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Agriculture, Livestock Production and Aquaculture

Advances for Smallholder Farming Systems Volume 2

Springer

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Foreword

Agriculture is an important sector of the Indian economy as more than half of its population relies on farming as a principal source of income and as the primary source of livelihood. The National Research and Extension systems play a vital role in generation, upscaling, and dissemination of agricultural technologies aiming at enhancing the income of farmers. The share of agriculture and allied sectors in gross value added (GVA) at current prices stood at 17.8 % in FY20. Farmers with marginal and small holdings, constituting about 86 percent, support the food security of the large population, but are often subjected to vulnerability of climate.

This book, divided into 5 parts and 15 chapters, presents cases from different countries with a main focus on agriculture, livestock, and fishery resources in the twenty-first century along with recent developments in these areas. It also includes the scope of low-cost production technologies and practices that are relevant and better-suited to smallholder farmers. Some of the key inclusive issues related to crop diversification, climate change in crop security, vulnerability of agricultural resources to floods and droughts, emerging new era for sustainable agriculture, mitigation strategies for sustainable soil health, catalyzing farmers' livelihoods, aquaculture resources towards farmers' income, livestock resource management and practices, livestock nutrition for enhancing livestock production, and farmers' income have been highlighted. The book provides a comprehensive account of various agricultural scenarios and their relative phenomena, which will benefit the academic and research community by providing information related to recent research innovations, problem-solving skills, and their future perspective in the field of agriculture.

I congratulate the editors, Arvind Kumar, Pavan Kumar, S. S. Singh, Bambang Hendro Trisasongko, and Meenu Rani, and other scientists, as contributors in the book, across the globe along with the publisher for bringing out a timely publication depicting agriculture, livestock production, and aquaculture and advances for smallholder farming systems. I am sure this would serve as reference material for different stakeholders and institutions working in this area.

(S. Ayyappan)

S. Ayyappan
Industrial Suburb, Mysuru, Karnataka, India
14 October 2021

Preface

Small-scale (or smallholder) farms support the livelihoods and food security of people in many regions but are often underproductive and typically exposed to substantial risk from climatic and other natural hazards. The socio-economic importance of these systems is likely to remain high, and even grow, as the number of small-scale farms increases as part of broader agriculture expansions underway in much of the developing world. This book provides an overview of agriculture, livestock production, and aquaculture. Modern technologies like remote sensing and GIS with timely and accurate information help to monitor and analyze wide range of phenomena like culture of fish, shellfish, and algae in freshwater and marine environments, genetics and stock improvement, nutrition and feed production, post-harvest technology, economics and marketing, and future developments of aquaculture. Inter-disciplinary studies are also noticed in human-environment interaction between stakeholders and decision makers for real-world applications. Remote sensing data products and their limitations are also discussed in the book. The book is organized into 5 parts spreading over 15 chapters. Part I discusses the advanced approaches to sustainable agriculture in smallholder farming system. Chapters 2, 3, 4, 5, 6, and 7 in the second part are devoted to adaptation and mitigation strategies in smallholder agricultural system under climate change scenario. Various applications of advanced technology in agriculture for smart faming are presented in Chaps. 8, 9 and 10 of Part III. In Part IV, livestock production, technology development and transfer, and opportunities have been discussed in Chaps. 11, 12, and 13 through advance modeling. Part V contains two chapters that deal with fisheries and aquaculture in food security and nutrition.

This book covers significant and updated contribution in the field of agriculture, livestock production, and aquaculture linked to climate change. The updated knowledge from countries like India, Indonesia, Kenya, Taiwan, Malaysia, and Australia is presented in this book through selected case studies for major thematic areas that have basic preliminary concepts and elaborates the scientific understanding of the relationship between agricultural resources and climatic drivers and influence of climate change. This book will be of interest to researchers and practitioners in the field of agricultural sciences, remote sensing, geographical information, meteorology, fisheries, and policy studies related to agricultural resource management and climate change. Also, scientists and graduate and postgraduate level students of various disciplines will find valuable information in this book. We believe that the book would be read by people with a common interest in sustainable development and other diverse backgrounds within Earth observation.

The scientific quality of the book was ensured by a rigorous review process where leading researchers from India, Indonesia, Kenya, Taiwan, Malaysia, and Australia participated to provide constructive comments to improve the chapters. Due to confidentiality of the review process, we are unable to provide their names; however, we are deeply indebted and thankful for their voluntary support. On behalf of the team of authors, we express our gratitude to the entire staff to Springer for all kinds of assistance that made this endeavor successful.

Keerbergen, Belgium Luc Hens

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The original version of this book was revised. The correction is available at https://doi.org/10.1007/978-3-030-93262-6_16

About the Editors

Arvind Kumar, a renowned educationist and researcher having more than four decades of experience, has been given the responsibility as first Vice-Chancellor, since May 2014, by the President of India to develop the campus and academic program of Rani Lakshmi Bai Central Agricultural University, Jhansi, an Institution of National Importance. Prior to this assignment, Prof. Kumar worked as Deputy Director General (Education), ICAR, New Delhi from 2009 to 2014; held the additional charge of Deputy Director General (Fisheries), ICAR, New Delhi, for about 5 months; and was the Director of the Directorate of Rapeseed-Mustard Research (DRMR), Bharatpur from 2002 to 2009. He is a fellow of the National Academy of Agricultural Sciences (NAAS) (2012) and a fellow of the International Society of Noni Science (2018). He has been also the President of ISOS, ISA, and SRMR. Prof. Kumar received the Lifetime Achievement Award for his significant contributions to agronomy and rapeseed mustard from the Indian Society of Agronomy and Society for Rapeseed-Mustard Research. He has been a member of the Board of Management of several nationally reputed institutions like IARI; GBPUA&T; CAU, Imphal; SKUAS&T, Jammu; and NDRI, Karnal. During his professional career at GBPUA&T, Pantnagar, for about 27 years, he was involved in teaching, research, and extension education and was also assigned various responsibilities, including Joint Director Extension. For his outstanding contributions to the field of rapeseed-mustard research, he was given "Membership" by the International Consultative Group for Research on Rapeseed, Paris (France) from India. Prof. Kumar has been honored for his professional achievements with several awards and fellowships. He has published more than 160 research papers in Indian and foreign journals, 90 popular articles, 60 books/booklets/chapters, and presented more than 200 papers in national and international conferences on aspects of oilseed research and management. He has visited 24 countries for professional reasons and holds a vast National and International experience.

Pavan Kumar is an Assistant Professor (Wildlife Biology) in the Department of Forest Biology and Tree Improvement, College of Horticulture and Forestry, Rani Lakshmi Bai Central Agricultural University, Jhansi, U.P., India. He obtained his

Ph.D. degrees from the Faculty of Natural Sciences, Jamia Millia Islamia, New Delhi. He did B.Sc. (Botany) and M.Sc. (Environmental Science) from Banaras Hindu University, Varanasi, India, and subsequently obtained a Master's Degree in Remote Sensing (M.Tech.) from Birla Institute of Technology, Mesra, Ranchi, India. His current research interests include forest, resilient agriculture and climate change studies. He is recipient of Innovation China National Academy Award for Remote Sensing. Dr. Kumar has published more than 60 research papers in international journals as well as authored several books and presented more than 40 papers in national and international conferences. He has visited countries like the USA, France, the Netherlands, Italy, China, Indonesia, Brazil, and Malaysia for various academic/scientific assignments, workshop, and conferences. Dr. Kumar is member of the International Association for Vegetation Science, USA, and Institution of Geospatial and Remote Sensing, Malaysia.

S. S. Singh is Director of Extension Education, Rani Laxmi Bai Central Agricultural University, Jhansi U.P. He has served as director of ICAR-Agricultural Technology Application Research Institute, Kolkata (2017–2020). Dr. Singh has handled 16 foreign/externally funded projects on natural resource management, crop management, livelihood development, and crop improvement funded by DFID, IFAD, USAID, BMGF, IRRI, CIMMYT, Ford Foundation, and European Union. As an agronomist, he has contributed to the development of five rice varieties which have been released by CVRC and Bihar SVRC and are suitable for aerobic drought prone, late direct seeding, contingency cropping, and rainfed lowland conditions. He has published 115 research papers, 6 books, 20 book chapters, 15 technical bulletins, 135 papers in proceedings/ symposiums/seminars, 50 popular articles, and 40 extension folders. He has visited the USA, the UK, Australia, Mexico, Thailand, Philippines, Bangladesh, and Nepal. He is recipient of Rajeev Gandhi Gyan Vigyan Award from the Ministry of Home Affairs, FAI award, Senior Research Fellowship of ICAR, and Excellent Team Research Award of ICAR in Social Science.

Bambang Hendro Trisasongko is an Assistant Professor in the Department of Soil Science and Land Resources, and a member of the Geospatial Information and Technologies for the Intelligent and Integrative Agriculture (GITIIA) research program at Bogor Agricultural University, Bogor, Indonesia. Dr. Trisasongko has 14 years of research teaching experience with a publication record in research articles, review papers, conference papers, and book chapters. Dr. Trisasongko is reviewing research articles for a number of scientific journals and has handled research projects in his capacity as PI and Co Pi. His research areas have been in remote sensing for agriculture, environment and forestry. His current research focus is plant productivity from remote and proximal sensors.

Meenu Rani is a Researcher in the Department of Geography, Kumaun University, Nainital, Uttarakhand, India. Dr. Rani received her M.Tech. degree in remote sensing from Birla Institute of Technology, Ranchi, India. She got working experience in the major disciplines of agriculture and forestry while working with Haryana

Space Application Centre, Indian Council of Agricultural Research, and GB Pant National Institute of Himalayan Environment and Sustainable Development. Dr. Rani has authored several peer-reviewed scientific research papers and presented works at many national and international conferences in the USA, Italy, and China. She has been awarded with various fellowships from the International Association for Ecology, Future Earth Coast, and SCAR Scientific Research Programme. She received an early career scientists’ achievement award in 2017 from Columbia University, New York, USA.

Part I
Advanced Approaches to Sustainable Agriculture in Smallholder Farming System

Chapter 1
Drone Technology in Sustainable Agriculture: The Future of Farming Is Precision Agriculture and Mapping

Arvind Kumar, Meenu Rani, Aishwarya, and Pavan Kumar

Abstract Today, we are using machine tools and a variety of technologies in almost all areas of agriculture. The drone is playing an important role in these techniques. Climate change and environmental pollution are the major global issues of the current era and severely impacting agricultural productivity. As seen, the current conditions are not favorable for Indian agriculture: first, the outbreak of corona epidemic and now the locust swarm can be seen. Working in crowded and far-flung areas is a difficult task during the the Covid pandemic. In view of these circumstances, bringing advanced changes in agriculture is becoming the need of the hour. The impact of ever-increasing technology on agriculture should be seen as a positive trend, as it can prove to be a useful means of sustenance for the growing population day by day.

Keywords Drone · India · Climate change · Farming system · Agriculture

1 Drone Technology at a Glance

Food security is the big question for Indian agriculture which should be taken against the backdrop of environmental degradation, pollution, and water scarcity, and its effective solution should be a high priority (Vanamburg et al. 2006; Ruwaimana et al. 2018). All of this is one area where the use of drones can warrant a permanent solution. Drone technology is an unprecedented innovation in agriculture that will have far-reaching implications for agriculture, changing the way we do hereditary farming and the way we do business. High-tech drones help farmers and

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Fig. 1.1 Drone technology and data processing

drone pilots improve certain aspects of the farming process and increase agricultural efficiency. From crop monitoring to planting, livestock management, pesticide and fertilizer spraying, irrigation and land mapping, and drone technology are used (Kalantar et al. 2017) (Fig. 1.1).

2 Application Areas of Drone in agriculture

Drone technology in agricultural sectors has been playing an important role the past few years, the benefits of which are becoming more apparent to farmers. In many countries, use of drone technology has turned out to be an essential part of precision farming at large scale. The high-resolution data acquired from drones assist farmers in managing their farm from sowing to harvesting and help them to attain the best possible crop yields (Bellia and Lanfranco 2019). The use of drones in the farming sector is gradually increasing as it provides effective approach towards sustainable agricultural goals. Critically, the high temporal and spatial resolution data provided by a drone can be effectively used to assess the fertility of soil, which assists farmers and professionals to more precisely apply fertilizer and provide a way to precision nutrient management without wastage of fertilizers. The robust data allow agronomists, farmers, and agricultural engineers to get effective insights into their crops. The technology is also effectively used in natural disasters, like flood and drought, and help farmers to monitor their field and assess damage across terrains, which otherwise is not easily reached on foot. Drone applications in agriculture are monitoring crop treatment, health, scouting, irrigation, fertigation, and crop damage assessments (Suo et al. 2019; Lazzeri et al. 2021).

3 Crop Health Assessment

Monitoring of plant health is at the top of the many uses of Drone Imagery which has already been started with great success. Drones equipped with special imaging equipment can capture multispectral and visual imagery of the farm (Fig. 1.2). A precise crop health investigation is then made using various vegetation health indices like Normalized Difference Vegetation Index (NDVI). This allows farmers to continuously monitor their crops, and any problem can be quickly dealt with. The multispectral data also help in the detection of nutrient deficiencies in the early

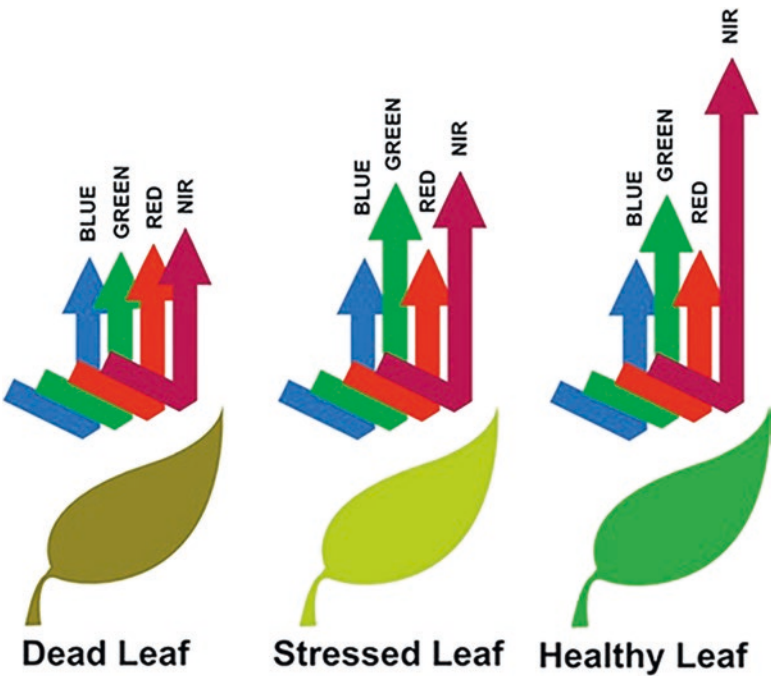

Fig. 1.2 Plant health assessment through high-resolution multispectral drone imagery

stage. It allows farmers to concentrate in the plant-stressed areas rather than the whole field, investigate the reason of crop stress, and take action before the crop stress transforms into yield loss (Rossi et al. 2018; Santos et al. 2015). Although many farmers are already monitoring crop growth and health through satellite imagery, satellite-based data are not as useful as a drone. Because drones provide very high-resolution data (up to few centimeters) and fly very close to fields, it is unaffected by cloud cover as in the case of using satellite data. After planting any kind of crop, disease or pest infestation can be detected very easily through drone flight even at small farms and treatment can be planned in the right way (Lucieer et al. 2014). Apart from this, drones are equipped with instruments that are capable of spraying the correct dosage of insect, weed, and disease control pesticides in a very precise and planned way that improves the overall efficacy of the products and therefore the overall benefit of farmers.

4 Crop Surveillance

Manually, it is not possible to assess the overall condition of crops in large agricultural farms. Drone-based mapping of field crops enables farmers to have a close eye on the entire crop area at once, which can help the farmers to find out which particular area in the field requires special attention (Cancela et al. 2019; Small 1973). Drones inspect the field with infrared cameras mounted on them, which is able to calculate light absorption rates to estimate crops stage. Based on this accurate and real-time information, problematic areas of the field can be instantly treated (Brunner et al. 2013; Bachrach et al. 2010; Cunha and Youcef-Toumi 2018).

5 Monitoring Field Conditions

Drone cameras are capable of monitoring the field conditions health of the soil. High-resolution capabilities of drones can provide elevation data and accurate mapping of farms, which allow growers to examine any irregularity in the field (Forooshani et al. 2013; Rivard et al. 2015). The efficiency of a drone to produce 3D maps that help in generating field elevation maps can be proved valuable in determining drainage patterns and high/low elevation spots, which require well-organized watering technique. Apart from this, the accurate 3D maps can be used to carry out soil analysis, moisture estimation, and soil erosion. Some agricultural drone traders and vendors also offer nitrogen level monitoring in soil. Drone technology can also be used very effectively for crop acreage estimation and to monitor crop growth stage (Ranjan et al. 2014). Based on this information, harvest decisions can be planned accordingly.

6 Spray Application

Drones can see the ground to detect any nutrient deficiency, disease, weed and pest infestation at any spot which help in monitoring plant stress. It is capable of spraying the right amount of liquid, adjusting distance from the ground, and spraying real time for equal coverage. Southeast Asian countries are already using drones for spraying the crops. South Korea is using drones for agriculture spraying at approximately 30% of their total agricultural land. Drone sprayers are capable of planning a route in remote and hard terrain areas, like steep slope tea farms in hilly areas, and protecting farmers from the hardship of carrying spray tanks on their backs, which could be potential health risk for them. However, the drone sprayer regulations vary extensively from country to country. For example, it is not legal in Canada, and flying spray drones is permitted only for trained professionals in Yamaha (Jakob et al. 2016; Zimmermann et al. 2016; Guo et al. 2018). Drone sprayers provide very precise applications of spray in a very cost-effective manner as they can be targeted to particular problem areas rather than the entire field to save chemical cost. A recent example of using agricultural drone for spraying to fight Locust swarm proved the efficiency of the drone, which sprayed approximately 2.5 acres in only 15 minutes (Xiang et al. 2019; Lally et al. 2019).

7 Monitoring Irrigation and Water Requirement

As climate change increasingly affects water resources and drought conditions, there is a critical need for more proficient irrigation solutions. Drones equipped with hyperspectral, multispectral, and thermal sensors are able to detect the deficiency of moisture in soil. Also, microwave sensors in drones are capable of acquiring very accurate soil moisture levels without any harm to crops. This information will help the farmers to identify which parts of a field need water or require irrigation. This helps in planning farm-specific irrigation schedule, and water can be dispersed in the field in a more organized manner (Eck and Imbach 2012; Waiser et al. 2007; Moseley and Zabierek 2012).

8 Scaring Birds

Birds and animals are a major problem for some crops after sowing seeds. Birds pluck up the seeds for food, and animals destroy seedlings with their feet while moving around. This requires hiring labor to protect the crop. A couple of drone flights can do this work to scare the animals and birds away from the field.

9 Planting and Seeding

Some companies have created additional attachment below the drone systems which is able to shoot pods containing seed nutrients into the already prepared soil. This can help farmers to reduce the costs of planting (Lee et al. 2002; Ovakoglou et al. 2016). Planting seeds is the newest and least used application of drones in agriculture. Till now, the automated drone seeders are widely being used in forestry; however, its potential is more widespread. It can be used in hilly terrains for planting seeds, where labor cost is high in inaccessible areas (Dube et al. 2016).

10 Crop Damage Assessment

Drones are capable of providing high-resolution data that can deliver crucial information for evaluation and documenting damage to plants/crops from unforeseen weather events such as floods and drought, and other factors like fires, pests, and disease. Data acquired from drones can be used by farmers to obtain an estimate of crop damage and as proof to claim crop insurance or accordingly. At the same time, surveillance with drones can help farmers or agricultural professionals to manage their fields to mitigate the impact of these disasters (Sallam et al. 2018; Ismail 2012).

11 Indian Scenario

The importance of technology in agriculture has its own importance as it is mostly associated with providing results, to feed the population of a country. Finding our way to food security due to environmental degradation, pollution, and water scarcity is always a priority question that needs to be addressed. Irrespective of the contribution of Indian agriculture to India's GDP, India has yet to increase productivity and efficiency in this sector. There are several areas and concerns that need to be identified, and once identified, they should be addressed with proposals. In the present time, there is a need to conduct the ever-increasing new experiments in agriculture on a small scale. According to the demand of modern times, the use of drones should be given place in agriculture. Therefore, the need of the hour is that in India too, farmers and people should be made aware of drones and digital technology by the government. It requires skilled and technical persons to operate the drones, which is a bit difficult in a country like India. Some expensive equipment is required to get high-quality data, which makes the initial cost of drones high, which makes such technology unsuccessful by small farmers in India (Fig. 1.3).

