ground and under the seafloor, where it often finds its way to the surface and in the Earth's atmosphere where it is known as atmospheric methane.

Methanofuran Coenzyme Is necessary for the first step of methanogenesis from CO_2. The well-characterised MF core structure is 4-[*N*-(γ-l-glutamyl-γ-l-glutamyl)-*p*-(β-aminoethyl) phenoxymethyl]-2-(aminomethyl)furan (APMF-γ-Glu_2).

Methanogenic Bacteria Are microorganisms that produce methane as a metabolic by-product in anoxic conditions. They are classified as archaea, a domain distinct from bacteria.

Methyl Coenzyme M Reductase Gene Is an enzyme that catalyses the final step in the formation of methane. It does so by combining the hydrogen donor coenzyme B and the methyl donor coenzyme M. Via this enzyme, most of the natural gas on Earth was produced. Ruminants (e.g. cows) produce methane because their rumens contain methanogenic prokaryotes (Archaea) that encode and express the set of genes of this enzymatic complex.

Microclimate The climate condition directly surrounding the animal.

Micrometeorology The branch of meteorology that deals with weather conditions on a small scale, both in terms of space and time. For example, weather conditions lasting less than a day in the area immediately surrounding a smokestack, a building or a mountain are studied in micrometeorology.

Multivariate ENSO Index Is a method used to characterise the climatic conditions contributing to the onset and physiology of the El Niño Southern Oscillation (ENSO) event. Given that ENSO arises from a complex interaction of a variety of climate systems, MEI is regarded as the most comprehensive index for monitoring ENSO since it combines analysis of multiple meteorological components.

National Adaptation Programmes for Action Is one of the types of reporting envisaged by the United Nations Framework Convention on Climate Change. They are prepared by Least Developed Countries, to describe the country's perception of its most 'urgent and immediate needs to adapt to climate change'. NAPAs are not supposed to include original research but use existing information and include profiles of priority projects that are intended to address those needs that have been identified.

National Dairy Development Board Is an institution of national importance set up by an Act of Parliament of India. The main office is in Anand, Gujarat, with regional offices throughout the country.

National Oceanic and Atmospheric Administration Is a scientific agency within the US Department of Commerce focused on the conditions of the oceans and the atmosphere. NOAA warns of dangerous weather, charts seas and skies, guides the use and protection of ocean and coastal resources and conducts research to improve the understanding and stewardship of the environment.

National Research Council The National Research Council is an agency of the Government of Canada which conducts scientific research and development.

Nationally Appropriate Mitigation Actions It refers to a set of policies and actions that countries undertake as part of a commitment to reduce greenhouse gas emissions. The term recognises that different countries may take different nationally appropriate action on the basis of equity and in accordance with common but differentiated responsibilities and respective capabilities. It also emphasises financial assistance from developed countries to developing countries to reduce emissions.

Natural Resistance-Associated Macrophage Protein 1 Is a protein that in humans is encoded by the *SLC11A1* gene. This gene is a member of the solute carrier family 11 (proton-coupled divalent metal ion transporters) and encodes a multi-pass membrane protein. The protein functions as a divalent transition metal (iron and manganese) transporter involved in iron metabolism and host resistance to certain pathogens.

Neutral Detergent Fibre Is the most common measure of fibre used for animal feed analysis, but it does not represent a unique class of chemical compounds. NDF measures most of the structural components in plant cells (i.e. lignin, hemicellulose and cellulose) but not pectin.

Next-Generation Techniques This describes a product that has been developed using the latest technology and will probably replace an existing product.

Nitric Oxide A colourless, poisonous gas, NO, produced as an intermediate during the manufacture of nitric acid from ammonia or atmospheric nitrogen and as a product of cellular metabolism. In the body, nitric oxide is involved in oxygen transport to the tissues, the transmission of nerve impulses and other physiological activities.

