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

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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-

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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

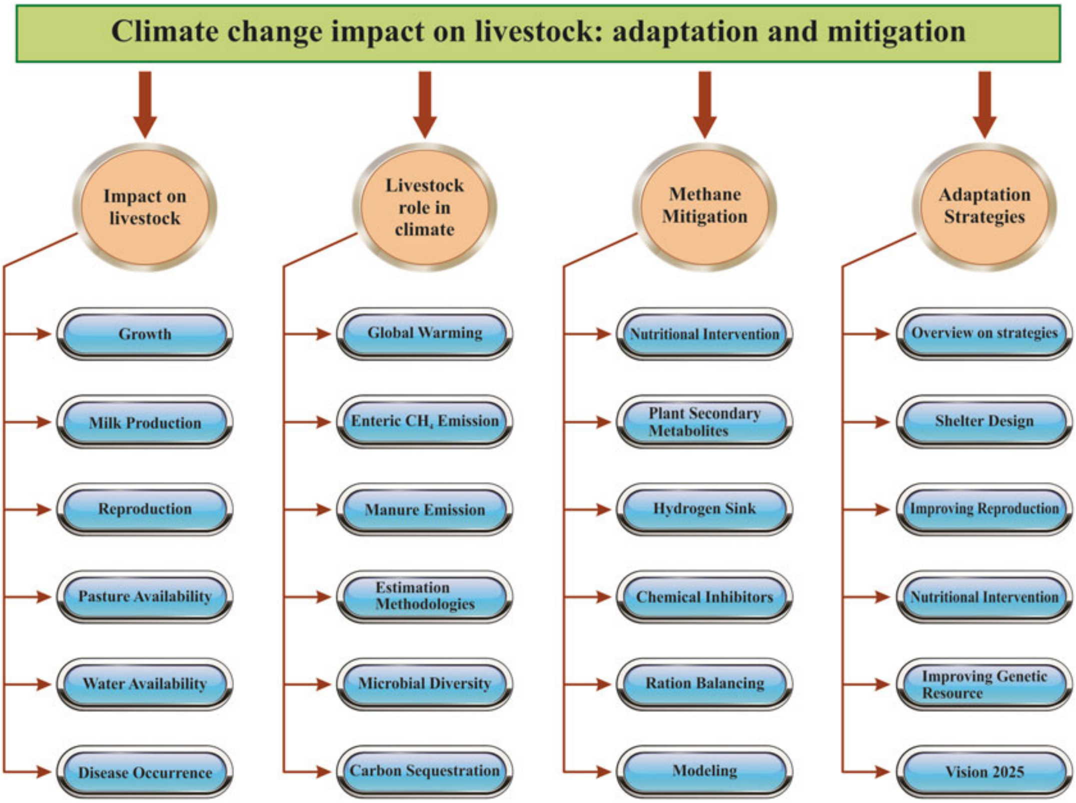

Fig. 1.1 Concepts of climate impact on livestock and its adaptation and mitigation

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