Drones, equipped with hyperspectral, thermal, or multispectral sensors, can easily detect the particular areas in the whole field that are too dry or require improvement. In this way, survey by drone helps farmers to improve irrigation water

Fig. 1.3 The drone is playing an important role in these techniques

efficiency and unveil possible pooling/leaks in the farm by providing irrigation monitoring system. Further, vegetation indices calculated through emitted or reflected heat/energy help to realize the health of crops and yields estimations. The drone survey makes farmers capable to get information about soil conditions of their lands. Multispectral sensors allow farmers to grab data which are useful for planning seed planting patterns, comprehensive field soil moisture analysis, irrigation management, and nitrogen-level management. Drones with multispectral sensors can accurately spot and treat inaccessible and problematic areas. Crop spraying through drone restrict save time and human contact with harmful chemicals. Agri-drones, which are designed especially for agricultural applications, can execute various tasks like spraying, irrigation, etc. much more rapidly than other air vehicles/planes. Professionals and agricultural experts are of the opinion that aerial spraying via drone is five times faster as compared to other methods.

12 Drone Policy in India

Unmanned aerial vehicle (UAV), commonly referred to as "drone," once limited to only a few ventures like military, surveillance, law enforcement, and safety inspection(s), now finds application in enormous civil and commercial work ranging from agriculture, surveying, and filming to journalism, shipping, product(s) delivery, disaster management, etc. These devices have now pervaded the genre of automation and consumer use. In due course, more and more people are entwining around them, finding more innovative and practical usage. In the fall of 2018, the

Government of India (GoI) released a drone policy, enabling the use of drones immediately following their application in infrastructure works. This policy also facilitated the use of drones in the agricultural sector, but with a few restrictions like prohibiting drones from spraying certain agricultural chemicals like insecticides, etc., unless warranted imperatively. The operation of drones was managed under the Unmanned Aircraft System (UAS) Rule 18 (part VI). Recently, on 26 Aug 2021 Ministry of Civil Aviation (MoCA), Govertment of India (GoI) released a new set of policies that materialized the draft policy presented earlier during the summer of 2021. GoI has now decided to annul the UAS rules of 2021 and replaced them with more flexible and unplugged under their "Drone Rules 2021." Some key features of the amendment are as follows: (1) Two types of the license were to be provided namely "student license" and "remote pilot license" with a renewal period of 2 and 10 years from the date of issue. (2) Security clearance was nullified to fly nano (<250 g) and mini drones. Further, one can fly micro-drones (mass greater than 250 g but less than or equal to 2 kg) also for non-commercial purposes but with a restriction of not crossing the vertical height of 15 m from average ground level (AGL). (3) No license is required to fly drones over private spaces under the green zone, though for all other operations, Unique Identification Number (UIN) and Unmanned Aircraft Operator Permit (UAOP) shall be compulsory. (4) Yellow zone, i.e., controlled airspace, which was earlier 45 km from the airport perimeter has been reduced to 12 km radius from the periphery of the airport. (5) A series of approvals, like Unique Authorization Number, certificate of manufacturing and airworthiness, remote pilot instructor authorization, etc., has been abrogated. Though all drones shall be registered online over the "digital sky platform." This shall also make the process of de-registration more fluid. (6) Maximum forfeiture associated with non-compliance of the drone is INR 100,000. On the other side, the fee for a remote pilot license has been positively reduced to INR 100 for all category drones. (7) Further, the payload limit which a drone may carry is now increased from 300 kg to 500 kg. The airspaces are still the same, i.e., red zone, amber zone, and the green zone, though as discussed earlier their boundaries are now adjusted under the new norms. The digital sky platform of the MoCA, GoI as usual shall act as the traffic control management system for the UAVs.

13 Way Forward

Drones technology has already transformed the farming industry and will expect to grow larger in the upcoming years. At the same time, as drone use is becoming more helpful for small farmers, there is still a long way to go before it develops as an essential part of each farmer's equipment list, specifically in developing and under-developed economies. Drone technology has extensive proficiency to perform a number of agricultural operations exceptionally fast and precisely. It can save man-power and also accomplish the statute of social distancing during the time of pandemics like COVID-19 and lockdown provision. Though high initial cost and restricted government policies are some of the challenges which act as hurdles in making the drone technology popular and farmers' friendly. Moreover, there is a need to carry out more research for optimizing operation protocol for drone use and calibrating and validating the drone data. As there is rare research available on the proficiency of the operations executed of dropping insecticides/pesticides, the scheduling of the field spraying practice is not feasible. Undoubtedly, drone technology is far better than conventional technologies of agriculture management; still there are a number of other issues which strictly need more scientific study and fine-tuning for efficient use of drone technology in the farming sector.

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Part II
Adaptation and Mitigation Strategies in Smallholder Agricultural System under Climate Change Scenario

Chapter 2
Revolutionizing Crops and Soil Resources' Resilience to Climate Change: A Case for Best-Fit Agronomic Practices in Low and High Input Systems

Erick Oduor Otieno, Joseph Onyango Gweyi, and Nathan Okoth Oduor

Abstract Climate change is the current and future threat to sustainable crop production and soil resilience in rain-fed agricultural systems. The high climatic variation, especially rainfall and temperature, has rendered agricultural productivity a high risk venture. Practices and technologies that abate the impact of climate change on agricultural production systems are thus imperative. There are several empirical studies of best-fit agronomic practices that have shown massive potential in curbing the devastating effects of climate change. However, these studies are isolated and do not clearly bring out how various agronomic practices cushion farmers against climate change. Consequently, little is known on how best-fit agronomic practices may be tailor-made to reduce and/or eliminate the impact of climate change in crop production systems. The aim of this chapter is thus to document and contextualize how various agronomic (herein referred to as best-fit) practices tackle climate change. It also looks at the policy and legal framework that strengthen the capacity of the practices. From the detailed literature, best-fit agronomic practices include: integrated soil fertility management, suitable tillage method, cereal-legume crop rotation/intercropping, greenhouse production, genetic modification, and soil and water conservation measures. Though the current policy and legal frameworks regulating the aforementioned practices are weak, there is an urgent need for them to be strengthened, farmer-sensitive, and implementable. There is therefore the need for up-scaling these practices by strengthening institutional support and adopting a bottom-up extension services approach.

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1 Introduction

There has been an increasingly volatile and erratic climatic pattern that has spread over the years (Oduor et al. 2020). Climate plays a key role in crop growth and development as it dictates the soil water balance which is one of the main factors in crop production. The effect of climate on crop production through soil moisture dynamics is twofold. First, rainfall supplies the required moisture for crop growth, and second, temperature regulates the potential evapotranspiration losses that are important for the available soil moisture. Therefore, declining rainfall and rising temperatures – two of the most important elements of climate – which are associated with climate change, will have a direct negative effect on agricultural production value-chain.

Climate change affects, directly or indirectly, both crops and agricultural soils. The high climatic variation, especially rainfall and temperature, has rendered agricultural productivity a high risk venture. At least 30% of yearly deviation in global average yields of top-six widely grown crops (corn, wheat, rice, sweet potatoes, cassava, and beans) is attributed to rainfall and temperature variations (Lobell and Field 2007). Sub-Saharan Africa (SSA) is projected to lose about 14% of cultivable land and about 20% of its pasture production potential by 2080 due to the climatic variations (Shah et al. 2008). This situation is expected to further deteriorate as it is forecasted that climate change will lead to warmer and drier conditions with more variable and extreme weather events in the near future (Meehl et al. 2007). This comes at a time when the effects of climate change are already deeply rooted given that around 80% of the agricultural land globally is rain-fed. This land contributes at least two-thirds of the world's food production (Alam and Ekhwan 2011).

The impact of climate change could be even worse in SSA where about 90% of staple food production is under rain-fed agriculture (Ngetich et al. 2014). The fact that farmers in critical regions require at least \$5246.52 ha^{-1} of Climate Risk Security (CRS) prior to the year 2021 shows the extent of strain in agricultural production. In highlighting the economic impact of climate change, Singh and Dhadse (2021) defined CRS as the compensation that should be extended to farmers based on their locality. There is need for urgent measures to reduce the current and future negative impacts of climate change since it is expected that the dependence on rainfall by most smallholder farmers will intensify in the future due to the rapid population growth .

Crops and agricultural soils face the brunt of the changing climate and are diminishingly being resilient. This could be because agriculture has been rendered risky venture and attracts little to no investments. In fact, farmers are starting to focus their attention on other lesser risky ventures at the expense of agriculture. This trend is not only detrimental to attaining sustainable food security and combating malnutrition, but also achieving the overall Sustainable Development Goals (SDGs). Formulating strategies to ensure sustainable agriculture intensification amidst the changes in the climatic patterns is therefore inevitable (Mupangwa et al. 2012; Mutuku et al. 2020). There is need for the identification and validation of climate-smart strategies that would sustainably improve agricultural productivity in the current and future climatic scenarios. Most of the approaches explored have revolved around forecasting on the future climatic patterns to enable appropriate agricultural planning, adapting to the drought and dry spells, mitigating the impacts of drought and dry spells, modification of the climatic conditions, and enhancing rainwater use efficiency. Nevertheless, it is customary that the available strategies have been blanket-applied with little attention to whether a production system is low or high input production system. Little is therefore known on how various strategies and agronomic practices perform in relation to enhancing agricultural production resilience to climate change. This chapter thus explores how climate-smart strategies and agronomic practices can be applied as best-fit approaches to enhance crops and soil resources' resilience to climate change in low and high input production systems.

1.1 Effect of Climate Change on Crops and Cropping Systems

Climate change, though may have some positive impacts depending on the locality and type of crop, has a range of devastating effects on crops and cropping systems. The effects can be typologically categorized into direct and indirect effects (Fig. 2.1). The direct and indirect effects include, but not limited to, reduced and erratic rainfalls, unpredictable seasons onsets, high temperatures/evapotranspiration/elevated CO_2 levels, floods and lodging, new pests and diseases, invasive species, erosions, soil fertility degradation, and droughts. On the other hand, indirect effects are: reduced land under agriculture, reduced biodiversity, and effect on wild relatives.

Though it remains unclear on how exactly climate change will affect crops in future, it has been widely suggested that increased adverse weather events like erratic rains, high temperatures and heat waves, rising carbon dioxide (CO_2) levels, heavy and fluctuating rainfall patterns, and frequent droughts currently pose a serious threat to crop production systems (Descheemaeker et al. 2016; Mall et al. 2017; Descheemaeker et al. 2020). Both heavy rains and drought affect response of crops to soil fertility inputs. Heavy rains cause leaching of applied nutrients while erosion caused by the rains washes away soil and nutrients. On the other hand, drier conditions occasioned by drought reduce nutrient uptake by crops. These two scenarios reduce nutrient use efficiency of the applied nutrients and hence reduction in crop yields. Also, heavy rains cause flooding, which leads to lodging and washing away of crops, thereby leading to loss of crops. High temperatures coupled with high evapotranspiration in low soil moisture regimes cause water stress to crops and may

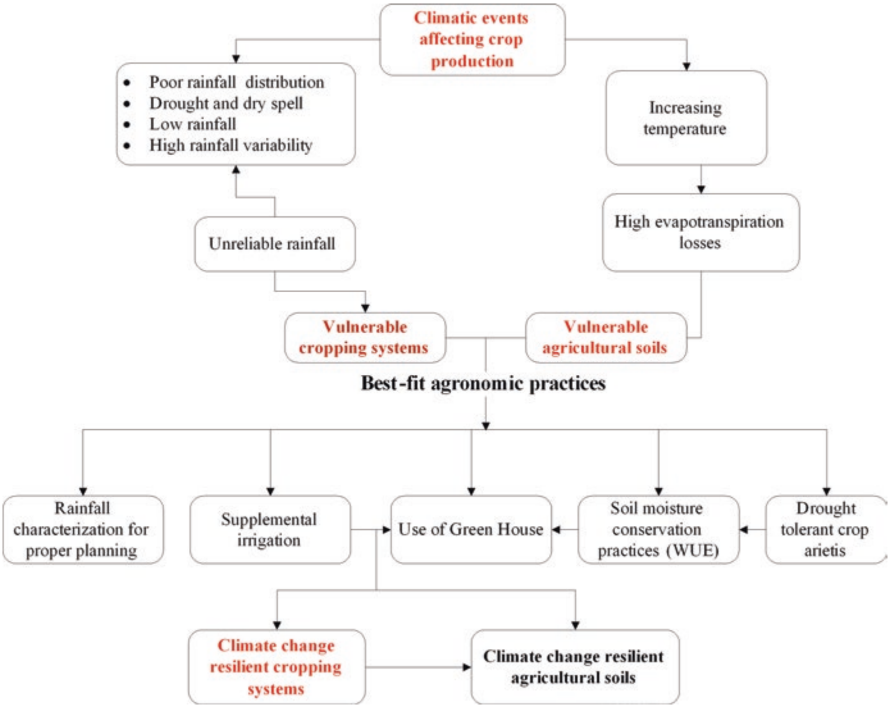

Fig. 2.1 Effects of climate change and interventions for resilient cropping systems and agricultural soils

lead to eventual death of the plant in adverse situations aside from enhancing soil water loss by evaporation.

Droughts are often characterized by high wind speed, temperatures, and evapotranspiration. This may cause loss in crop biodiversity as some vital species in an ecosystem may be more vulnerable to changes in climate than others. Cereal crops are very susceptible to climate variability caused by climate change (Wang et al. 2018). The effect of climate change could also affect access to agricultural produce and inputs. Adverse weather conditions may affect the timely delivery of agricultural inputs leading to delayed or failure to use the inputs thus further increasing the incapability of the cropping systems to be resilient to climate change. This could probably explain why, for instance, sunflower yield would reduce by 95% by the year 2100 under predicted climate change scenarios (Abd-Elmabod et al. 2020).

Crop improvement and control of yield losses that could be caused by weeds and crop pests stand to be negatively affected through the impact of climate change. Though it is beyond the scope of this chapter to discuss how climate change affects crop wild species, it is important to note that it does negatively affect crops wild relatively which are vital sources of genetic diversity for crop improvement. Future climate data covering a period beyond the year 2055 estimates that 16–22% of all the crop taxa will be extinct and more than half of all species are already losing their range size (Jarvis et al. 2008). In fact, a prediction of a worse-case CO_2 emission scenario by Intergovernmental Panel on Climate Change stated that there would be significant decrease in the yield of food crops (Luck et al. 2011). Climate change also affects crop production through favoring crop-pathogen interaction. For instance, a past study revealed that elevated atmospheric CO_2 levels may favor conditions in which pathogens like *Fusarium pseudograminearum* thrive (Luck et al. 2011). Modifications of weeds and crop pests associated with climate change also pose a serious threat to crop production (Raza et al. 2019), especially in smallholder farms with limited financial capabilities.

Climate change has varying devastating effects on major crops across the globe. Changing rainfall patterns dictate and make the onset of seasons to be unpredictable. This could have negative impact on farm operations like land preparation and planting making the cropping systems less resilient. Unpredictable rainfall patterns could mean shortened growing period that directly reduces food crop yields (Malhotra 2017). This is in addition to changing climatic events rendering agricultural land unsuitable for crop production (Abd-Elmabod et al. 2020). For instance, land under rice production in China shifted west and northwards as a result of climate change impact on agricultural land (Ye et al. 2015).

Monocropping systems are more susceptible to climate change than intercropping production systems. This is because this cropping system does not optimally utilize available resources such as soil moisture and nutrients in different depths due to root architecture of the mono crop (Huang et al. 2020; Leisner 2020; Mustafa et al. 2021; Xiao et al. 2021). It also limits biodiversity and only relies on one crop species that if affected by climate change leaves the farmer exposed to the effects of climate change. Moreover, monocropping may encourage mechanization, which in turn increases the use of fossil fuel, thus increasing emission of GHGs, thereby further making the system less resilient to climate change. Also the system may encourage the use of synthetic fertilizers to meet the nutrient requirement of crops. Tubiello et al. (2000) thus warned that yield of crops would be suppressed if the current agronomic management practices are not modified to handle the challenges caused by climate change. Taking rice cropping systems in southern China as our example, farmers in the region have significantly increased land under late double rice-cropping systems while deceased land under single rice- and early double rice-cropping systems (Ye et al. 2015) as a response to climate change.

1.2 Low and High Input Production Systems

Agricultural production systems are broadly categorized into two systems based on the amounts of farm inputs, such as pesticides and soil fertility amendments, used. These production systems are: (1) low-input production system (LIPS) and (2) high-input production system (HIPS). Often, LIPS is associated with biological production management, while HIPS favors the use of synthetic production management (Clark and Tilman 2017). It is worth noting that conventional versus conservation agriculture remains controversial and inconsistent. Whereas HIPS is commonly practiced in developed nations, LIPS is the main production system in most developing countries where smallholder farmers are the dominant agricultural producers. This location-based difference in input application is more of a disparity in resources (financial) endowment rather than climatic attributes of the two regions.

The two production systems respond differently to input application. Thus, they are likely to be impacted differently by climatic changes. For instance, crop yields are not significantly reduced when input application rate is reduced in HIPS. Thus, at this point, the main driver of crop yield is climatic dynamics. Conversely, reducing application rates of inputs in LIPS could greatly affect crop yield. Deschee maeker et al. (2016) pointed that low input productions are more responsive to mineral fertilizer application than high input production systems. Increasing inputs (especially soil fertility amendments) improves crop yields in LIPS to a point that climate change becomes the main driving factor. Inconsistency in the reaction of the two production systems to climate change brings to the fore the challenge of understanding agricultural production systems and enhancing input efficiency (Clark and Tilman 2017; Kravchenko et al. 2017). Consequently, climate change-input application/management interaction remains unclear and an area that much research attention has been devoted. Though these two production systems may be affected and react differently to climate change, discussed below are the best-fit agronomic management practices that improve resilience along crop production value chain.

2 Enhancing Crops' Resilience to Climate Change

Enhancing crops' reliance to climate change is best summed by the 4Rs. We christen this as climate-resilient 4Rs and include: farm structural re-organization; farm financial re-orientation; information repackaging and sharing; and policy and regulation restructuring (Fig 2.2). Enhancing crops and soil resilience to climate change calls for urgent research, funding, and capacity building on the 4Rs. Building a resilient agricultural production system requires that all the four interventions (4Rs) are addressed concurrently. The 4Rs are simple, yet best-fit agronomic and institutional adjustments that not only minimize risks associated with the changing climate but also ensure sustainable and resilient crop production systems (Mall et al. 2017; Wang et al. 2018).

Briefly, changing of cultivation is currently being used by farmers in Europe as an adaptation to climatic change strategy (Tubiello et al. 2000). For instance, it has been revealed that combining early planting of spring-summer crops together with the use of slower-maturing winter cereal crops has been able to maintain crop yields in the modern levels (Olesen et al. 2011).This adaptation strategy could be as a result of crops being more susceptible to climate change events, especially winter crops. They are affected by high and low rainfall, evapotranspiration, and temperatures. Crops are also indirectly affected by attacks of new and mutant pests and diseases. It is estimated that a temperature rise up to 2 °C will have a localized

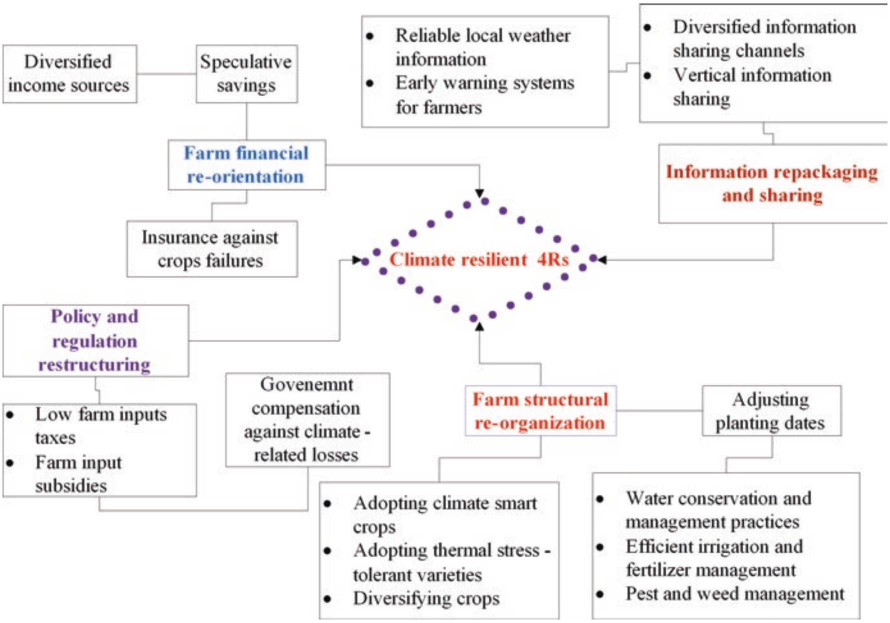

Fig. 2.2 Conceptualized climate-resilient pathways within the 4Rs

negative impact on crop yields (Singh and Dhadse 2021). Crops' production is affected by reduced soil moisture and unpredictable planting dates. It is estimated that up to 10% loss in yield results as a consequence of late planting/not synchronizing planting with rainfall onset.