Nitrogen Oxides Is a generic term for the mono-nitrogen oxides NO and NO_2 (nitric oxide and nitrogen dioxide). They are produced from the reaction of nitrogen and oxygen gases in the air during combustion, especially at high temperatures. In areas of high motor vehicle traffic, such as in large cities, the amount of nitrogen oxides emitted into the atmosphere as air pollution can be significant. NOx gases are formed whenever combustion occurs in the presence of nitrogen—as in an air-breathing engine; they also are produced naturally by lightning. In atmospheric chemistry, the term means the total concentration of NO and NO_2. NOx gases react to form smog and acid rain as well as being central to the formation of tropospheric ozone.

Nonesterified Fatty Acid The fraction of plasma fatty acids not in the form of glycerol esters.

Non-methane Volatile Organic Compounds Organic compounds, other than methane, that participate in atmospheric photochemical reactions.

Nonprotein Nitrogen Is a term used in animal nutrition to refer collectively to components such as urea, biuret and ammonia, which are not proteins but can be converted into proteins by microbes in the ruminant stomach.

Nonstructural Carbohydrates Nonstructural carbohydrates are those that occur either as simple sugars in the horse's feed or that can be broken down by enzymes produced by the horse. Included in this category are glucose and fructose, lactose, sucrose and starch. They range from being almost nonexistent in a grass hay diet to comprising a high percentage of the total diet in a high grain-low fibre ration.

Operational Taxonomic Units Operational taxonomic unit, species distinction in microbiology. Typically using rDNA and a percent similarity threshold for classifying microbes within the same, or different, OTUs. The number of OTUs defined may be inflated due to errors in DNA sequencing.

Organic Matter Is matter composed of organic compounds that has come from the remains of dead organisms such as plants and animals and their waste products in the environment. Basic structures are created from cellulose, tannin, cutin and lignin, along with other various proteins, lipids and carbohydrates. It is very important in the movement of nutrients in the environment and plays a role in water retention on the surface of the planet.

'Over-the-Counter' Market A decentralised market (as opposed to an exchange market) where geographically dispersed dealers are linked by telephones and computers. The market is for securities not listed on a stock or derivatives exchange.

Ovum Pick-Up The term ovum pick-up is used to describe a technique where oocytes (immature ova) are collected from the follicles in the ovaries by aspiration using ultrasonic guidance through the vaginal wall. The oocytes are matured in the laboratory for 24 h then fertilised and cultured for a further 7 days before being transferred to prepared recipients or frozen for use at a later date. The number of embryos fit for transfer is still low, and, in some cases, in vitro fertilised embryos can develop into calves with a higher than average birth weight resulting in calving difficulties.

Oxygen A colourless, odourless reactive gas, the chemical element of atomic number 8 and the life-supporting component of the air.

Ozone A colourless unstable toxic gas with a pungent odour and powerful oxidising properties, formed from oxygen by electrical discharges or ultraviolet light. It differs from normal oxygen (O_2) in having three atoms in its molecule (O_3).

Packed Cell Volume A measure of the proportion of blood volume that is occupied by red blood cells.

Parts Per Million ppm is an abbreviation of parts per million. ppm is a value that represents the part of a whole number in units of 1/1,000,000. ppm is a dimensionless quantity, a ratio of 2 quantities of the same unit.

Per Fluorocarbons Any of various hydrocarbon derivatives in which all hydrogen atoms have been replaced with fluorine and that include blood substitutes used in emulsified form.

Peripheral Blood Mononuclear Cells A peripheral blood mononucleated cell (PBMC) is any blood cell having a round nucleus (as opposed to a lobed nucleus).

Plant Secondary Metabolites Refers to products that aid in the growth and development of plants but are not required for the plant to survive. These metabolites are effectively used in ruminant livestock to reduce enteric methane emission. The typical examples are tannin, saponins and essential oils.

Progesterone-Impregnated Intravaginal Device PRID refers to an artificial device which is used for synchronising oestrus cycle in livestock. These techniques are broadly used in the control of reproductive management in livestock.