Enhancing crops' resilience to the immediate and future climatic events is strongly dependent on abating causes of climate change such as greenhouse gas (GHGs) emissions in the present crop production systems. Crop production goals should be in tandem with reduction or elimination of GHGs emissions. Apparently, reduction of GHGs is not an objective in smallholder farms whose main aim is to maximize crop yield. This is could be because of the trade-off that exists between GHGs reduction and crop production (Sihvonen et al. 2021). In most cases, the objective of GHGs emissions reduction is the cost of the forgone best alternative. We thus discuss, in the subsequent paragraphs, possible best-fit agronomic practices that may reduce GHGs emissions but still enhance crop resilience to climate change.

2.1 Gene Modification

Maintaining food productivity with the changes in climatic conditions is a great task. Climatic changes subject crops to harsh conditions that involve changes in rainfall amounts and drought, temperatures, new pests and diseases, and salinity amongst other hazardous conditions. Reducing disruptions in crop productivity as a result of the changes is important in ensuring food security. Development of crop cultivars that can suit the changing crop growth conditions is critical. Achieving the desired crop cultivars that are able to withstand the impact of harsh climatic changes entirely depends on gene modification. A lot of studies have focused on improving crop tolerance to various conditions such as drought and high rainfall regimes, pests and diseases, temperatures, and heat waves. However, genetic modifications have always been done after the challenges have been experienced. There is need for the modifications to be tailored towards the projected conditions due to changing climates to reduce the impacts of the changes.

2.2 Spacing

Plant spacing is among the agronomic practices that significantly affect the productivity of various crops. Reduced spacing for instance could reduce sorghum tillering and productivity (Ara et al. 2007). This is due to root competition, which limits the maximum potential of expansion and utilization of soil resources. Under cassava and tomato production, reduced spacing was also observed to reduce productivity. On the other hand, increased spacing reduces plant population, thus reducing the overall output per land unit. Optimum plant spacing enhances better utilization of spaces, high yield, and quality production. Amidst climatic changes, adjusting plant spacing and plant density will help abate the impact of the climate changes which are normally associated with harsh crop growth conditions.

2.3 Rainfall Characterization

Rainfall is the major climatic factor affecting agriculture production in the rain-fed agriculture. Rainfall pattern has been characterized in various regions to forecast the likely rainfall scenarios to help in proper agricultural planning. This was to be as a calendar for the agronomic practices that allow farmers to plant at the right time and what to plant during the different cropping season. The rainfall parameters characterized include the onset cessation and the length of crop growth period. The planning helps evade the impact of varying climatic patterns in agricultural production. In addition, it was to characterize the various seasons in terms of the length of the rainy season to help in deciding on the best crops to be grown with the expected length of crop growth period. Rainfall distribution pattern and the dry spell characteristic also ensured proper planning for the within-season dry spells that have crippled rain-fed agriculture production. Farmers thus could plan for the expected dry spell as they shall have known the expected length, magnitude, and frequency (Mugalavai et al. 2008; Recha et al. 2011; Ngetich et al. 2014; Kisaka et al. 2015;

Oduor et al. 2020). However, rainfall characterization only allow for planning, thus should be integrated with the use of climatic smart mitigation measures.

2.4 Drought Tolerance Crops

Drought is projected to be among the key contributors to food insecurity in Africa. The severity of the damage to crops depends on the crop aside from the stage of the crop growth. Drought-tolerant crops are able to withstand moisture stress without significant reduction in their productivity. Up to 25% increase in maize yield has been reported when a drought-tolerant maize variety was used due to its ability to withstand moisture stress during the dry spells. Use of drought-tolerant variety has been promoted in drought-prone/low rainfall to improve food security . Some of the widely grown and promoted drought resistance crops include sorghum, pigeon pea, millet, and green grams. However, the adoption rate is still low among the small-holder farmers. The choice of crop to be grown by the farmers is normally guided by market demand among other prevailing socio-economic factors. In the end, farmers still continue growing their traditional food crops which keep failing in most seasons. Besides, in most cases, the droughts and dry spells have become too long for the survival of most drought-tolerant crops varieties. Other interventions that enhance soil moisture conditions are required.

2.5 Supplemental Irrigation

Supplemental irrigation has been explored to mitigate the effect of drought and dry spell in both the high and low rainfall potential areas. Under rain-fed agriculture especially in low rainfall regions, within-season dry spells have been observed to be the major cause of crop failure (Oduor et al. 2020). Supplementing irrigation can avert the impact of drought and dry spells especially at the critical stages of crop growth stage, which results in improved crop productivity. It is normally employed where other and water conservation are unable to mitigate the impact of prolonged dry spell extending to 2–3 weeks. The supplemental irrigation is only done when soil moisture drops below the moisture stress coefficient of the crop gown, below which crop productivity is likely to be affected. Irrigation scheduling procedures are normally employed in determining when or whether to irrigate depending on the crop grown and the stage of crop growth. While it has boosted crop productivity in the drought-prone region, obtaining irrigation water is a challenge. In addition, it increases the cost of production, thus uneconomical for the small-holder farmers in the drier areas where obtaining water is costly hence the strategy is only suitable for growing high value crops.

2.6 Green House

The ideal mitigation for the highly variable climatic pattern on agriculture is to regulate the conditions to suit the optimal crop growth requirement. Since the causes of climatic variations are natural, controlling climatic pattern is very difficult, especially over a wide region. Green houses can allow for regulating various crop production factors, including climatic to optimal conditions. Green housing involves the growth of crops under a controlled environment that can be regulated to the optimal crop growth requirements. Supplemental irrigation and temperatures are thus regulated for optimal crop performance under the green house conditions. However, the installation and maintenance of the green houses are expensive and uneconomical for low value crops and unaffordable for the poor small-scale farmers who are the majority. Therefore, the green houses are normally limited to the commercial high value crops for sustainability. Furthermore, the green houses are normally restricted to small land areas due to high capital investments involved. Alternative approaches for non-commercial small-scale farmers with low capital investments are thus critical to ensure sustainable productivity with the changing climate.

2.7 Soil Management Practices

The technology targets the conservation of available rainwater for agricultural use by ensuring efficient utilization of water . The technologies improve soil water infiltration and retention capacity, reduce water loss through evaporation and surface runoff, and contribute towards recharging groundwater . Soil management practices are among the most used approach by the small holder farmers due to the availability of the technologies and ease of access. Most of the technologies use locally available resources at the farmers' disposal, and thus widely adopted. Some of the practices that have been promoted in the low rainfall regions include ridging and tied-rides, minimum tillage and mulch, use of organic and inorganic resources, Zai pits, cover cropping, and cereal-legume systems.

2.8 Ridging and Tie-Rides

Ridging involves construction of sand walls conserve soil water and on which crops are planted. Farming is normally done on the ridges or while the furrows store the rainwater. The technology allows the capture and retention of rainwater for a while, hence reducing runoff losses. Water infiltration is also enhanced in the process, thus efficient utilization. However, the drawback of furrows is that they become ideal waterways when there is a lot of rainfall causing erosion. This can be overcome by connecting the ridges every 2–3 m so that small basins are formed; this system is known as tied ridging, furrow diking, basin tillage, furrow blocking, soil pitting, micro-basin, or reservoir tillage depending on the scale of application (. The rides are normally higher than the ties and thus it is easier for water movement from one pud to another within the furrow than from one furrow to another. Normally planting is done on the ridges in high rainfall potential areas while on the furrows in low rainfall regions. Tied ridging reduced runoff by 49–52% and doubled grain yield in the CHK (Okeyo et al. 2014).

2.9 Minimum Tillage and Mulch

Minimum tillage enhances soil moisture retention, crop yield, and nutrient use efficiency and reduces surface runoff (Mrabet et al. 2012). Ngetich et al. (2014) attributed the improved infiltration to reduced soil disturbance that encouraged the continuity of the soil pores. Constant soil disturbance in conventional tillage can be an effective compaction alleviation method when well implemented . The disturbance generates an initial reduction in bulk density and increase in infiltration that can delay runoff generation. The increased soil roughness immediately following tillage can also reduce runoff volume and velocity . However, the effect is short-lived; the created surface roughness by tillage disturbance can be degraded by raindrops impacts, aggregate breakdown, and collapsing . This can result in similar or increased soil loss as compared to non-disturbed soils under minimum or no tillage . The disturbed soil can also recompact easily when trafficked than the undisturbed . Tillage also reduces infiltration rate as a result of surface sealing and soil crusting (Miriti et al. 2013; Martínez-Mena et al. 2020). Additionally, it causes more tortuous soil pores that reduce infiltration rate, which encourages runoff losses .

The combination of minimum tillage with organic residue mulch enhances soil aggregate stability, bulk density, infiltration rate, and hydraulic conductivity (Mrabet et al. 2012; . The organics add soil organic carbon which improves properties such as aggregate stability and soil water retention capacity . However, there have been inconsistent reports on the benefits of minimum tillage over conventional tillage especially in combination with other soil management practices . Furthermore, the effectiveness of different tillage methods varies with the climate and soil type . There is need to conduct more research on reduced tillage and no tillage on agricultural productivity in tropical environments, especially in regions with low uptake like the Central Highland of Kenya before further promoting the technologies.

2.10 Organic and Inorganic Resources

Soil inputs like mineral fertilizer, animal manure, and *Tithonia diversifolia* have been reported to enhance crop yield and soil properties (Ngetich et al. 2014; Kiboi et al. 2019). Mineral fertilizer is however expensive and unaffordable to most of the farmers in Kenya who lack financial resources to purchase sufficient fertilizer amounts, considering fertilizer cost up six times more in Africa than in Europe (Mugwe et al. 2009; Sitienei et al. 2017). Additionally, mineral fertilizer has low nutrient conversion efficiency due to poor management by the farmers . The use and effectiveness among the farmers are therefore low. Organic inputs, e.g., animal manure, are needed in large quantities to be effective, because of their low nutrient supply capacity (Lukuyu et al. 2011). The availability of the inputs in sufficient amounts is a challenge considering they face other competitive uses such as construction material, in the case of animal manure (Mulumba and Lal 2008).

A combination of mineral fertilizer and organic inputs, which is within the farmers' socio-economic circumstance, emerged to have the highest and most sustainable gain in water productivity per unit nutrient or water used from various studies across SSA (Vanlauwe et al. 2010). The combination results in synergistic effect that improves synchronization of nutrient release and uptake by crop . However, the performance varies with the management. For instance, N immobilization has been observed when organic inputs with high C:N ratio, such as maize stover is used together with mineral fertilizer, which contributed to eventual reduction in crop yield (Liang et al. 2011). In other studies, use of organic plus mineral fertilizer has recorded high yield (Vanlauwe et al. 2015). The combined use of fertilizer and organic inputs with other soil management practices needs further investigation.

2.11 Zai Pits

Zai is among the most renowned technology which has been developed based on indigenous knowledge and traditionally used to improve poor and bare soils and conserve water . The Zai pits are dug and filled with organic materials such as manure, compost, or dry biomass. This leads to increased microbial activities which in return increases the rate of water infiltration during the rainy season. This creates a micro-environment that increases drought resistance and improves crop yields. Zai pits are most suited for ASAL areas where infertile, encrusted soils receive low and often highly unreliable rainfall, causing the small-scale farmers to face constant challenge to produce enough food to feed their families and generate much-needed incomes. Consequently, Zai pits as an innovation address issues of land degradation, soil infertility, and moisture retention.

2.12 Cover Cropping

Cover cropping enhanced soil surface cover which reduces soil moisture loss through direct evaporation and surface runoff. This is because the canopy created by the cover crop reduces soil temperatures thereby reducing the sun evaporation potential. The cover cropping also add vegetative materials to the soil, which help improve soil hydrological properties aside from acting as barriers to runoff loss. The most widely grown cover crops are sweet potatoes and other legumes such as beans, peas, and groundnuts.

2.13 Cereal–Legume Systems

Cereal and legumes provide an efficient utilization of environmental resources, decreases the cost of production, provides higher financial stability for farmers, decreases pest damages, inhibits weeds' growth more than monocultures, and improves soil fertility through nitrogen increasing to the system and increase yield and quality . Cereal–legume intercropping is one of the climate-smart cropping practices suitable to smallholder farmers. This is due to its potential to achieve multiple benefits that relate to climate mitigation and adaptation and general risk aversion via diversification . This makes the cereal legume systems more popular aside from the diversification of diet and maximizing the efficiency of labor to the farmers . Intercropping system is a type of mixed cropping and is defined as the agricultural practice of cultivating two or more crops in the same space at the same time .

The cereal–legume intercropping complements each other in terms of rooting system, growth pattern, aboveground canopy, and water and nutrient demand which enables efficient utilization of crop production resources, leading to improved crop productivity (Ngetich et al 2014). This is because the legume intercrop uses deeper soil resources at about 0.3–0.9 m deep while most cereals utilize the resources within 0–0.3 m deep avoiding the competition of water and nutrient resources aside from ensuring the nutrients that could have been leached are recycled . In addition, the legumes have the ability to replenish soil mineral nitrogen through its ability to biologically fix atmospheric nitrogen without competing with cereal for nitrogen resources . This is where the free leaving bacteria in the root nodules of the legumes biologically fix the nitrogen in the air into the nitrates in the soils that can be directly utilized by the plants. In crop rotation, legumes contribute to a diversification of cropping systems and as N_2-fixing plant, it can reduce the mineral N fertilizer demand. Due to improved fertility and water use efficiency under the intercrop and cereal legume rotation, there is increased foliation which provides vegetative material into the soil and improves the soil cover. Soil physical properties are further improved and hence low runoff and evaporation water losses. However, legumes have been observed to compete with cereal crops for the limited resources, which lowers overall productivity . Managing Beneficial Interactions in Legume Intercrops (MBILI), which involves alternating two rows of cereals and two rows of legumes, was observed to enhance water use efficiency, reduce surface runoff, and increase crop yield (Ngetich et al. 2014).

3 Policy and Legal Frameworks for Resilient Crops Production Systems

Sustainable and climate change resilient crops production systems require strong, context-based and functional legal and policy frameworks. Several sustainable policies have been suggested within the Indian crop production system context, which include subsidizing high yield crop seeds to vulnerable farmers, insurance cover against failed crops as a result of climatic events, etc. (Singh and Dhadse 2021). At micro-level, farming communities are able to adopt remedial measures against climatic change risks. The possible adaptive or remedial measures are: seasonal changing for crop types, change of crop variety, and adjusting planting dates. Nonetheless, these measures do not guarantee farmers' long-term economic sustainability and survival because of their incapability to understand long-term climatic trends (Singh et al. 2016). In fact, provision of insurance cover against climate change vulnerability may restore economic security of farmers and go a long way in ensuring their survival in the long term (Panda et al. 2013). In addition, most of the regulatory frameworks have not been accompanied by strict enforcement measures, and thus they are not being fully implemented.

4 Conclusion

Climate change remains the most complex biophysical factor threatening crop production and soil resilience in SSA. There are agronomic practices that best suit approaches of managing the impact of the changing climatic events. However, these practices have not been viewed holistically in addressing the challenges posed by climate change on crop production and soil resilience. Approaches/practices such as genetic modification, soil moisture and fertility management, planting spacing, integrated weather forecasting approach, and cropping pattern can be great interventions in dealing with the current and future menace of climate change. This can be achieved by strong, implementable, and farmer-sensitive policy and legal frameworks. However, it is important to note that most of the approaches used in mitigating the impact of climatic changes on agricultural production have been effective but with limitation. No strategy in isolation has the ability to holistically mitigate the impact of climatic change; thus an integrated approach should be employed depending on the situation at hand.

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Chapter 3
Drought-Resilient Climate Smart Sorghum Varieties for Food and Industrial Use in Marginal Frontier Areas of Kenya

Symon M. Njinju, Joseph Onyango Gweyi, and Rose N. Mayoli

Abstract *Sorghum bicolor* (L) is classified globally as the fifth most important cereal crop after wheat, maize, rice, and barley. The demand for sorghum in Kenya is increasingly at 275,000 T per annum against the estimated production value of 150,000 T, providing income to more than 3 million people. Apart from food, Kenya Breweries Limited consistently provides a ready market to a huge amount of sorghum estimated at 60,000 tonnes annually and is expected to rise with time. In Kenya, the sorghum productivity level is at 0.7 t/ha in Arid and Semi-arid Lands areas (ASALs), which is far much below the potential yield ranging between 2 and 5 ton/ha. Sorghum's rich diversity in ASAL areas makes it suitable for adaptability to Climate Smart Agriculture, Technologies Innovations Management Practices. This makes it a worthy crop for supporting livelihoods under the harsh climatic condition caused by climate change. In Kenya, Sorghum crop is usually cultivated at 0–2200 m above sea level in Eastern, Nyanza, and Coastal regions. Being a C4 plant, it has an efficient carbon dioxide fixation that makes it perform well in lower altitude areas with high temperatures, low, intermittent, and unreliable rainfall. Farmers in such areas opt to grow local varieties instead of the high-yielding hybrids due to poverty, inability to afford irrigation facilities, and essential necessities for production. Drought and water stress caused by inadequate and unevenly distributed rainfall in ASALs limit sorghum productivity. Also, pests, diseases, low yields, weeds, local planting seeds, and use of fertilizers are other challenges. On the other hand, enhancement of drought tolerance in arid climatic conditions involves

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mechanisms that maintain plant water status upon which genes and proteins are activated. This process most likely can affect plants resulting in a good number of physiological and biochemical changes that are crucial for growth and survival. Among them, changes in grain weight and protein content may affect the malt quality. As a defense mechanism in response to drought, sorghum landraces native to ASALs are likely to activate and involve participation of numerous proteins that may affect the grain and malt quality. It is imperative to come up with a drought-tolerant sorghum variety with good grain and malt quality and new technologies to be recommended to the stakeholders for improved sorghum production.

Keywords Sorghum bicolor · Drought tolerant · Climate change

1 Introduction

Sorghum bicolor (L) ranks as the fifth most important cereal crop after wheat, maize, rice, and barley globally (Batista et al. 2019). The best-known sorghum varieties are *Sorghum vulgare* and *Sorghum bicolor* L. Moench. *Sorghum vulgare* species accounts for all annual types (Owuama 1999), while *Sorghum bicolor* L. Moench accounts mostly for the cultivated grains in Africa (Taylor 2003). Sorghum production is chiefly exercised in developing countries with 90% of the cultivated lands being located in Asian and African countries. Africa produced a sizeable amount of sorghum yield which accounts for one-third of worldwide production. This production is aided by the fact that Africa experiences tropical conditions (Munda et al. 2019). In Kenya sorghum is mainly grown in Eastern, Nyanza, and Coast regions. This is aided by the fact that sorghum has the capability of performing fairly well under unfavorable weather conditions which dominate in Sub-Saharan Africa (SSA). Also, it can tolerate exposures to waterlogging; in this case, Power et al. (2019) reported that it prominently serves as a viable cereal crop in most food-insecure households. In addition, subsistence farmers in the same regions most of the times lack necessary farm inputs as well as finances to adopt irrigation systems (Glantz 1987; Leichenko and O'Brien 2002). As a result, the crops are mechanically forced to react through production of biochemical responses for compensation (Izanloo et al. 2008; Tekele 2010).