Pulse Rate The pulse rate is a measurement of the heart rate or the number of times the heart beats per minute. As the heart pushes blood through the arteries, the arteries expand and contract with the flow of the blood.

QTL Quantitative Trait Locus Are stretches of DNA containing or linked to the genes that underlie a quantitative trait. Mapping regions of the genome that contain genes involved in specifying a quantitative trait is done using molecular tags such as AFLP or, more commonly, SNPs.

Radio-Frequency Identification Is a technology that incorporates the use of electromagnetic or electrostatic coupling in the radio-frequency (RF) portion of the electromagnetic spectrum to uniquely identify an object, animal or person.

Reactive Oxygen Species Are chemically reactive molecules containing oxygen. Examples include oxygen ions and peroxides. ROS are formed as a natural by-product of the normal metabolism of oxygen and have important roles in cell signalling and homeostasis.

Rectal Temperature Body temperature as measured by a clinical thermometer placed in the rectum. This is the commonly used methodology to measure body temperature in livestock.

Reduced Emissions from Deforestation and Degradation Is a mechanism that has been under negotiation by the United Nations Framework Convention on Climate Change (UNFCCC) since 2005, with the twin objectives of mitigating climate change through reducing emissions of GHGs and removing greenhouse gases through enhanced forest management in developing countries.

Relative Humidity It refers to the amount of water vapour present in air expressed as a percentage of the amount needed for saturation at the same temperature.

Representative Concentration Pathways Are four greenhouse gas concentration (not emissions) trajectories adopted by the IPCC for its fifth Assessment Report (AR5). The pathways are used for climate modelling and research.

Residual Feed Intake Is defined as the difference between actual feed intake and that predicted on the basis of requirements for production and maintenance of body weight.

Respiration Rate It is also known as ventilation rate, ventilatory rate, ventilation frequency, respiration frequency, pulmonary ventilation rate or breathing frequency, is the rate of ventilation, that is, the number of breaths taken within a set amount of time.

Single-Nucleotide Polymorphisms Is a DNA sequence variation occurring commonly within a population (e.g. 1 %) in which a single nucleotide—A, T, C or G—in the genome (or other shared sequence) differs between members of a biological species or paired chromosomes.

Soil Organic Matter Is the organic matter component of soil, consisting of plant and animal residues at various stages of decomposition, cells and tissues of soil organisms and substances synthesised by soil organisms.

Special Report on Emissions Scenarios Is a report by the Intergovernmental Panel on Climate Change (IPCC) that was published in 2000. The greenhouse gas emissions scenarios described in the report have been used to make projections of possible future climate change.

Sulphate-Reducing Bacteria Are those bacteria that can obtain energy by oxidising organic compounds or molecular hydrogen while reducing sulphate to hydrogen sulphide. In a sense, these organisms ‘breathe’ sulphate rather than oxygen, in a form of anaerobic respiration.

Superoxide Dismutase Are enzymes that catalyse the dismutation of superoxide (O2–) into oxygen and hydrogen peroxide. Thus, they are an important antioxidant defence in nearly all cells exposed to oxygen.

Sulphur Hexafluoride Is an inorganic, colourless, odourless, non-flammable, extremely potent greenhouse gas which is an excellent electrical insulator. SF 6 has an octahedral geometry, consisting of six fluorine atoms attached to a central sulphur atom. SF_6 is commonly used in SF_6 tracer technique to measure enteric methane emission in ruminant livestock.

System of Rice Intensification Is a methodology aimed at increasing the yield of rice produced in farming. It is a low-water, labour-intensive, organic method that uses younger seedlings singly spaced and typically hand weeded with special tools.

Temperature–Humidity Index Is an index used for expressing the discomfort felt as a result of the combined effects of the temperature and humidity of the air. This is commonly used to quantify stress expressed by livestock species.

Thermal Comfort Zone Thermal comfort zone is a range in ambient temperature in which body temperature is possible and an animal needs not change the metabolic rate.