In Kenya, Sorghum is well adapted to the arid and semi-arid lands (ASALs). This accounts for 80% of Kenya's total landmass, which receives less than 750 mm of rainfall annually. It is approximated that sorghum requires about 332 kg of water for 1 kg of dry matter compared to 368 kg and 514 kg of water for similar amount of dry matter in maize and wheat respectively, and this makes it a smart choice for climate smart agriculture. In Kenya, there are approximately 240,000 smallholder sorghum farmers with land sizes that ranges from 0.4 to 0.6 ha (KAVES, 2013). Though mono-cropping is greatly recommended for sorghum, only a few farmers adhere to this directive because of the small pieces of land (KAVES, 2013). The production of sorghum in the country has been rising in the recent past (approximately in the last 10 years from 54,000 tonnes in 2008 to about 180,000 tonnes in 2018 (FAOSTAT, 2019)).

In 2014, statistics showed that sorghum provided income to more than 3 million people in Kenya (MOALF 2014). Besides, it serves as an essential food security crop in semi-arid areas of Africa (Munda et al. 2019). It is estimated that more than half of sorghum production is consumed as food, 1% as livestock feed, about one-fifth is processed, and about 15% lost in the field and after harvest (FAO 2019). The grains and sweet stalk can be utilized in food and non-food sectors for the production of commercially valued products, such as syrups, glucose, modified starches, maltodextrins, jaggery, sorbitol, and citric acid (Ratnavathi et al. 2016). Also, sorghum is used to manufacture wax, starch, dextrose agar, and edible oils (Dicko et al. 2006). Sorghum is a rich source of phytochemicals including tannins, phenolic acids, anthocyanins, phytosterols, and policosanols, which have remarkable impact on human health such that it reduces chances of cardiovascular disease, cancer, and obesity (Awika and Rooney 2004).

Besides, it can be used as a basic ingredient in beer production as malt and adjunct with a big market in the brewing industry in the country. To this end the Kenya Breweries Limited (KBL) is reportedly to be among the top most users of sorghum, thus providing a ready market which stands at 60,000 tonnes of sorghum annually and this is expected to continue rising with a projected increase in beer consumption (Tegemeo, 2018). Statistics reveal that the demand for sorghum is on the rise at an average amount of 275,000 tonnes/year against the estimated production level of 150,000 tonnes (FAO 2019). This was occasioned by sorghum promotion strategy for its use in making beer in Upper and Lower Eastern as well as Western regions. This has enhanced its production and industrial use. Therefore, due to its huge demand by various sectors of the economy, this prompted sorghum to be identified as one of the priority crops for enhancement through research by Kenya Climate Smart Agriculture Project (KCSAP), which is being implemented in various counties including Baringo and Siaya counties (Fig. 3.1).

Drought is one of the most important environmental stresses that critically impairs plant growth and development; this limits plant production and performance immensely than any other environmental factors (Shao et al. 2009). Although sorghum reveals resilience to the effects of water stress, some specific growth stages of its life cycle are more susceptible to water stress than others. For instance, drought inhibits sorghum establishment in early vegetative seedling growth stage through to the reproductive stages (pre- and post-flowering) (McKersie and Leshem 1994; Tuinstra et al. 1997; Kebede et al. 2001; Wani et al. 2012). However, to counter the effects of water stress, plants show coping mechanisms such as avoidance, tolerance, and escape (Tuinstra et al. 1997; Bray et al. 2000). Drought escape mechanisms are revealed when plants complete their life cycle before severe water stress arrives, while avoidance mechanisms are brought up when the plant maintains relatively high quantities of water in their tissues despite there being moisture shortage in the atmosphere (Shashidar et al. 2000). Finally, in drought tolerance, the plants balance between turgor pressure maintenance and reduction of water loss assisting them in surviving incidences of drought stress (Shashidar et al. 2000).

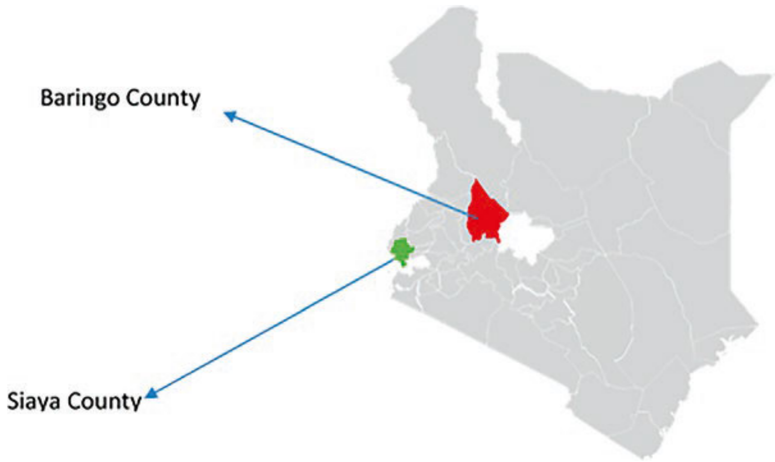

Fig. 3.1 Map of Kenya showing sorghum-growing counties of Baringo and Siaya

Even though water is essential for biological processes, periods of drought have profound effects on physiological processes. Under field conditions that are subject to cyclical changes with unpredictable climatical conditions, intermittent rains may follow a drought period prompting biochemical responses to a rehydration event which is a good indicator of recovery after rehydration. Crops have been found to exhibit a compensatory effect after exposure to such stress (Adalsteinsson 1994; Devnarain et al. 2016). In ASAL environments there is a tendency of intermittent rainfall that interferes with the plant's biophysical processes resulting in stress. Though it is important to have higher drought resistance during drought periods, drought stress in plants is usually transient and the capacity to recover is also very important. Among the important aspects to consider while selecting sorghum varieties for increasing yields and income in the drought-prone areas is compensatory of losses during drought stress.

The drought situation has been exacerbated by the effects of climate change which leads to erratic rainfall and salinity stress in arid and semi-arid regions (ASALs). This is coupled with high incidences of pests and diseases, weeds, high soil salinity, and low soil fertility. In addition, sorghum is less preferred by the farmers as compared to maize which is more susceptible to drought (Riziki and Maina 2013). Furthermore, sorghum production in the country in some areas has stagnated due to lack of adoption of suitable drought-tolerant genotypes (Timu et al. 2014). This has led to low sorghum yields which cannot meet its rising demand. Thus there is an urgent need to utilize well-adapted drought resistant sorghum varieties that would then help in climate change mitigation. This is because well-adapted sorghum can endure high temperatures and drought and can withstand long periods of exposure to waterlogging, hence a good alternative for improving livelihoods.

2 Traits Favoring Sorghum Production in Kenya

Sorghums varieties being grown in tropics are influenced by photo-periodism and thus they are categorized as short day plants. Therefore their response to day length is an important adaptation mechanism. Just like other C4 photosynthetic plants, sorghum has a CO_2 fixation mechanism that is effective prompting it to perform well in low altitude areas experiencing incidences of high temperature and drought (Paterson 2008). The crop is also cultivated in altitude range (0–2200 m) above sea level and has a potential for increased production in Kenya since it has large ASAL areas accounting to 82% of the total landmass (Munyiri et al. 2010) that are characterized by high temperatures and low intermittent and unreliable rainfall. However, all is not lost since some sorghum genotypes both landraces and improved ones are well adapted and can be grown successfully in these areas in combination with viable technologies. This is because sorghum is documented to be drought resistant and produces better yields with minimum precipitation and thus it is one of the crops of ensuring food security (Riziki and Maina 2013). The available local varieties have characteristics none other than high yielding, drought resistance, and early maturity among others (Muui et al. 2019). Additionally, there are several hybrids with special attributes like high yields that have been recommended and released for adoption in Kenya as shown in Table 3.1.

Table 3.1 Hybrid sorghum varieties grown in Kenya

Variety	Grain color	Maturity (months)	Eco zone and area	Special attributes
Gadam	Gray	3.5	Semi-arid lowlands of Machakos, Kitui, Kajiado, Embu, Makueni, Mwingi, Parts of Rift Valley, NEP	Tolerant to birds, stem borers, shoot fly, and foliar diseases
Seredo	Brown	3.5		Wide adaptability
Serena	Brown	3		Wide adaptability
KARI Mtama 1	White	3–3.5		Attractive to birds
KARI Mtama 2	White	3.5		Resistant to birds
E1291	Brown	7	Baringo, Nakuru, Koibatek, Taita Taveta, Narok	Dual purpose, good beverage
E6518	Brown	8		Good beverage
IS76	White	3		Tolerant to stem borers
BJ28	Brown	7		Dual purpose

Source: Greenlife Crop Protection Africa (2019); http://www.kari.org/ENGLISH/Sorghumfood.htm

3 Challenges in Sorghum Production

Despite its critical roles, sorghum production margins in Kenya have stagnated for long, leading to importation of more than one-third of the total consumption. This is because sorghum production is faced with numerous challenges that lead to low yields. The major constraints limiting attainment of high yield include pests and disease, drought, weeds, and marketing. Also, there are issues to do with lack of certified seeds (Muui et al. 2013; Tegemeo, 2018). In addition, there is genotype interaction, environmental factors, and production issues. Drought is one of the main challenges, especially in the ASALs, that hinders growth and yield of sorghum (Cicek and Cakirlar 2002). In actual sense, the permanent or temporary water deficit severely affects plant growth and development more than any other environmental factors (Anjum et al. 2011).

In terms of weeds, a study by Muui et al. (2019) revealed that low sorghum yields were attributed to Witchweeds, although the study also captured pests, diseases, and lack of fertilizers as other important negative factors. In ASALs, water stress is classified as a major constraint leading to low yields in ASALs. This water stress is caused by inadequate, erratic, and unevenly distributed rainfall. This is conjoined with other factors such as farmers being poor, and therefore, they are unable to afford irrigation technologies and other necessary equipment due to their poverty-stricken characteristics (Jaetzold et al. 2006). Furthermore, there are limited efforts to deliberately avail and promote sorghum varieties that are suitable and well adapted.

4 Effect of Drought on Sorghum Grain and Malting Quality

Drought stress prompts manifestation of some of the main survival mechanisms, including the genes and proteins getting activated, and these affect many processes such as physiological and biochemical changes that are critical for survival and growth (McDowell 2011). For instance, under water stress, barley grain weight and protein content are known to reduce and increase, respectively, consequently worsening the malt quality (Wu et al. 2017). Sorghum landraces native to ASALs are likely to activate several defense mechanisms that involve participation of numerous proteins in response to drought effects (Gong et al. 2005; Farmer and Mueller 2013; Calzada et al. 2019). Also, such physiological and biochemical mechanisms may affect the sorghum grain and malt qualities desirable to the consumers.

4.1 Grain Quality

The sorghum grain quality to a great extent depends on the grain type. It includes a range of properties that can be defined in terms of physical (moisture content at 12.5%, kernel size), hygiene (fungi and mycotoxin count), and intrinsic (fat content, protein content, endosperm texture, hardness, and starch content) quality characteristics (Ratnavathi et al. 2016). In addition, Ratnavathi et al. (2016) reported the alpha amylase and diastatic activity of different cultivars.

The quality properties of a grain are influenced by their genetic makeup growth period, time of harvesting, handling equipment, drying system, storage practices, and transportation mechanisms (Ratnavathi et al. 2016). Studies have shown that moisture stress has notable effect on the chemical composition of sorghum varieties. Increased drought shows decreased protein and starch content in sorghum grains (Khaton et al. 2016). Grain protein and starch contents also differ with varieties where drought-tolerant varieties have higher quality grains than less tolerant varieties (Khaton et al. 2016).

4.2 Malt Quality

Sorghum primary processing stages involve grading, cleaning, destoning, dehulling, and polishing of the grain to improve its appearance and market price while secondary processing involves its conversation into food products. In sorghum malting, its quality and phenolic contents provide it with important raw material (Embashu and Nantanga 2019). Therefore, it is necessary to select sorghum genotypes fit for brewing considering the malt quality parameters including hot water extract (HWE), malting weight loss (MWL), diastatic power (DP), and free amino nitrogen (FAN). The actual malting procedure involves controlled grain steeping in water, germination in moist air, and drying (Bekele et al. 2012). Its presence assists in mobilizing endogenous hydrolytic enzymes (α- and β-amylases in the grain) to modify the structure of the grain so that it will be readily solubilized during the brewing process to produce fermentable worts of desirable characteristics; flavors, nutrients, and color with a minimum loss of dry weight.

Sorghums' malt quality is highly affected by the malting processes, in particular steeping, germination, brewing conditions, and variety. This remarkably affects the hectoliter weight, crude protein, germination energy, and flour starch amylose content (Bekele et al. 2012). Steeping sorghum grain in dilute formaldehyde and sodium hydroxide enhances the malt quality in genotypes with high levels of condensed tannin by suppressing inhibitory effects on the malt enzyme (Taylor et al. 2006; Beta et al. 2000), while sodium hydroxide increases water uptake by the sorghum grain (Beta et al. 2000). Also, waxy and hetero-waxy varieties have the best malting potential, and thus, they are usually fit in the brewing industry since their soft endosperm texture allows hydrolytic enzymes ingress to starch granules that already have increased gelatinization in comparison with normal non-waxy sorghums (Taylor et al. 2006; Beta et al. 2001).

5 Opportunities for Sorghum Research in Kenya

Globally, there is a huge market potential for sorghum that needs to be exploited. Among the top 10 sorghum producers globally, only the USA and Argentina have notable volumes for exportation. On the other hand, countries like Japan, Mexico, and India still import huge volumes of sorghum to meet domestic consumption (Tegemeo 2018). In Kenya, Sorghum production has increased due to its unexploited potential, which can be harnessed for poverty alleviation, income generation, employment creation, and malnutrition reduction. For these reasons, sorghum cultivation has been revitalized as a traditional high value crop (MOALF 2015). Sorghum production potential in Kenya ranges from 2 to 5 ton/ha against the realized production yield of 0.7 tons/ha which is unlikely to meet the ever-increasing domestic market. It is grown on an estimated area of about 184,654 ha, and this has the ability to support over 25% of Kenyans in food supply and more than 26% for livestock feeds (Fig. 3.2).

Sorghum has become an important crop despite its unique viability. Sorghum can be utilized as a source of food and industries for the production of alcohol, biofuels, and livestock feeds. With the low productivity level, it is expected that the country will not satisfy the demand. Sorghum for consumption has the potential for value addition in manufacturing alternative products, for example, gluten-free flour. Gluten can be availed to patients with gluten-related disorders. Sorghum is preferred as an alternative to maize for making livestock feeds production because it is a bit cheaper to produce. Therefore, the reduction in costs of livestock feeds could have a notable impact on the livestock industry because the cost of feeds is one of the key important factors in the livestock sector.

Sorghum production offers multiple possibilities for selection of genotypes adaptable to both CSA and TIMPs and a wide range of uses. Sorghum has potential to produce a wide range of products like sorghum syrup, baking, brewing, agrochemical, ethanol, and bio-energy (Njagi et al. 2019). Therefore increased sorghum supply will not only provide required raw material for Kenya Breweries Limited,

Fig. 3.2 Hybrid grain sorghum field in Siaya county: demonstrates the high potential for sorghum production in ASALs of Kenya

but also it will create opportunities for other value chain actors. As a consequence, breeders and seed companies will renew their interest in investing in the production of sorghum seeds. Also, production inputs and extension services demand will rise creating more opportunities. Since Kenya has bilateral agreements with countries such as China, Japan, and India who are among the leading countries in utilizing sorghum, this can be a platform for negotiations with an aim of getting more market opportunities for sorghum or its products.

6 Approaches for Resolving Sorghum Shortage and Need for Research

The main approaches should be centered on high investment in inputs such as improved seeds; this is because adoption of modern varieties of sorghum is quite low (Gebretsadik et al. 2014). Also the focus should be on investing in fertilizers and related inputs for enhancement of crop intensification, commercialization, and value additions. Additionally, other factors to be considered include identifying and bringing together all the key stakeholders in the sorghum industry, and this can be achieved through initiatives. Also there should be formation of production cells and farmers will be able to receive trainings and be able to get ready market. Another key issue is marketing, and as a country, the focus should be in investing in the progression of market institutions, processing methods, and innovations that reduce marketing costs. This could be achieved effectively by embedding on the options for enhancing competitiveness and demand creation (e.g., food and non-food uses). Actually, the sorghum venture should be sustainable “market-oriented” enterprise enabled to successfully compete with rest of the crops. Also new technologies such as modelling using Agricultural Production Systems sI-Mulator (APSIM) model to help in designing more resilient and productive farming systems using the diverse sorghum genotypes available in the region. A model by Adiku et al. (2015) on the impact of climate change on productivity of locally important traits could help in developing adaptation and mitigation strategies in sorghum as no blanket approach is applicable.

Research programs should be on proper understanding of the mechanisms that underlie drought tolerance by carrying out research on the physiological and biochemical processes. Although grain sorghum manifests resilience to the effects of water stress, particularly during the growth stages in its lifecycle, the most susceptible stages to drought stress are the early vegetative stage and reproductive stages (that is pre- and post-flowering) where water requirement is on high demand (Anjum et al. 2011; Kebede et al. 2001). Water stress during pre- and post-flowering stages also impacts negatively on grains. Therefore the ability to withstand water deficit and recover after drought at these stages is of importance for increased plant growth and yield. Intensive research should be carried out to understand plant responses to water deficit, because works describing the effects of water stress and re-watering on plants are limited (Takele, 2010). In addition, there are good reports indicating compensatory effects of crops under stress. It would be important to understand such compensatory effects in sorghum genotypes under different water regimes. Some of the main mechanisms for sorghum recovery after drought are suggested to be as a result of the genes and proteins which are activated. This affects many processes in the plants causing physiological and biochemical changes of genotype. These changes include loss of cellular turgor, membrane fluidity and composition, osmotic potential, and protein–protein interaction.

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Chapter 4
Optimizing Nitrogen Management for Improved Productivity, Nitrogen Use Efficiency, and Food and Nutrition Security: African Context Perspectives

Joseph P. Gweyi-Onyango and Winnie Ntinyari

Abstract Sub-Saharan Africa (SSA) experiences a challenge of low soil fertility due to inadequate application of fertilizers. To achieve food sufficiency, it is recommended to adopt improved nutrient management strategies specifically Nitrogen (N) that plays a critical role to crop productivity. Due to its reactive nature, understanding N cycling into the food systems is complicated. In SSA, the problem of N management is two-fold due to too little application of N inputs and high losses to the environment. Therefore, there is a need to understand the key indicators that can be used to monitor and benchmark performance of N into the systems. Nitrogen use efficiency (NUE) and budgeting are two tools that have been recommended to analyze performance of N into the food systems. N budget takes into consideration all N flows into and out of the system and is used to identify sources of surplus either in terms of excess or deficit. On the other hand, NUE presents a conceptualized comparison of output to inputs to depict the ranges of safe operating boundaries for specific crops or at farm levels. From the existing N budgets in SSA, there is a glaringly higher nutrient mining due to large negatives where crop removal exceeds the applied N. For NUE, most of the farmers or cropping systems operate above the safe operating boundaries for N management, implying continuous depletion of soil fertility. Although two tools (NUE and N Budget) present feasible opportunities to N management, there is need for strong policy and institutional linkages to benefit farmers through improved crop productivity and enhance a food secure Africa.

Keywords Nitrogen budget · Policies · Soil fertility · Crop productivity · Sub-Saharan Africa

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1 Introduction

Africa is classified as one of the impoverished regions across the world with matters of soil fertility, economy, and living standards (Erlyset al. 2019). Due to uncertainty in returns on investments, farmers have not been fully convinced on application and purchase of mineral fertilizers. Nitrogen (N) use in sub-Saharan Africa (SSA) is limited due to high costs and associated difficulties in accessing it (Rware et al. 2016). Consequently, fertilizer use in sub-Saharan Africa is rare and has remained low in the distant past, with commodity use being stagnant in some countries. This has led to persistently lower yields as compared to other parts of the world (Rware et al. 2016), despite more than 66.67% of the population in the region relying on agriculture for livelihoods. Moreover, SSA constitutes only 3% of the total global fertilizer use which averages 7 kg ha^{-1} compared to over 150 kg ha^{-1} in other parts of the world, such as Europe and Asia (World Bank 2007), despite a clear trend of high soil nutrient deficits (Morris 2007). Consequently, there has been reported a lack of intensification of modern inputs with resultant lower average yield of crops, particularly cereals in SSA as compared to other most developing regions of the world (World Bank 2007). The main source of N supply in African cropping systems is from the existing soil N reserves. However, over-reliance of these soil N pools leads to soil N depletion since more is not added into the system and yet the reservoirs are not renewable (Smaling et al. 1997). Depleting the soil status notwithstanding, there is positive increment in food production for the rapidly growing population, while causing significant problems by reducing soil fertility and releasing Nr into the environment (Hutton et al. 2017). According to Drechsel et al. (2001), the estimated balances in SSA farms were negative (–) 26 kg N ha^{-1} $year^{-1}$, and this depletion has escalated due to more mining of N as farmers continue to grow crops without balanced N replenishments. Accordingly, the phenomenal soil N depletion has adversely affected the African food security goals.

There is need to advocate for increased nitrogen supply for improved food productivity and for reduced yield gap in order to feed Africa's burgeoning population. However, increased fertilization will not improve the existing negative balance due to higher crop uptake and uncontrolled N loss pathways. Moreover, in absolute terms, food supply will increase land degradation and continue to be a menace in the cropping systems (Drechsel et al. 2001). Low agricultural yield in Africa is associated with inadequate inputs emerging from pervasive conflict, poor governance, unstable climatic conditions, land degradation and low fertility of agricultural land (Sasson 2012). The recently rampant and unplanned rural–urban shift has further aggravated the situation in the food market system in SSA by creating nutrient depletion in rural farmlands and accumulating nutrients in urban regions and cities. It is not only the absolute food availability that is a concern but the food quality as well, which is a sum total of food security. Food security refers to the ability to have sufficient, safe, and nutritious foods that meet the dietary needs and recommendation of human. In SSA, there is need to advocate for N optimization for better nutrition security while reducing environmental threats. In the region, the challenges related to managing N that is linked to both insufficient N input and excessive loss should first address the "too little" and "too much" paradox (Masso et al. 2017). Although Nr has made contributions towards dietary needs for humans, large areas in Africa are deficient of available N to achieve food and nutrition sufficiency (Alexandratos and Bruinsma 2012; Ciceri and Allanore 2019; Pradhan et al. 2015). Recently, the United Nations Environmental Programme has identified Nr as one of the top five emerging issues that impact climate, public health, and environment and are linked to over-reliance of Nr by the globe for food production (UNEP 2019).

2 Methodology

The materials used in this chapter are from a critical review of the papers that contained data on nitrogen fertilizer use and management in African agriculture. The literature search was based on keywords including Nitrogen, Africa, soil fertility, nutrient management, nutrient depletion, nitrogen use efficiencies, fertilizer use, cropping systems, food security, nutrition security, and yield gap. The search based on keywords was also complemented with the search through the articles found in the literature.

2.1 Role of Nitrogen in Soil and Food Productivity in SSA

Anthropogenic N through fertilizer input is the new source of Nr to the global. Nitrogen has a critical role in increasing productivity and meeting the food needs of the populations. Availability and proper management of N promote reconciliation in terms of economic status and environmental consideration (Ladha et al. 2020). N cycling in cropping systems presents a complex challenge due to diverse pathways of N loss to the environment upon application, leading to adverse effects (Canfield et al. 2010; Galloway et al. 2008; Schlesinger 2009; Vitousek et al. 2009). The amount of N lost and the extent of pollution caused show that currently the world has transgressed suitable the planetary boundary for N (Steffen et al. 2015). Major pathways of loss from applied N to the environment include leaching, volatilization, and emissions (Battye et al. 2017; Sutton et al. 2013) that lead to numerous adverse effects on aquatic, terrestrial, and human health (Ladha et al. 2020). Researchers globally are facing challenges of managing N to meet the required dietary requirements while lowering the flow of unused N to the environment. A feasible key approach that has been considered and can be applied in all regions is optimizing Nitrogen use efficiency (NUE); a metric that is not only considered to monitor improved or efficient crop productivity but also shows the extent N lost to the environment and the need for improved management. Taking into consideration the importance of N in both environment and food systems, proposals have been made to include NUE as an indicator to measure progress towards sustainable development goals (SDGs) (Zhang et al. 2015). Besides, recent resolutions by the General Assembly of the UN Environment Programme were passed to develop a globally coherent approach for enhancing sustainable N management (United Nations 2019).

Approximately 80% of food produced in SSA come from small-scale holders with production below the required potential to achieve the SGDS on food, nutrition security, and poverty reduction (Gaffney et al. 2019). The average per farmer production in SSA is approximated at around 1 t ha^{-1} which is very low compared to what is produced by Chinese and American farmers (AGRA 2014; Morris et al. 2007). Disaggregating at the county level reveals that many nations in SSA fall short of the fertilizer set target of 50 kg N ha^{-1} set during the Abuja 2006 fertilizer summit declaration (African Union 2006; Sheahan and Barrett 2017). The low/insufficient use of N fertilizers results in extreme cycles of soil N nutrient mining, degradation, reduced resilience on climate adaptation, and erosion.

Approximately, 80% of the agricultural land in SSA is under N deficit and most of the farms have negative balances ranging from -2kg ha^{-1} from the case of Botswana to 67kg N ha^{-1} in Malawi (Masso et al. 2017). The application of too little N for grain production in these countries has been identified as one of key the factors contributing to large yield gaps, food insecurities, and increased rates of malnutrition (Masso et al. 2017; FAO 2017). Obtainable yield by SSA farmers is more than 30% lower compared with the estimated potential in most staple crops (Timsina et al. 2021). Adopting sustainable management of both organic and inorganic sources of nutrients is key to enriching African soil both for food and nutritional security (Adhikari et al. 2018). To achieve sustainable management of N in SSA, an increased access to efficient N to meet the required productive potential as well lowering the associated losses to the environment are pertinent (Ladha et al. 2020). Furthermore, poor agronomic practices like blanket fertilizer application and unbalanced N use are common. There has been advocacy for most of the countries to put in efforts to increase the efficiency of N use through application of the 4R nutrient stewardship principles of using the right source of N fertilizer, there right rate and timing as well right placement method (Banerjee et al. 2018). In addition, focused specific agronomic practices including the 4R should be integrated with other soil fertility management practices like site-specific management and use of improved seeds, organic inputs, and liming can greatly optimize NUE in cropping systems (Vanlauwe et al. 2010).

2.2 Nitrogen and Crop Productivity

The physiological requirements of crop N can be controlled by the efficiency at which N taken by the plant is converted to biomass and grain yield (Hirel et al. 2007). The fact that cereals are grown for grain, physiological N efficiency (PEN) as the change of grain yield per unit of nutrient accumulation in the aboveground biomass is the most relevant indicator (Cassman et al. 2002). The PEN of the crop is governed by two factors: the photosynthetic mode that is genetically determined as either C_3 or C_4 photosynthetic pathways, and the concentration of N in the grain which is also under genetic control but affected by N supply. Examples of most commonly grown cereals in SSA are rice and wheat (both belong to C_3) plants and maize that is a C_4 plant. For the C_4 plants, a higher PEN is observed compared to C_3 because they have a relatively higher rate of photosynthesis per unit leaf-N that leads to accumulation of greater biomass (Cassman et al. 2002). Managing reactive N and at the same time sustaining adequate content of gain N, the cereals require optimization of NUE that begs for innovative crop production and improved soil management practices. Besides, more focused strategies to enable economic benefit to cost ratio should be considered as it has the greatest influence towards farmers' adoption of the new technologies (Shanahan et al. 2008). Although some management practices could increase NUE while reducing losses, adoption by farmers will be more likely to be difficult, particularly without clear information on the economic impact on grain and in relation to N inputs applied. Assuming that in well-managed crop, the recovery efficiency and profit from applied N fertilizers are optimized with minimal losses of N. This is achieved when the plant-available N pool is maintained to the minimum and required level matches the demand of the crop at each growth stage (Cassman et al. 2002). Too little N can contribute to reduced yields and profits while too much N is vulnerable to losses to the environment, and hence the need for having a balanced synchrony.

Increment in crop yield can contribute to higher NUE since both indigenous and N from application and this is due to the fact that fast-growing plants have deep rooting systems that are more effective in exploiting available N sources (Maiti et al. 2020). The applied N that is not taken by the crop or immobilized in soil organic pools is vulnerable to several losses including leaching, denitrification, and volatilization. Therefore, increasing NUE can be obtained through enhancing higher uptake efficiency from the applied N input through minimizing quantity of N lost to both organic and inorganic N pools. Besides, farmers also need to estimate the portion of grain yield obtained from indigenous soil-N and yield increase from applied N as a way of making informed choices on how much N is required for optimal productivity (Ladha et al. 2005).

2.3 Key Nitrogen Management Indicators: Nitrogen Use Efficiencies and Budgets

The continued loss of Nr from agro-ecosystems is likely to raise a critical question on whether such systems could have attained an N equilibrium that prompted Ladha et al. (2020) to post an important question on whether such systems could be reaching an N disequilibrium already. These authors went further to state that N equilibrium in agro-ecosystem would be in N equilibrium when the sum of N inputs balances the sum of N outputs, an indication that the soil is not a sink for N or its source. N budgeting is not only critical for book-keeping purposes but rather an exercise for taking into consideration all N inputs/outputs as well as the soil N changes, a reflection of quantifying N cycling in crop-soil systems. However, N budgeting does not always serve as a tool for evaluating N management with the sole aim of improving N use but rather tracks the N flows in and out of the systems. Nitrogen budgets in crop production are mostly known as N balances and are applied by different stakeholders in different sectors. They provide clarification on N flows that quantify the potential N losses and raise awareness on nutrient management practices. Farmers as the key managers of cropland N use N budget to help in making decisions regarding fertilizer and manure application rates and for management purposes (Quemada et al. 2020). Such information are scanty or lacking in SSA farming setups. Policymakers globally have also started using N balance to monitor the environmental impacts of agricultural production and make an evaluation at regional and national levels. The components forming up an N budget model include N inputs like synthetic fertilizer, animal manure, biological N fixation, and atmospheric deposition. The N outputs in the model are harvestable N in crop products, N losses in form of gaseous emissions (N_2O and NH_3) runoff and leaching (Zhang et al. 2021) as illustrated in Fig. 4.1.

The difference between N input and harvested N is defined as the surplus in the system where positive values represent excess while negative values show deficits. In SSA, the cropping systems present a surplus in the form of deficits that are revealed through negative values within the cropping systems. These negative balances are influenced by higher amount of N harvested than what was initially applied, leading to a situation referred to as soil N mining (Zhang et al. 2021). According to Elryset al. (2021) and Masso et al. (2017), African countries present two major problems in N budgets and N management, which include higher N losses in fertilized farms and depletion in under fertilized farms. Therefore, calculating N footprints (NF) by quantifying the amount of N released to the environment per unit of N consumed for each of the foodstuffs considering the fertilized and

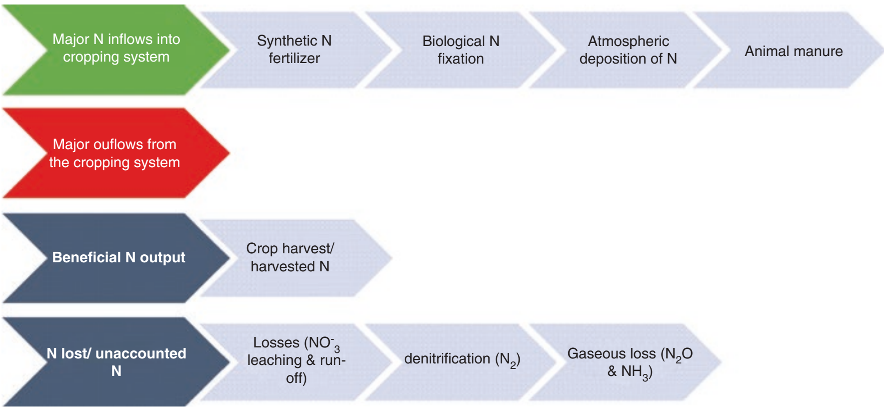

Fig. 4.1 Model structure of N budgeting key components in cropping systems

unfertilized systems is critical towards minimizing the current problems Africa is facing.

NUE is an "umbrella" metric applied wisely to compare the performance of N in agronomic, physiological, and environmental sections to evaluate the possible consequences. Although the estimation of NUE focuses mostly on components of N budgeting, it is a bit complex since it compares the efficiency of different components and expressed in different measures (Ladhaet al. 2005, Ntinyari and Gweyi-Onyango 2021). The NUE measurements are implemented for two reasons; first to increase production through efficient use of N fertilizers and second to reduce losses relating to regulatory compliance with an aim of minimizing environmental burdens (Hutchings et al. 2020). NUE is commonly defined as the ratio of N output to N input. The components considered as input for NUE model are harvested N, i.e., crop biomass, economic yield as the dry biomass, or the N content composition. On the other hand, N output considered includes synthetic N fertilizers, atmospheric deposited N, biologically fixed N, and N from organic sources. The three efficiency ratios that are used in quantification of the NUE are: agronomic efficiency (AE_N), which is defined as the ratio of yield to N amount supplied; recovery efficiency (RE_N), which represents a ratio of plant N to the N applied; and physiological or internal efficiency (PE_N), which is defined as the ratio of yield to plant N (Cassman et al. 2002). The N removal efficiency is the most used indicator as it is the easiest to measure based on the crop N content. NUE optimization is one of the ways for reducing N losses to the environment through the use of technologies that favor both high-input and low-input cropping systems.

Achieving an equilibrium NUE of 50-90% in the arable production systems would be ideal in situations where technical measures for optimizing NUE are applied. According to Oenema et al. (2015), an indicative NUE value of above 90% implies a higher risk of soil N depletion in arable land. Unfortunately, most SSA farmers operate above the stated percentage. Identification of safe operating boundaries for NUE in the cropping systems can be achieved through the use of graphical conceptualization with key zones including risks of soil N depletion, acceptable boundaries, and regions with inefficient use of N as defined by EUNEP (2015). Following a similar approach by the EUNEP, Ntinyari et al. (2021) showed that most of the smallholder farmers in Kenya are operating in the region of soil N mining with abnormally higher NUE values.

The limitation in NUE metrics used currently lies in capturing the whole N cycling process in cropping systems or in the farmland levels to help design sustainable systems that not only considers crop production but also incorporates the aspects of soil fertility and mitigation of environmental pollution (Congreves et al. 2021). Another missing linkage in developing proper NUE scales for SSA cropping systems is the lack of proper accounting on the synchrony between availability of N and the plant N demand. Even in short single growing seasons, there are fluctuations of available N in the soil and may imply sufficient N is not available to match the crop demand and therefore the synchrony factor should always be considered (Congreves et al. 2021). The N synchronization depicts the rate at which N is available to crop being closely linked to the rate at which the growth of crop demands it.

Crops with higher N demands are linked to maximal genetic yield potential and high harvest indices, ensuring high synchrony and hence optimal NUE. Moreover, this kind of synchrony can also be achieved by adopting sound and improved agronomical practices like biodiversity deployment and proper use of cover crops and with genetic modifications of the crops. Therefore, holistic N management practices will maximize uptake of N by crops and reduce losses of N in the soils (Udvardi et al. 2021). The application of the 4R framework of nutrient management denoting the right source, right rate, right timing, and right placement could help in the optimization of the NUE values. Furthermore, several precision N tools for chlorophyll content detection and agronomic techniques can be put forward to support improved N management.

Global efforts are accelerating to improve fertilizer formulations with a target of optimizing NUE (Venterea et al. 2012). The formulations specifically from nanotechnology can be used to achieve a targeted release at specific profiles to supply N at the time of demand. Fertilizer and application technologies should also be designed to match the physiological needs of the crop including nutrient uptake, redistribution, and utilization to serve as an entry point of new fertilization development specifically for sub-Saharan Africa where use of fertilizers is quite limited and still very low amounts are in use (Njoroge et al. 2019). Another practical opportunity for optimizing NUE is through enhanced efficiency of fertilizers (EEFs) which are formulations with some coatings. These EEFs help optimize NUE by preventing immediate solubilization by temporarily slowing the activity of the enzymes and other nitrifying microbes in the soils. Li et al. (2018) reported increasing NUE by 29% and reducing N losses by 41% in paddy rice when EEFs were used. According to Cassman et al. (2002), adoption of new management practices such as crop rotation, which has effect on organic carbon in soil, will also cause a significant effect on overall N balance since the C/N ratio of soil organic matter remains relatively constant. In addition, when soil-N content is increasing, the amount sequestered N also contributes to higher NUE of the cropping systems, and conversely, a decrease in soil N stocks will also result in reduced NUE and recovery efficiencies (Gweyi-Onyango et al. 2021).

Better utilization of fertilizer in Africa can be achieved through improved agronomic nitrogen use and agronomic nitrogen recoveries as reported by Gweyi-Onyango et al. (2021) in Kenya. These authors’ findings revealed these indicators to be variable but relatively low. These were not startling since previous findings show that the recovery of N in soil–plant systems, particularly in paddy rice, seldom go above 50%, which may imply the applied N leaks through different pathways such as volatilization and leaching (Ladha et al. 2020). The increase in the gap between applied N and that which is taken up by the crops has been linked to a monumental lowering of NUE as reported by Raza et al. (2018). Moreover, Jing et al. (2007) suggested that recovery of N fertilizer cannot depend on crop growth and genotype and also could be affected by the management practices adopted by the specific farmer. According to Kombali et al. (2016), it is possible to optimize fertilizer N recovery through the application of smaller doses since it is easier to predict the crop demand by splitting the whole fertilizer dosage.

2.4 *Fertilizer Subsidy, Socio-economic Status on Adoption of Integrated N and Other Input Management*

Recent analyses have demonstrated that yield gaps have the potential of being reduced through increasing the current amount N application for countries where rice is widely grown but interventions from government subsidy (Tsujimoto et al. 2019). Figure 4.2 shows a conceptualized framework on the role of environment and management of N fertilizers including access, regulations, and timing of application, agronomic practices, and the resulting variables on nitrogen use efficiencies.

Similarly, an increment in use of synthetic fertilizers in SSA could be a critical step towards sustainable development through soil fertility and food security improvement (Van Ittersum et al. 2016). This can be achieved through effective promotion of fertilizer input with clear communication on the economic and sustainability benefits. For instance, subsidized fertilizer sources have the possibility of enabling farmers to gain valuable knowledge regarding the benefits of using fertilizer without putting much risk in the main capital outlay (Carter et al. 2014). With such information in mind, it is easier for farmers to continue purchasing fertilizer commercial even without the availability of subsidies. However, excessive subsidies may seem to be a burden in most national economies for SSA counties, and at the end, the costs may outweigh the benefits in long-term funding (Jayne et al. 2013). In addition, subsidies should be done with caution since excessive subsidy would lead to reduction in N use efficiency as evident in the case of China where use of N fertilizers is responsible and contributes to high environmental pollution, hence reducing the efficiency of fertilizers (Zhang et al. 2015).

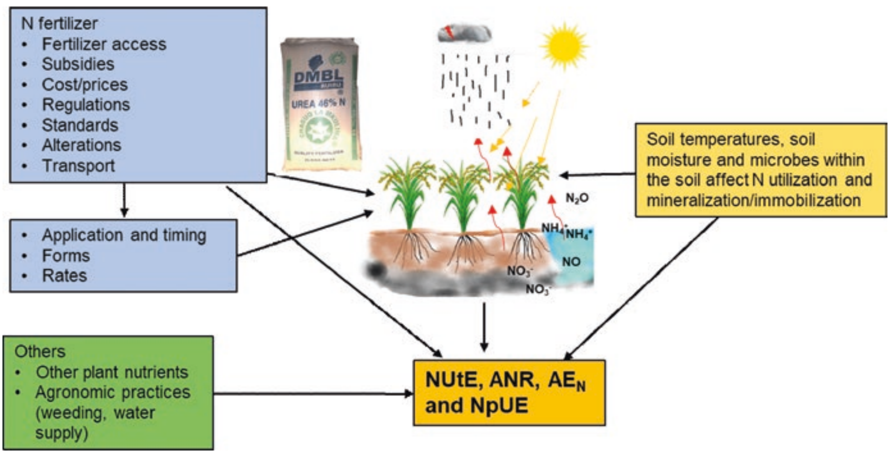

Fig. 4.2 Environments, plant genotypes, and management issues on nitrogen use efficiency

2.5 Policies and Institutions Influencing N Consumption and Management

Achieving food security in SSA for 1.3 billion people by 2050 is one of the fundamental issues, and hence, insufficient N and other nutrients must be resolved before then (Mc Carthy et al. 2018). With the current fertilizer application rates, it is challenging to attain the goals of the first three SDGs in the region. This, therefore, calls for urgent appeal and the need to improve the market, increasing access to credit services and promoting effective extension services to make fertilizer input accessible and more profitable to farmers. African governments have revolutionized to improve agriculture through budget allocation investments (Onyiriuba et al. 2020; Benfica et al. 2019). Several states have also reinstated on increasing agricultural inputs subsidy a strategy for promoting access and improving variable success for farmers (Jayne et al. 2018). Previous research shows that at the nation level, factors including differences in policies are far more predictable due to varied agricultural input in comparison to socio-economic features, farm, market, and biophysical factors across 10 countries in SSA (Sheahan and Barrett 2017). Many nations lack or have not implemented policies on recycled organic water from cities, and nutrient recovery from wastewater and municipal for agricultural use which is a great approach to increasing nutrient availability. It is essential to understand NUE components effectively to decide on management to maximize returns from the indigenous and applied N sources in the cropping. Owing to the cryptic nature of the NUE both public and private sectors require to execute a critical role in offering knowledge to growers about the best management and technological options to influence N components (Bahn et al. 2021). Policies should also support strong extension and research programs that have the capacity to enhance intensive crop production. Policies should also base their recognition on possible interactions between varying environmental goals. Notably, profit margins should be put into consideration to encourage farmers to adopt improved management by taking into consideration the environmental regulations (Ladha et al. 2020). Preference of incentive programs for adoption of N-efficient management practices to enable farmers cope with stringent measures on environmental regulations should be given priority.