Thermoneutral Zone (TNZ) The range of environmental temperatures over which the heat produced by a 'warm-blooded' animal remains fairly constant. Hence, it is the range in which the animal is 'comfortable', having neither to generate extra heat to keep warm nor expend metabolic energy on cooling mechanisms, such as panting. Animals adapted to cold environments tend to have broader thermoneutral zones than ones living in hot environments. The TNZ ranges from lower critical temperature (LCT) to upper critical temperature (UCT) and depends on age, species, feed intake, diet composition, previous state of temperature acclimation or acclimatisation, production, specific housing and pen conditions, tissue insulation (fat, skin), external insulation (coat) and behaviour of an animal.

Thyroxine Is the storage form of thyroid hormone.

Total Digestible Nutrients The energy value of feedstuffs, comparable to digestible energy in accuracy. TDN overestimates the energy value of roughages in comparison to grains.

Total Dissolved Solids Is a measure of the combined content of all inorganic and organic substances contained in a liquid in molecular, ionised or micro-granular (colloidal sol) suspended form.

Triiodothyronine Is the active form of thyroid hormone. It affects almost every physiological process in the body, including growth and development, metabolism, body temperature and heart rate.

United Nations Convention to Combat Desertification Is a convention to combat desertification and mitigate the effects of drought through national action programmes that incorporate long-term strategies supported by international cooperation and partnership arrangements.

United Nations Economic Commission for Europe This was established in 1947 to encourage economic cooperation among its member states. It is one of five regional commissions under the administrative direction of United Nations headquarters.

United Nations Environment Programme Is an agency of the United Nations that coordinates its environmental activities, assisting developing countries in implementing environmentally sound policies and practices.

United Nations Framework Convention on Climate Change Is an international environmental treaty negotiated at the United Nations Conference on Environment and Development (UNCED), informally known as the Earth Summit, held in Rio de Janeiro from 3 to 14 June 1992. The objective of the treaty is to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

US Environmental Protection Agency Is an agency of the US Federal Government whose mission is to protect human and environmental health.

Verified (or Voluntary) Emission Reductions Are a type of carbon offset exchanged in the voluntary or over-the-counter market for carbon credits.

Volatile Fatty Acid Volatile fatty acids are fatty acids with a carbon chain of six carbons or fewer. They are now usually referred to as short-chain fatty acids. They can be created through fermentation in the intestine. The type of volatile fatty acids produced in the ruminant livestock determines the quantity of methane produced.

Volatile Organic Compounds Are organic chemicals that have a high vapour pressure at ordinary room temperature. Their high vapour pressure results from a low boiling point, which causes large numbers of molecules to evaporate or sublimate from the liquid or solid form of the compound and enter the surrounding air.

Voluntary Feed Intake Is the amount of feed eaten by an animal when the feed is given to it without restriction.

Water-Soluble Carbohydrates These include carbohydrates that are extracted from a sample by dissolving them in water. Simple sugars and fructans make up this measure, which is simply termed 'sugar' on some analyses. Interpreting and using this value depends on the proportions of sugars and fructans in the sample; simple sugars are digested and absorbed in the small intestine and have a significant impact on blood (glycemic response), while fructans are fermented in the large intestine and induce sugar a much smaller response.

Weather The short-term day-to-day fluctuations of the metrology variables, as distinguished from climate, which is the long-term manifestation of the weather.

World Business Council for Sustainable Development Is a CEO-led, global association of some 200 international companies dealing exclusively with business and sustainable development.

World Health Organization Is a specialised agency of the United Nations (UN) that is concerned with international public health.

World Meteorological Organization The United Nations agency concerned with the international collection of meteorological data.

World Organization for Animal Health Is the intergovernmental organisation responsible for improving animal health worldwide. The need to fight animal diseases at global level led to the creation of the Office International des Epizooties through the international agreement signed on 25 January 1924.

World Resources Institute Is a nongovernmental global research organisation which seeks to create equity and prosperity through sustainable natural resource management.