If more scientific evidence in the near future supports the need for a more drastic option to minimize the N loading to the environment, then a global based plan should be developed to enhance food crop production in agro-ecosystems that have great biophysical potential and the ability to maximize grain output, minimize losses, and prevent environmental damage. For instance, through agricultural land ownership and more competitive prices based on property right, farmers could become more sensitive to loss of the productive land and therefore apply the required options to maintain the quality and productivity (Deininger and Byerlee 2012). In addition, governments can contribute significantly to fertilizer through expanding of the private-sectors fertilizer supply networks and by consolidating the usage of right fertilizer doses in addition to investing in proper infrastructure to facilitate transportation (Bahn et al. 2021). Besides, there is need for the governments to coordinate the development of polices on organic N input. Particularly it is necessary to organize and sensitize programs that inform policymakers and other actors to enhance beneficial gains accruing from organic N input management as well as offering them better chances and favorable environments to adopt the practices (Elrys et al. 2019). Therefore, incorporating policies in African agriculture would stimulate fertilizer consumption, production, provide markets in the wider context of agricultural production systems, and hence poverty reduction.

3 Conclusions

Optimal management of N in sub-Saharan Africa for improved crop productivity, food security, and environmental sustainability is possible with the adoption of the right tools and policies. Through N budgeting, farmers can easily manage how much N is needed in the cropping systems as a way of matching the demand of the plant growth at different growth stages. Through extension services, farmers can also be assisted to define safe operating levels of N that support both soil fertility and minimal losses to the environment. Government subsidies on fertilizer input will also go hand in hand to ameliorating the problem of too little N input into the cropping system as well as correcting the existing negative balances in the farms. Moreover, government coordination should put more focus on policies that support organic input use and management. Adopting use of more fertilizers, for instance, controlled release, nitrification inhibitors, and enhanced efficiency fertilization, have been shown to minimize losses and increase NUE, which should be a focus for Africa. Improved crop varieties that are bred for higher NUE to enhance N uptake will enable optimal management of N at the farm level and promote more yields, hence contributing towards reducing the yield gaps in Africa.

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Chapter 5
Soil Carbon Pools Under Different Farming Practices

Hement Kumar, Pooja Arora, Ganpat Louhar, Vipin Kumar, and Smita Chaudhry

Abstract Soil organic carbon (SOC) stocks constitute a major portion of the global C stocks in tropical regions. It is an important component to contribute towards soil structure, soil fertility, crop productivity, and soil sustainability. A field experiment was conducted in 2016–17 to study the effect of different farming systems on various organic carbon pools in the soil. Surface (0–15 cm) and subsurface (15–30 cm) soil samples were taken from organic (O_F) as well as conventional fields (C_F) of wheat, sugarcane, mustard, and barseem from two districts of Haryana state. Results revealed that organic fields had higher very labile carbon pool, active pool, and microbial biomass carbon as compared to conventional fields. Surface soils were observed to be repositories of higher organic carbon pools as compared to subsurface soils in all fields. The organic fields of mustard showed the highest very labile SOC pool and microbial biomass carbon. Sugarcane was observed to have the highest active carbon pool as compared to other crop fields. Soil microbial biomass carbon increased from traditional to organic farming, which explains the high microbial activity of the soil in organic farming practices.

Keywords Organic farming · Carbon pools · Microbial biomass carbon · Haryana

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1 Introduction

The global concentrations of atmospheric CO_2 have passed 410 ppm and will continue to rise (NASA 2020). This increase in atmospheric concentrations of greenhouse gas (GHG) is a clear indication of anthropogenic impact on the climate (IPCC 2014). Agriculturally induced methane and nitrous oxide contribute toward climate change, but soil carbon sequestration is a crucial step in agriculture to reduce these emissions (UNFCCC 2008). Soil carbon sequestration can be described as the process of storing carbon dioxide (CO_2) from the atmosphere into the soil. It is achieved through the addition of residues of various crops and various organic solids in the soil. The sequestration occurs in a form which is not instantly and easily re-emitted back to the atmosphere. This storage or "sequestration" of carbon helps in offsetting emissions which accrue from combustion of fossil fuels and other such activities which are responsible for carbon emissions. This process simultaneously enhances soil quality and long-term productivity. Soil carbon sequestration can be efficiently accomplished and improved by applying management systems that incorporate high levels of biomass to soil, create minimal soil disturbance, preserve soil and water, strengthen soil structure, and promote soil microbial activity (Syswerda et al. 2011). Soil organic carbon (SOC) is an important measurable component of soil organic matter (SOM). It contributes significantly to soil structure, soil fertility, crop production, and soil sustainability (Gelaw et al. 2014). Different studies have reported varied amounts of organic carbon stocks in the soils of India (Table 5.1). These stocks constitute about 3% of the global C stocks of the tropical regions (Velayutham et al. 2000). A small increase in soil organic carbon in large areas under agricultural and pastoral can significantly reduce atmospheric carbon dioxide. For this reduction to be more efficient and long-lasting, soil organic matter has to be more stable or resistant to degradation.

Most of soil organic matter and hence the amount of SOC are found near the soil surface. Storage of organic carbon content in the topsoil is determined by the interactions among topography, climate, soil type, and other aspects of crop management which further includes crop rotation, fertilization, tillage (Peigne et al. 2007), irrigation, mulching, and manuring. Also, sustainability of agricultural production systems depends on soil quality which gets affected by the characteristics and

Table 5.1 Estimated Organic carbon stocks in soils of World and India

Depth	SOC density/stock/pool (Pg)	Region	References
0–30 cm	684–724	World	Batjes (1996)
0–150 cm	2376–2456	World	Batjes (1996)
44–186 cm	24.3	India	Gupta and Rao (1994)
0–30 cm	9.55	India	Bhattacharyya et al. (2000)
0–150 cm	29.92	India	Bhattacharyya et al. (2000)
0–30 cm	21	India	Velayutham et al. (2000)
0–150 cm	63	India	Velayutham et al. (2000)
1 m to 1 km	6.8	India	

features of the farming system encompassing strategies such as cultivation with a single crop for a prolonged period, tillage, and removal of the crop residues. These factors are also responsible to accelerate the rate of decomposition of SOM which accounts for 20–67% of soil C loss (Yang et al. 2019). It further leads to soil degradation such as diminished or degraded physicochemical and biological properties of the soil (Lal 2014).

Change in land use pattern has also been reported as one of the major causes of soil degradation and loss of soil organic carbon as carbon dioxide. Guo and Gifford (2002) have reported 42% of SOC loss due to change from forest land to crop and 59% loss of SOC due to changes from pasture to crop land through meta-analysis of data on stocks of soil carbon and land use land cover changes. Therefore, it is necessary to increase the storage of soil carbon either by enhancing the carbon pools or by reducing the emissions through the decomposition of organic matter to achieve the goals of sustainable agricultural production and better management of the environment.

The potential of C sequestration in cropland is reported to be about twice than that in managed pastureland; however, the global surface area under cropland is less than half. Gazdar (2020) reported that 0.4%improvement in soil organic carbon could sequester ≈1 gigatonne (GT) carbon per year over a period of the next three decades, which is equivalent to 10% of global anthropogenic emissions. Several management practices have been suggested to enhance SOC contents in agricultural lands which include organic amendments, manures, cover crops, crop rotations in diversified form, application of biochar and biofertilizers, reduced use of chemical pesticides and insecticides, no tillage, crop residue management, integrated pest and nutrient management, agroforestry, organic farming, and conservation agriculture. Conservation agriculture is in practice in about 180 mha (million hectares) all over the world (Kassam et al. 2017) of which Indian contribution accounts for 1.5 mha (Jat et al. 2012). Conservation agriculture is a farming system which emphasizes minimum soil disturbance through no-till farming, maintaining permanent soil cover in the fields by adding crop residues or retaining live mulch intact and diversifying the plant species through crop rotation or intercropping. The benefits of conservation agriculture include enhanced biodiversity, efficient above- and below-ground biological processes, gradual increase in SOM, increased water retention, infiltration and use efficiency, appropriate soil moisture conditions, better nutrient management and their utilization by soil biota, suppression of weed species, and prevention of erosion of topsoil. It also reduces the cost factor associated with the use of mechanical instruments, fuel, labor, and time required to till the fields. Hence, conservation agriculture ultimately leads to sustainable crop production system or sustainable intensification.

SOC content has been reported to persist in organic farming systems under diversified crop rotations, intercropping, and organic fertilizers' application. However, it decreases under systems of conventional farming (C_F) with the application of inorganic or chemical fertilizers. Under organic farming systems, the basic concept is rotation of components in the field, which are built on three main key elements: (1) the avoidance of synthetic fertilizers and pesticides; (2) the use of farmyard manure to attain high soil fertility; and (3) the reduction of high-energy-consuming feedstuffs (Fließbach et al. 2007). Agricultural practices in organic farming (O_F) systems are said to benefit various components of agroecosystems such as soil, surface and groundwater, biodiversity, and air (FAO 2003). Crop productivity in O_F is dependent on soil nutrient transformation mechanisms. Thus, soil quality is a crucial issue in O_F, and SOC is a key component of this system.

SOC was shown to be stable in an O_F system that included ley-based crop rotations and organic fertilizer application, whereas it declined in C_F with mineral fertilization (Gadermaier et al. 2011). Fließbach et al. (2007) and Munro et al. (2002) also observed organically managed top soils to have a higher percent amount of organic matter as compared to conventional management. The reason may be the addition of higher quantity of organic matter in O_F. It further leads to an additional accumulation of SOC (Drinkwater et al. 1998).

Based on the length of residence, soil organic carbon can be classified into five pools: less labile, labile, highly labile, active pool, and passive pool (Parton and Rasmussen 1994). Under soil organic pools, the active pools include labile elements that provide available meal for microorganisms and are altered by fresh residue inputs, making them an ideal indication of soil quality (Joshi et al. 2017). The SOC fraction with the fastest turnover rates is the labile C pool. Despite the fact that this pool of SOC is critical for crop productivity, its oxidation quickly adds CO_2 to the atmosphere, contributing to the process of global warming (Majumder et al. 2008). The very recalcitrant or passive pool is transformed quite slow by microbes and thus cannot be regarded a good indication of soil quality and production (Weiler and Naef 2003; Sherrod et al. 2005; Majumder et al. 2008).

Soil microorganisms play a significant role in regulating soil organic matter trends and nutrient availability (Six et al. 2006). Microbial biomass in soil and their interactions are indeed the markers of biological soil fertility, which OF greatly improves (Fließbach et al. 2007). Excessive use of chemicals such as herbicides and pesticides in C_F practices can severely alter the structure and function of microbial communities residing in soil, modify the terrestrial ecosystems along with substantial changes in soil quality and fertility (Pampulha and Oliveira 2006). Moreover, some organic additions have the potential to boost soil microbial activity and improve biodiversity (García-Orenes et al. 2010). This research was designed to compare various soil carbon pools under conventional and organic farming systems in various crops.

2 Materials and Methods

2.1 Study Sites and Farming Practices

Four different farmer's fields, in villages Matak Majri, Nanhera, and Pathera in Karnal and village Mehra in Kurukshetra districts of Haryana, India were selected for this study. Out of four farmers, three farmers have been practising organic

Table 5.2 Farming systems under study

S. no.	Farming system	No. of years	Crop
1	Organic (O_F1)	3	Wheat
2	Organic (O_F2)	3	Berseem
3	Organic (O_F3)	3	Mustard
4	Organic (O_F4)	8	Sugarcane
5	Conventional (C_F1)	–	Wheat
6	Conventional (C_F2)	–	Berseem
7	Conventional (C_F3)	–	Mustard
8	Conventional (C_F4)	–	Sugarcane

farming for the last 3 years, while for the fourth farmer, this span was 8 years (Table 5.2). Along with organic farming, all the farmers were also practicing conventional farming on the remaining field. Soils of the fields were alluvial with clay loam texture. Wheat, berseem, mustard, and sugarcane were grown by farmers hailing from the villages of Matak Majri, Nanhera, Pathera, and Mehra, respectively, under both organic and conventional systems.

All four organic and conventional fields were tilled as per the recommended package practice every year before cropping. In all organic fields, 12 t ha^{-1} dried cow manure was applied prior to seeding Kharif season crops, while prescribed fertilizer doses were applied in conventional fields. All the fields were irrigated with ground water. The crops were grown using organic agricultural practices, with no herbicides used. Mechanical weeding was done three times during the stages of emergence and leaf development. Inorganic fertilizers and insecticides are used in conventional systems.

2.2 Soil Sampling and Analyses

Soil samples were taken in bulk in March 2017, after 6 months of farmyard manure application. These samples were collected from all the eight fields. Samples were taken from two different depths 0–15 cm and 15–30 cm. They were then air-dried at a constant room temperature (25°C). After drying, the samples were then sieved (2 mm) to eliminate coarser soil particles. In order to limit experimental error, four replicates for every sample were analyzed in the laboratory. Soil bulk density was determined with the core cylinder method (Blake and Hartge 1986). In a soil suspension with deionized water (1:2.5, w/v), the pH (Guitián and Carballas 1976) and 1:1 suspension in water EC (Smith and Doran 1996) of dried samples at 60°C for 24 h was determined. The modified Walkley–Black method reported by Chan et al. (2001) was used to separate total SOC into various C pools 6.0, 9.0, and 12.0 M H_2SO_4 (Ghosh et al. 2010). It entailed varying the quantities of 1/6 M dichromate solution and H_2SO_4. The soil was kept at room temperature for 1/2 h to react with the dichromate-acid mixture. Total SOC was thus allowed to divide into four pools based on their stability Chan et al. (2001). SOC fraction oxidized by 6.0 M H_2SO_4 is considered as very labile pool, the difference between SOC fraction which is oxidizable by 9.0 M H_2SO_4 and that by 6.0 M H_2SO_4 estimates the labile pool, and the difference between SOC fraction which is oxidized by 12.0 M H_2SO_4 and that oxidized by 9.0 M H_2SO_4 estimates the less labile pool (Chan et al. 2001). The active pool was generated from the highly labile and labile pools. Estimation of soil microbial biomass C was done with fresh moist soil samples by chloroform-fumigation-extraction according to Vance et al. (1987). Stocks of organic carbon (Mg ha^{-1}) in each extracted SOM fraction of each sampling layer (0–15 cm and 15–30 cm depth) were calculated using the below equation (Wang and Dalal 2006):

$$\text{Carbon stock} = \frac{\text{SOC} \times \text{BD} \times d \times \left(1 - 2\,\text{mm}\ \%\right)}{10}$$

where:

SOC: content of soil organic carbon (gkg^{-1}),
d: thickness (cm) of the soil layer
2 mm: fractional percentage (%) of soil mineral particles >2 mm in size,
BD: soil bulk density (Mgm^{-3}).

Statistical analyses were done using Microsoft excel.

3 Results and Discussion

3.1 EC, pH, and Bulk Density

Soil sample analysis for physicochemical properties was done for all the soil samples. In all the agro-system, EC significantly decreased with increasing depth (Table 5.3). The same trend was recorded by Ozlu and Kumar (2018). All the conventional farming systems recorded higher EC than O_F. Among the organic fields, the highest EC was recorded under wheat field (194 μS). Higher EC values in C_F are most likely connected with high salt deposition from inorganic fertilizer use (Velmourougane 2016). Inorganic fertilizers contain a higher concentration of accessible nutrients. These nutrients get dissolved into various types of ions in the soil, resulting in a higher electrical conductivity (Sihi et al. 2017). Under different agro-system, pH significantly increased with increase in soil depth. pH was less under O_F fields as compared with C_F of the same systems except for berseem fields with the lowest pH (7.3). Reeves and Liebig (2016) also observed the increase in the pH as depth increases because acidification is most pronounced near the soil surface. Bulk density of the soil gets affected by field management practices and integration of green manure. However, no variation in bulk density under varying soil depths was found in all the farming

Table 5.3 Depth-wise changes in different soil properties under different farming systems

Crop	Farming system	Depth (cm)	EC (μS)	pH	BD (gm cm^{-3})
Wheat	Organic	0–15	188.2 ± 5.74	7.6 ± 0.40	1.22 ± 0.01
		15–30	169.3 ± 3.95	7.64 ± 0.11	1.2 ± 0.004
	Conventional	0–15	194.0±4.21	7.9±0.15	1.24±0.02
		15–30	183.8±4.50	7.92±0.17	1.23±0.02
Barseem	Organic	0–15	162.8±7.81	8.2±0.17	1.2±0.02
		15–30	153.8±3.78	8.3±0.26	1.21±0.01
	Conventional	0–15	163.7 ± 23.2	7.3 ± 0.26	1.23 ± 0.01
		15–30	152.0 ± 16.3	7.9 ± 081	1.23 ± 0.01
Mustard	Organic	0–15	187.5 ± 1.73	8.1 ± 0.55	1.19 ± 0.009
		15–30	169.6 ± 11.6	8.3 ± 0.40	1.21 ± 0.008
	Conventional	0–15	190.1 ± 12.0	8.4 ± 0.23	1.28 ± 0.02
		15–30	185.2 ± 3.95	8.4 ± 0.35	1.26 ± 0.02
Sugarcane	Organic	0–15	132.9 ± 26.6	8.4 ± 0.1	1.21 ± 0.02
		15–30	109.8 ± 9.46	8.7 ± 0.1	1.23 ± 0.028
	Conventional	0–15	153.5 ± 11.3	8.5 ± 0.1	1.22 ± 0.01
		15–30	138.1 ± 15.0	8.7 ± 0.1	1.22 ± 0.02

systems. In all of the conventional fields, bulk density was reported to be higher than that in organic fields. According to a number of studies (Khaleel et al. 1981; Pagliai 1988; Novara et al. 2019), it has been suggested that organic matter is responsible to decrease the bulk density due to a drop in denser mineral component, as well as an increase in aggregation and soil pores. Hence, it is the improvement and enhancement in soil structure by appropriate organic manures addition which is responsible for decreasing bulk density in the organic fields. Sheeba and Kumarswamy (2001) also observed a similar trend of decreasing bulk density with the increasing addition of organic matter. On the other hand, the reason for increment in bulk density under fields of conventional farming can be attributed to soil structure deterioration with the application of chemical or synthetic fertilizers. The deterioration of soil structure may also be due to the less retention of crop residues into the soil. The trend of increasing bulk density with the application of inorganic fertilizers has also been reported by Tadesse et al. (2013).

3.2 *Different SOC Pools*

In all farming systems, different pools of SOC were observed to be decreasing significantly with depth increment (Table 5.4). Santos et al. (2012) also observed higher soil organic carbon at 0–15 cm soil depth than 15–30 cm under organic farming. The same trend was also recorded by Jacinthe et al. (2011). These findings contradicted previous studies (Leifeld and Fuhrer 2010; Marriott and Wander

Table 5.4 Depth-wise distribution of different pools of SOC (mg kg^{-1}) under different farming systems

Crop	Farming system	C_{LL}		C_L		C_{VL}	
		0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Wheat	Organic	3.3 ± 0.1	0.7 ± 0.02	4.0 ± 0.22	3.3 ± 0.13	6.6 ± 0.45	6.3 ± 0.56
	Conventional	9.2 ± 0.89	8.4 ± 0.77	4.0 ± 0.31	3.4 ± 0.26	3.5 ± 0.29	2.3 ± 0.33
Barseem	Organic	6.1 ± 0.35	2.3 ± 0.17	6.6 ± 0.23	6.5 ± 0.29	2.7 ± 0.12	1.5 ± 0.089
	Conventional	5.3 ± 0.68	5.2 ± 0.87	11.5 ± 1.2	9.4 ± 1.5	12.7 ± 2.3	2.9 ± 0.98
Mustard	Organic	3.0 ± 0.97	0.9 ± 0.06	3.4 ± 0.75	2.6 ± 0.83	12.3 ± 3.2	6.9 ± 1.1
	Conventional	18.9 ± 3.5	18 ± 2.6	11.6 ± 1.8	10.9 ± 1.5	3.5 ± 0.91	2.8 ± 0.81
Sugarcane	Organic	15.9 ± 3.5	10.5 ± 1.5	3.9 ± 0.99	1.9 ± 0.84	13.4 ± 2.5	10.0 ± 1.9
	Conventional	16.5 ± 4.6	13.4 ± 2.6	4.0 ± 1.7	1.4 ± 0.87	1.1 ± 0.09	0.8 ± 0.1

SOC soil organic carbon, C_{LL} less labile carbon, C_L labile carbon, C_{VL} very labile carbon

2006) that found significant increase in organic carbon content of the soil with organic farming. However, in study sites with equivalent crop rotation, Leifeld and Fuhrer (2010) discovered that there is no consistent difference in soil organic carbon between different farming systems and cautioned against drawing hasty conclusions about the effects of organic farming on SOC stock restoration. Variations in research time and soil depth tested could potentially contribute to these contradictory findings. Organic fields of different farming systems recorded low less labile carbon rather than C_F fields of the same systems. The highest labile carbon was recorded under conventional mustard from 0 to 15 cm depth (11.6 mg kg^{-1}) which is 241% higher than O_F system of that crop. Organic fields of wheat and sugarcane didn't show significant change in labile carbon content compared to conventional of the same. According to Herencia et al. (2008), plots adopting organic treatments had a numerical improvement in SOC at the conclusion of the conversion phase; however, it is only after four to five crop cycles that the SOC rise became significant. All O_F fields of different farming systems recorded higher very labile carbon rather than C_F fields of the same systems except berseem which is 370% lower than the organic field of that system because higher biomass increases higher microbial activity which further helps in increase in higher labile organic carbon (Xavier et al. 2006). The difference in less labile carbon was significant between organic and conventional farming systems ($p < 0.05$).

3.3 Microbial Biomass Carbon (MBC)

In all fields, microbial biomass carbon significantly decreased with increasing soil depth (Table 5.5). Jacinthe et al. (2011) also reported the trend of decrease in MBC as increase in depth. These investigations (Castellazzi et al. 2004; Potthoff et al. 2006; Babujia et al. 2010) show a decrease in soil microbial biomass as depth increases. Under sugarcane and mustard organic fields, from 0 to 15 cm depth, higher MBC was recorded than their conventional counterpart. The differences in microbial biomass carbon were however not significant between organic and conventional farming systems ($p>0.05$) of barseem and wheat. In wheat, higher MBC was recorded in the conventional field than that of organic (0.24 μgC gm^{-1}). Considerable changes in soil microbial markers can be observed in 2–3 years of organic farming (Jacinthe et al. 2011). O_F of mustard had the highest MBC, i.e., 55% more than sugarcane and 53% more than wheat as well as berseem. For O_F, the persistent input of organic residues may favor the increase of the soil microbial biomass (Xavier et al. 2006). Organic fertilizer treatment significantly enhanced soil microbial biomass C on sampling day. Despite the fact that similar amounts of organic C were provided, this rise was much higher in the manure treatments than in the compost treatments in the majority of cases (Jannoura et al. 2014).

Table 5.5 Depth-wise changes in MBC (μgC gm^{-1}), C stock (Mg ha^{-1}) and active carbon pool under different farming systems

Crop	Farming system	MBC (μg C gm^{-1})		C stock (Mg ha^{-1})		Active pool (mg kg^{-1})	
		0–15 cm	15–30 cm	0–15 cm	15–30 cm	0–15 cm	15–30 cm
Wheat	Organic	0.21 ± 0.07	0.16 ± 0.03	6.0 ± 0.99	1.3 ± 0.05	10.6 ± 1.1	10.6 ± 1.2
	Conventional	0.24 ± 0.08	0.18 ± 0.02	17.1 ± 0.13	15.5 ± 1.1	7.5 ± 0.98	5.7 ± 0.55
Barseem	Organic	0.21 ± 0.02	0.13 ± 0.09	11.0 ± 0.52	4.2 ± 0.21	9.3 ± 0.99	8.2 ± 0.56
	Conventional	0.21 ± 0.05	015 ± 0.05	9.8 ± 0.54	9.6 ± 0.39	24.2 ± 2.1	12.3 ± 1.5
Mustard	Organic	0.45 ± 0.10	0.10 ± 0.04	5.4 ± 0.24	1.6 ± 0.15	15.7 ± 1.9	9.5 ± 0.89
	Conventional	0.26 ± 0.04	0.23 ± 0.08	36.3 ± 1.4	34.0 ± 1.1	15.1 ± 1.1	4.8 ± 0.56
Sugarcane	Organic	0.20 ± 0.04	0.11 ± 0.08	29.3 ± 1.2	19.1 ± 1.69	15.3 ± 1.4	13.9 ± 1.56
	Conventional	0.10 ± 0.05	0.02 ± 0.01	30.2 ± 1.2	24.5 ± 1.9	5.1 ± 0.69	2.2 ± 0.87

MBC microbial biomass

3.4 Carbon Stock

C stock significantly following the patterns of labile carbon pools decreased with depth increment (Table 5.5). SOC is regulated by soil depth in addition to treatments (Joshi et al. 2017), and decreased SOC with increasing soil depth has been found by numerous researchers (Venkatesh et al. 2013; Yang et al. 2014). Bhattacharyya et al. (2011) revealed that fertilization impacted SOC up to a depth of 30 cm, but had no effect in the 30–45 cm soil layer. It could be associated with lesser rhizobium activities, lower rhizode position, and less biomass return to subsurface layers. Under O_F at 0–15 cm soil depth sugarcane recorded the highest C stock (29.3 mg ha^{-1}) followed by berseem (11.0 mg ha^{-1}), (wheat 6.0 mg ha^{-1}), and mustard (5.4 mg ha^{-1}). The reduced C stock in lower layers is due to low downward movement of crop residue and compacted soil layers (Liangang et al. 2020). Litter, crop residues, organic or green manures, and spontaneous vegetation over the soil surface provided additional C to the first layer, resulting in a significant rise in SOC content. During the first 5 years after converting to organic farming, the rate of rise in SOC was slower. This indicates that pruning crop residues and other organic inputs in the form of weed biomass that were not absorbed into the soil will take around 5 years to become part of the soil. The SOC exhibited a logarithmic growth in the surface soil layer after the first 5 years, but not in the deeper layer (Novara et al. 2019). Under O_F systems lower C stock was recorded than C_F practices. This may be attributed to the lesser duration of O_F being in practice, tillage practices, higher microbial activity with input of organic fertilizer, and other climatic conditions (Hábová et al. 2019). Also, the difference in carbon stocks of soil in O_F and C_F systems was observed to be significant ($p < 0.05$).

3.5 Active Pool of Carbon

In all the studied fields active pool significantly decreased with increasing depth following the patterns of very labile carbon pool (Table 5.5). The application of easily decomposable crop residues increased the active SOC pools in the topsoil (Parihar et al. 2018). As effective root systems are mostly found in the plow layer (0–15 cm), and litter breakdown of residues and stubble material occurs in the topsoil, our findings imply that the 0–15 cm soil depths have higher SOC content than the 15–30 cm soil depths. Some researchers have found higher SOC levels in the top soil layer in agricultural land (Chivenge et al. 2007; Singh et al. 2015). All O_F in different farming systems have high active pool value than the C_F of same crop except berseem. Among O_F systems active C pool was highest in mustard (15.7 mg kg^{-1}) followed by sugarcane (13.9 mg kg^{-1}), wheat (10.6 mg kg^{-1}), and berseem (9.3 mg kg^{-1}). Active pool contains the easily degradable organic carbon (labile, very labile), as transitional practices from C_F

to O_F clearly impact the size of the soil microbial biomass which leads to the higher active pool under O_F (Santos et al. 2012). However, the differences in active pools of carbon between O_F and C_F systems in the present study were not significant ($p > 0.05$).

4 Conclusion

Current status and changes in soil properties and organic carbon pools as response to agronomic practices are extremely important today. The stocks of soil organic carbon along with agricultural practices, soil structure and texture, soil depth, organic and chemical fertilizers input, and climatic conditions determine the status of soil as a sink or source of carbon. The problems associated with conventional farming are attracting the concerns of farmers, researchers, and policymakers towards organic farming. SOC serves as a significant component for maintaining soil quality and productivity. The various strategies of conservational and organic farming such as conservation tillage, persistent cover crops, mulching, efficient nutrient cycling, composting, manuring, and sustainable soil and water management practices can enhance soil quality and potentially increase soil carbon sequestration.

The present study also concluded that the very labile carbon pool was higher in O_F soil as compared to C_F soil because in organic farming the micro flora and fauna are not disturbed much, but in conventional farming, the microbial activity is altered. Higher the number of years of organic practice, higher will be the microbial activity which would further increase the sequestration of carbon in the soil. Also, organic manures and compost applications or the strategies of organic farming have reported to increase more of the SOC content as compared to the similar amount of inorganic or synthetic fertilizer applications (Chai et al. 2015; Gregorich et al. 2001).

In the present scenario, where we are struggling with the problem of climate change and where agriculture is becoming a source rather than a sink of greenhouse gases, we have to put more efforts in the agricultural sector. This sector can be a promising field as a mitigation strategy of climate change. Even organic farming can provide us with financial gains and prestigious status in agribusiness. It can offer many benefits such as sequestering more of soil carbon, mitigating climate change, enhancing soil quality and prolonged productivity, and improving the economic status of a country in global agribusiness. The percentage of SOC content has come down to 0.3–0.4% in India whereas it should be between 1 and 1.5% (Jaisankar 2014). The main reasons for the degradation can be attributed to ever-increasing atmospheric temperatures, soil degradation, and conventional farming practices such as extensive soil tillage, poor land and crop management, and inappropriate use of fertilizer. These factors also accelerate soil erosion and loss of soil fertility and productivity. There needs to be a massive reduction in dependency on chemical fertilizers and pesticides and more use of biopesticides and organic fertilizers. Conservation agriculture over conventional agriculture should thus be implied to get these benefits at minimal costs. It should be part of any policy or development strategy for its effective implementation.

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Chapter 6
Effect of Conservation Agriculture on Energy Consumption and Carbon Emission

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Abstract Conventional agriculture systems with an increased cost of cultivation reduce partial factor productivity, and deterioration of energy, soil, water, and environmental quality threatens food security and aggravates climate change. A holistic package of reduced tillage, residue recycling, crop diversification, and best-bet agronomic practices offered by the conservation agriculture (CA) system seems promising in achieving food security and developing climate resilience in the food production system. This study highlights the overview of CA system, global and national status of CA, opportunities and constraints in adoption of CA, resource efficiencies, particularly energy budgeting in CA, the scope of climate resilience and greenhouse gas emissions (GHGs) mitigation through CA adoption, indices of soil health and carbon sequestration potential under CA systems, and prospects and critical areas of research for scaling of CA systems. Synergies and trade-offs need

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to be precisely taken care of for need-based site-specific redesigning of CA systems for assured farmer's income, ecological services, and sustainable development.

Keywords Conservation agriculture · Energy use efficiency · Carbon sequestration · Climate change · Global warming potential · Soil health

1 Introduction

In the present climate change scenario, where the global population presently remains at simply over 6.7 billion and is projected to exceed 9 billion by 2050, the critical role of farming communities in the upcoming years is to give safe and quality food to the consistently expanding global population. Though the conventional farming practices that rely on improved agricultural technologies, including farm mechanization and release of high yielding dwarf varieties of cereals, have led to achieving the self-sufficiency target, it was at the expense of nature of food, deterioration in environment, and degradation of natural resources. During the period from 1965 to 2015, the population of the world has expanded by 111%. In contrast, crop production increased by 162% (Burney et al. 2010). It is expected that further expansion in crop production and productivity would be feasible through intensive utilization of land resources, fertilizers, irrigation, insecticides, the latest machinery, and advanced innovative practices. On the other hand, intensive farming cultivation is causing tremendous pressure on natural assets (soil and water), bringing about degradation and depletion (Burney et al. 2010) of these valuable resources. The decline in the quality of these resources obliges a severe hazard to the maintainability of present farming systems that rely entirely on agrochemicals and high energy inputs.

Moreover, these inputs injuriously affect soil and water, causing degradation as erosion, salinity, alkalinity, waterlogging, acidification, and multi-nutritional insufficiencies that eventually influence the soil quality and crop productivity (Lopes et al. 2011). Likewise, the usage of fertilizers and pesticides in excess may cause the accumulation of venomous elements in the soil and their leaching from soil strata cause eutrophication of shallow waters and adulteration of groundwater (Alam et al., 2014). When applied agrochemicals fail to reach their intended target, they have a deleterious influence on ecosystems by leaching/aerial drift altering the variety and populations of non-targeted microorganisms, causing adverse effects on ecosystem processes and trophic interactions (Pimentel and Edwards 1982). As a result, the scientific community has recognized and sought alternative systems that may make agriculture more sustainable and profitable, owing to the rising environmental, economic, and social concerns of chemical-dependent traditional farming. Conservation agriculture (CA) systems are numerous ways of managing the farm's natural resources, minimizing erosion hazards, building resilient soil systems, and improving overall productivity while achieving sustainability (Mishra et al. 2018). In other words, CA is a long-term agricultural production strategy that aimed at protecting the soil against the hazards of erosion and degradation while improving the quality of soil along with its diversity, thereby contributing to the preservation of natural resources, such as soil, water, and air, while sustaining yields at optimum level. It is a climate change adaptation strategy being promoted for small-scale farmers in India. Components of CA directly put into mitigation and adaptation to climate change, particularly emphasizing taking it to the reach of small farmers, where the practical on-farm resources observed to be a significant constraint. CA sustainably intensifies the smallholder farming systems and positively affects the environment via natural processes while helping the farmers adapt to and increase profits in the present climate change scenario (Chaudhari et al. 2015; Kumar et al. 2021a, b).

2 Origin of Conservation Agriculture

Agriculture has become more intensive and mechanized, threatening the sustainable production and components like tillage operations, mono-cropping systems, and heavy dependence on chemical fertilizers, and pesticides have simultaneously raised many severe issues like degradation of soil health and shrinking water resources, coupled with decline in environmental quality (Mishra et al. 2014; Chaudhari et al. 2015; Srivastava et al. 2016; Mishra et al. 2016; Singh et al. 2014; Mishra et al. 2018, 2021). The idea of conserving soil by avoiding tillage and keeping the ground covered grew in popularity throughout time. Conservation tillage was the name given to this method of soil protection (Friedrich et al. 2012). Tillage was introduced to obtain good soil tilth, ensuring a good seedbed for germination of seedlings, managing weeds efficiently, and nutrient cycling in soil (Hobbs et al. 2008). With time, emphasis is being laid on the concept of carbon sequestration, where soils are considered a potential sink for carbon sequestration to combat global warming and climate change and tillage being the single most expensive component of crop production in modern times' mechanized farming system. However, the development of seeding machinery reduced the tillage operations considerably and sowing crops without tillage operations is now possible (Friedrich et al. 2012; Mishra et al. 2016). During the 1970s, farmers were attracted by resource-conserving technologies, showed a positive trend towards these farming systems, and adapted to conservation agriculture where soil quality and other resources were saved (Haggblade and Tembo 2003). The concept of minimizing soil disturbance originated in the 1930s, during the Dust Bowl of the USA. Later, CA was coined in the 1990s. In the 1970s, CIMMYT pioneered no-till training programs and experiments in Latin American on maize and wheat systems. This approach was also applied in agronomy initiatives in South Asia in the 1980s. In the 1990s, CIMMYT began conservation agriculture in Latin America and South Asia, and in the early 2000s, it started in Africa. Conservation agriculture is gaining popularity among the farmers and their number is also increasing worldwide in adopting conservation agriculture (FAO 2011). Higher adaptation is based on clear evidence of CA's effects on (1) reducing wind erosion by 50–60%; (2) reducing runoff by 80%; and (3) boosting yield by 0.60–32%. In the USA, 60% of farmers in Tennessee use CA to grow cotton, wheat, maize, and soybeans. Erosion control was included in the National Agricultural Bill, 2005, which aided CA development. In 1995, a "No-Till" day was held, which attracted 1000 people in 1995 and 4000 in 2005. In the USA, the focus has shifted from erosion management to soil quality conservation. With almost 25 million hectares under conservation agriculture, the USA leads the world. Conservation agriculture covers 23 million hectares at commercial agricultural levels in Latin America, mainly Brazil. Paraguay is now the foremost country regarding no-tillage adoption globally (Lamourdia and Meshack 2009). Sowing of wheat without tillage operations in Asia, which includes countries such as India, Bangladesh, Pakistan, and Nepal, has reached 5 million hectares in recent years, particularly in the rice-wheat cropping system (Friedrich et al. 2012), and is expected to continue to rise in the coming years. Research taken up by the scientific community globally in this field could play a key role in promoting and adapting conservation agriculture by farmers to reap the fruits of a diversified cropping system.

3 Fundamentals of CA, Its Principles, and Drivers

In this era of climate change, resource conservation technologies such as CA, which aid in reducing and responding to the negative effects of climate change, are seen as critical for increasing crop output while maintaining soil health and achieving the goal of agricultural sustainability. Around the world, conservation agriculture is making land use more sustainable by relying entirely on one ecological principle (Behera et al. 2007; Lal 2013a, b). CA as a holistic approach relies on three interconnected principles: minimal or no soil disturbance, sustaining soil cover, and crop diversification with other complementary crop production management strategies (Kassam et al. 2018).

These principles include:

- *Minimal or no soil disturbance*: Tillage is the mechanical manipulation of soil to obtain fine soil tilth for crop growth. In contrast, under conservation agriculture, minimum or no soil disturbance is done, which means no-tillage where the direct placement of seed and fertilizer is carried out to achieve the objective of minimal soil disturbance.
- Maintaining soil cover throughout the growing season through crop residues or intercropping is considered another principle of conservation agriculture. To protect the soil surface from erosion, at least 30% of the crop residue is retained on the surface. However, it is recommended to have more than 60% residue retention cover to control soil degradation effectively. Organic matter content in soil increases in this method, which increases water infiltration, inhibits weed growth, and reduces water evaporation from the earth.

- *Crop diversification*: Crop diversification refers to the inclusion of new crops/crop species or cropping systems in existing agricultural systems on a particular piece of land/farm. These practices may reduce insect pests and disease outbreaks by breaking their growth cycles maintained in mono-cropping systems. Moreover, the addition of such crops can boost soil fertility and biodiversity by adding a substantial amount of organic matter to the earth.

4 Global and National Status of CA

4.1 Global Status

The region under CA cropland was estimated to be 106 million hectares (75% of global cropland) in 2008–2009, but it has since grown to 157 million hectares (11% of global cropland), a difference of 51 million hectares over the long period (2013–2014) was found (FAO-AQUATSTAT 2014). CA cropland continued to expand in 2015–2016, reaching 180 million hectares (Fig. 6.1), a difference of 74 million hectares (69%) over 7 years (2008–2009) and around 23 million hectares (15%) during 2 years (2013–2014) (Kassam et al. 2018). CA has grown from 2.8 million hectares in 1973–1974 to 6.2 million hectares in 1983–1984 and 38 million hectares in 1996–1997 (Derpsch 1998).

Overall, reception was 45 million hectares in 1999, and by 2003, the region had grown to 72 million hectares. From 1999 to 2013, the CA grew at an annual rate of

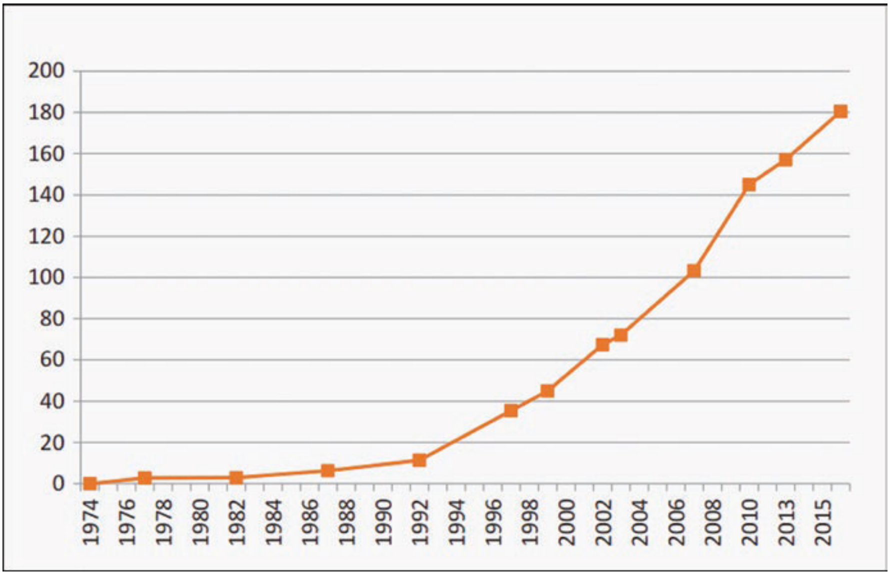

Fig. 6.1 Global uptake of CA in M ha of cropland. (Source: Kassam et al. 2018)

around 8.3 million hectares, from 72 to 157 million hectares (Kassam et al. 2015). CA has recently become a rapidly developing production system for a variety of reasons, including increased factor productivity and farm output with lower production costs and higher profits, greater flexibility to biotic and abiotic stresses, reduced soil erosion and degradation, improved soil health, and climate change adaptation (Kassam et al. 2017; Farooq and Siddique 2014).

The USA, Brazil, Argentina, Canada, and Australia have the most land under CA. As shown in Table 6.1, South America accounts for around 69.9 million hectares (38.7%) of global CA cropland area, compared to 63.2% of the region's cropland. In contrast, North America, primarily the USA and Canada, accounts for 63.2 million hectares (35.0%) of global CA cropland area, or 28.1% of the region's cropland. The rest of the world accounts for nearly 10.8 million hectares (6.0%) of the total CA region, with 5.7 million hectares in Russia and Ukraine, 3.6 million hectares in Europe, and 1.5 million hectares in Africa, corresponding to about 3.6%, 5.0%, and 1.1% of their total cropland regions, respectively.

Europe and Africa are the developing continents in terms of CA adoption. In 2015–2016, the CA area estimated was approximately 3.6 M ha, which was more noticeable by 127.4% than the 1.56 M ha surveyed in 2008–2009 (Kassam et al. 2018). While in Africa, the CA space of 1.5 million hectares in 2015–2016 represents a 211% increase from 0.48 million hectares in 2008–2009. Because numerous types of research have proven excellent outcomes for CA frameworks, there has been a massive expansion in the CA sector in Europe and Africa.

4.2 Adoption of CA India

India is still at the underlying phase of CA adoption. Zero-tillage and CA adoption have increased to around 1.5 million hectares (Jat et al. 2012). In the rice-wheat (RW) system of Indo-Gangetic plains (IGP), zero-till (ZT) in wheat is the most

Table 6.1 CA cropland area by each region in 2015–2016; CA area as a percent of total world cropland, and CA area as percent of cropland area in region

Region	CA cropland area (M ha)	Percent of global CA cropland area	Percent of cropland area in the region
South America	69.90	38.7	63.2
North America	63.18	35.0	28.1
Australia and New Zealand	22.67	12.6	45.5
Asia	13.93	7.7	4.1
Russia and Ukraine	5.70	3.2	3.6
Europe	3.56	2.0	5.0
Africa	1.51	0.8	1.1
Global total	**180.44**	**100**	**12.5**

Source: Kassam et al. (2018)

critical CA-based technology being used. Traditional crop management approaches gradually move away from intensive tillage and toward zero-tillage in other cropping systems (Mishra et al. 2016). Apart from ZT, a different idea of CA should be mixed in the framework to enhance further and sustain agricultural productivity. CA-based resource conservation technologies (RCTs) include research on livestock, crops, land, and water management. Several attempts have been made by State Agricultural Universities and ICAR institutes to adopt and promote the conservation technologies over the last 8–10 years and the result is that farmers are accepting CA-based technologies. The rice-wheat cropping system dominates in the irrigated region of IGP, where the technique is more widely used. The planting of wheat through zero-till seed cum fertilizer drill in rice-wheat cropping system promotes the CA and it has been documented that zero-till drill is gaining popularity and around 25–30% of the wheat has been planted using zero-till drill in Indo-Gangetic regions of India (Bhan and Behera 2014). Raised-bed planting method, laser land leveling equipment, residue management approaches, and alternatives to the rice-wheat system are other technologies that promote CA, but they are not as common as zero-till drill (Singh et al. 2018).

5 Prospects and Constraints in Adoption of CA Systems

Heavy machinery and improper agricultural practices are being practiced, leading to high crop productivity to fulfill the world population's ever-increasing food and energy demands (Mishra et al. 2021). Yet, it significantly impacts natural resources, climate change, and global energy security. Soil deterioration, increasing production costs, and climate change are the key threats contemporary agricultural practices pose. Shifting to no-till or minimum-tillage farming is a much-needed technology today to tackle the issues mentioned above. The CA has the following prospects:

1. Reduce the cost of production: Several research studies have documented that adopting no-till technology could reduce the cost of cultivation by saving the diesel, labor, and input cost (FAO 2008).
2. Reduction in weeds incidence: Under CA, crop residues affect the weed seed germination and emergence (Sims et al. 2018). When spread as mulch in the field, surplus crop residues suppress weed seed germination by reducing light transmission and allelopathic effect (Vivek et al. 2019; Chauhan et al. 2012a, b). Weed emergence is delayed, giving the crop a competitive advantage over the weed.
3. Saving in water and nutrient: About 10–15% of water and 5–10% of nutrients are saved under CA systems (Mishra et al. 2016; Singh et al. 2018; Mishra et al. 2021).
4. Increased grain yields: Yield improvements have been reported under CA on different crops. The main factor responsible for increasing output improves physical soil conditions and soil fertility status (Govaerts et al. 2009). Edralin et al.

(2017) studied the influence of CA on various crop yields and discovered a considerable increase in average production in plots with CA compared to conventional agriculture. The same was reported by Thierfelder et al. (2015) under maize crop in Southern Africa.
5. Environmental benefits: CA with no-till cultivation provides the opportunity to eliminate crop residue burning, which mainly contributes to the emission of greenhouse gas, i.e., CO_2, CH_4, and N_2O. Burning surplus crop residues removes the plant nutrient from the field, but it can be recycled if incorporated into the area.
6. Crop diversification opportunities: Adoption of CA offers opportunities to adopt crop rotation/sequence and agroforestry system by following proper spatial and temporal patterns, e.g., sugarcane, chickpea, mustard, and lentil.
7. Enhancement of resources: No-tillage or minimum tillage combined with effective crop residue management allows for the slow decomposition of organic matter, enhancing soil physico-chemical qualities by supplying necessary plant nutrients and organic carbon. Surface residues operate as mulch, helping to maintain a consistent soil temperature, reduce evaporation, and promote soil biological activity. Edralin et al. (2017) documented a potential increase in organic carbon content with rice mulch at 15 Mg ha^{-1} in CA field before planting.

5.1 Constraints in Adopting CA

Change of mindset of the farming community, extension workers, and researchers would help change farmers' attitudes towards adopting no-till drill technology (Meena and Singh 2013). The most critical barrier in adopting CA technology is overcoming the mentality about tillage (Hobbs and Govaerts 2010). The most difficult challenge in implementing CA on a broad scale is persuading farmers that effective cultivation utilizing reduced tillage or no-tillage is even viable (Mishra et al. 2018). So, there is a need to call the scientific research and demonstrations at farmer fields, which would be more helpful for convincing farmers about the potential benefits of CA. The following are the few critical constraints that impede the adoption of the CA system.

1. Burning of crop wastes: Due to less time gap between the harvested crop paddy and succeeding wheat, farmers choose to burn surplus crop residues in the field for timely sowing (Mishra et al. 2014; Singh et al. 2018). Such practice is being followed in the rice-wheat cropping system of North India. The government, on the other hand, has outlawed this practice.
2. Competition between CA and livestock feeding: Crop residues are used for livestock feeding and fuel purpose. Under rain-fed conditions, farmers face scarcity of crop residues due to less biomass production from different crops. So, farmers take out the crop residues for livestock feeding, a significant constraint for the CA system.

3. Inadequate farm implements for small and medium-sized farmers: Although numerous efforts have been made to build wheat seeder machinery for the no-tillage method, more work is needed to standardize and promote high-quality machines that can handle a wide range of cropping sequences. This could help include permanent bed and furrow planting systems and harvesting practices, promoting the CA system by managing crop residues.
4. High machine and implementation costs: CA implements are extremely expensive. Small and medium farmers in the IGP region may not be able to afford the CA implements.
5. Lack of knowledge about CA system potential: There is a need to develop a whole package of practice for CA, including planting, nutrient management, irrigation scheduling, insect and pest control, and harvesting for easy adoption of CA.

6 Resource Efficiencies, Particularly Energy Budgeting in CA

For energy management, intensive agricultural production systems rely mainly on fossil fuel burning, which accounts for most energy input and GHG emissions (Jat et al. 2019). The consumption and expense of energy in agriculture have increased, necessitating the adoption of more energy-efficient farming practices (Soni et al. 2018). The agricultural industry in developing economies has seen phenomenal improvement in farm mechanization, significantly enhancing agricultural energy inflows (Saad et al. 2016). Crop productivity and production economics are determined mainly by the magnitude of energy investment and the availability of resources (Shahbaz et al. 2017; Mishra et al. 2018). The proportion of energy consumed is determined by the degree of mechanization, the amount of active agricultural work performed, and the area of cultivable land available (Ozkan et al. 2004; Alam et al. 2005). Energy- and input-intensive production systems raise several sustainability challenges (Kumar et al. 2020). Agriculture rapidly recognizes the importance of non-renewable energy conservation and effective resource management for cleaner and more sustainable production (Kumar et al. 2019). As a result, for increased crop and energy productivity, profitability, and resource-use efficiency in the region, the current agricultural situation emphasizes the use of cost-effective, energy-efficient, and climate-resilient strategies such as zero-tillage, crop residue retention, and crop diversification mostly with legumes (Singh et al. 2011; Adak et al. 2013; Bhattacharyya et al. 2015). Input-output analysis of energy is customarily used to appraise production systems' effectiveness and ecological impacts besides comparing different production systems (Mobtaker et al. 2010). Increased energy usage in agricultural production systems not only boosts output and profits for farmers, but also has an unfavorable impact on the environment, adding considerably to global warming (Arora et al. 2018; Pokhrel and Soni 2019). The increase in population will increase food consumption which will eventually entail higher energy use in agriculture (Gathala et al. 2020; Deng et al. 2021).

6.1 Crop Establishment Strategies Based on Tillage and the Energy Relationship

Tillage elimination or reduction could reduce non-renewable energy sources such as diesel in some farming systems. As a result, using less fossil fuel in conservation agriculture operations will reduce greenhouse gas emissions into the environment, thereby improving services rendered by the ecosystem (Busari et al. 2015; Gupta et al. 2016). Traditional cultivation approaches have a higher cost of cultivation due to multiple tillage operations, labor-intensive crop installation, and more significant investment for regular irrigation, resulting in a poor economic return to farmers. New resource- and energy-efficient sustainable production technologies are required (Jat et al. 2014; Nandan et al. 2018). Nisar et al. (2021) quantified the effect of tillage systems with or without straw mulch on energy management. They evinced that no-tillage decreased input energy compared to conventional tillage, thereby signifying that no-tillage combined with mulching is the most energy-efficient approach. Minimal tillage, residual retention, mulching, and reduced traffic are examples of CA-based agro-techniques that could help reduce energy use and GHG emissions (Lal 2015).

6.2 Crop Residue Retention and Energy Relations

Proper management of crop residues in the field affects the efficiency of applied fertilizers, irrigation, and other inputs in the agricultural system (Chauhan et al. 2012a, b). Compared to residue removal, crop residue retention reduced net energy, energy productivity, and energy ratio (Nandan et al. 2021). According to Jat et al. (2019), crop residue retention is a renewable energy input that boosts system production by roughly 12% in conservation agriculture-based diversified systems. In the maize-wheat system, zero-tillage combined with CA-based residue retention reduced total cultivation costs by 18% compared to traditional tillage systems (Erenstein and Laxmi 2008).

6.3 Cropping System and Energy Relations

Cropping systems and management tactics directly impact energy use and productivity (Tuti et al. 2012; Nandan et al. 2021). The input requirement of legumes to complete their life cycle is low compared to other crops (Das et al. 2018) because legumes tend to capture N from the atmosphere via biological nitrogen fixation; thus, the energy for the allocation of N fertilizer is reduced (Deng et al. 2021). Parihar et al. (2017) evaluated a maize-wheat-mung bean system's energy requirements and productivity in a semi-arid agro-ecosystem and identified a suitable cropping system to attain greater energy efficiency. Minimum tillage is an ideal ecologically benign technology for mitigating climate warming as it results in reduced energy utilization, thereby having lower global warming potential (Pratibha et al. 2019). Reduced tillage is an environmentally benign technique because it saves significant amounts of fuel and reduces CO_2 emissions (Vilma et al. 2018) besides mitigating the disadvantages of traditional ploughings, such as high energy and fuel usage (Pratibha et al. 2019).

6.4 Energy-Economics Relationship

Economics, particularly net returns, is an important judgment tool in identifying the composition of an entity, management alternatives, and measuring the economics, energy demand, and carbon footprint of systems (Choudhury et al. 2016). Among the various aspects of crop production, seedbed preparation is among the significant providers of energy input (Yadav et al. 2018). Partially mechanized tillage lowered the cost of cultivation by 23% compared to fully mechanized tillage, indicating that partially mechanized tillage is the most energy-efficient option (Kumar et al. 2021a, b). Pratibha et al. (2019) suggested that using primary tillage with minimal soil disturbance and fewer operations results in a lower cost of cultivation with the slightest compromise on yield. When compared to conventional agriculture plots, the conservation agriculture plots produced a net return that was 110% higher than the maize–wheat system as a whole (Ghosh et al. 2015). Intensive tillage and crop establishment procedures in the rice-wheat and maize-wheat systems contribute significantly to high energy and labor expenses, resulting in low economic returns (Aryal et al. 2015; Parihar et al. 2017). Because of lower cultivation costs and increased crop output, conservation agriculture-based systems delivered higher net returns (Choudhary et al. 2018).

7 Scope of Climate Resilience and Greenhouse Gas Emissions (GHGs) Mitigation Through CA Adoption

Conservation agriculture is often considered a sustainable farming practice that maintains or increases crop productivity, improves the quality of the environment, assists in carbon storage, and provides plenty of ecosystem services. According to The FAO (2014), CA is a "sustainable approach that could manage the agro-ecosystems to maintain sustainable crop production while protecting the natural resources and the environment" (Lal 2013a, b).

Furthermore, appropriate agricultural practice aids in sequestering the carbon in soil and plant biomass and reduces the emissions from combustion of fossil fuel and soil-associated emissions, resulting in climate change mitigation. Since soil disturbance in conventional agriculture promotes soil carbon loss due to soil organic matter erosion and enhanced organic matter decomposition. However, zero-tillage practiced in CA put forth the advantage of soil carbon gain. In addition to this, employment of zero-tillage in CA accounts for reduced power and energy requirements consequently, resulting in lesser fuel consumption, slower depreciation rates of equipment, and lower working time; all these collectively lead to reduced emission of GHGs both from the machinery and equipment manufacturing operations as well as from farm operations (West and Post 2002). For instance, farmers of Indo Gangetic Plains (IGP), on average, could save 36 L diesel ha^{-1} by employing zero-tillage in the rice-wheat system for land preparation and crop establishment.

Consequently, this is equivalent to a reduction of CO_2 emission at the rate of 93 kg CO_2 ha^{-1} yr^{-1} (Erenstein and Laxmi 2008). Since CA emphasizes the retention of crop residue in the field itself, it improves soil fertility and overall soil health by adding carbon fixed in the crop biomass through photosynthesis. This feature of CA, in turn, also minimizes the amount of fertilizer used and, consequently, the associated GHGs emission (Corsi et al. 2012). Further, in northwest IGP, electricity is used to pump irrigation water, while diesel pumps are employed for pumping irrigation water in the eastern IGP, contributing to CO_2 emissions. Therefore, CA also saves irrigation water and consequently reduces CO_2 emissions.

Along with reduced emission due to minimal power and energy utilization, CA also influences the emission of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) from the soil. In the context of agro-ecosystem, the decomposition of plant residues emits CO_2, which is further amplified by soil disturbance in conventional agriculture practice. Emission of methane (CH_4) from soil occurs due to methanogenesis in the anoxic microenvironment, while in the aerobic microenvironment, consumption and oxidation of CH_4 by methanotrophs emit CH_4. Nitrous oxide (N_2O) is mainly produced through nitrification and denitrification under aerobic and anaerobic soil conditions. Further, puddling and continuous flooding of rice fields also aid in methanogenesis, thereby increasing CH_4 emission.

In contrast, safe alternate wetting and drying in CA have resulted in a noticeable reduction in the emission of CH_4 (Yan et al. 2003). Further, in the rice-based production systems of IGP, CH_4 emission can be reduced by preceding puddling and tillage and judicious management of water, thereby contributing lower GHG load into the environment and aiding in climate resilience. In addition, the GHGs emission from the rice-wheat production system of northwest India was continuously monitored by employing the static chamber method in an experiment by Sapkota et al. (2015). It was observed that CH_4 emissions were much low for rice production through the direct-seeded production system of CA (<50 mg CH_4 m^{-2} d^{-1}) as compared to the puddled transplanted field with continuous flooding of conventional agriculture (50–250 mg CH_4 m^{-2} d^{-1}). In the same experiment, the GHGs emissions from conventional tillage based rice-wheat systems, compared with CA-based systems, showed 27% higher total cumulative GHGs emissions (emission of CO_2, N_2O, and CH_4) in terms of CO_2-equivalent from the former practice. Therefore, CA generally enhances soil organic carbon storage in comparison to intensive agriculture, particularly in the topsoil. This can ultimately help with climate resilience, water regulation, carbon sequestration, and reduced emission of greenhouse gases (CO_2,

CH_4, and N_2O). Under CA-based management approaches, Jat et al. (2020) reported 39% (4-year average) reduced CH_4 emissions than conventional tillage based rice-wheat systems (Table. 6.2). This was primarily due to anaerobic conditions created by puddling and constant flooding, which encouraged the formation and emission of CH_4.

8 Indices of Soil Health and Carbon Sequestration Potential Under CA Systems

Agricultural production and future food, feed, and fiber security are all threatened by climate extremes worldwide. Crop production losses due to extreme weather events cost developing countries $80 billion between 2003 and 2014. Climate extremes threaten crop security around the world. CA is predicted to provide significant climate adaptation benefits worldwide (Mishra et al. 2018; Kumar et al. 2021a, b; Jat et al. 2020). However, the synergistic impacts of conservation strategies on yield in normal and harsh climates and the underlying regulatory systems are yet unknown. Thus, the adverse effects of substantial seasonal and yearly weather variability on natural resources and field crop output are anticipated to become more pronounced even in the short run.

Soil reserves are an essential link in a complex web of interrelated atmospheric processes. The soil system acts as a climate buffer by controlling the hydrological cycle, exchange energy, and heat, reducing stress on plants and biota. The basic elements of the earth's crust have a profound effect on climate change. Proper land use and soil management, on the other hand, have been shown to improve the stability of the earth's structure, which has led to increased permeability during heavy rainfall, increased water retention during droughts, and improved gas exchange through natural respiration and heat adaptation. Despite certain variances, soil resilience is a key component of "soil quality/health" and "soil degradability." General frameworks for soil quality assessments do not usually consider the long-term effects of

Table 6.2 Effects of various scenarios on rice/maize, wheat, and systems' energy usage efficiency and global warming potential (GWP) (based on 4-year average, 2014–2018)

Scenarios	Energy use efficiency (MJ^{-1} MJ^{-1})			Area scaled (GWP; kg CO_2 eq. ha^{-1})		
	Rice/maize	Wheat	System	Rice/maize	Wheat	System
1	3.95C	7.44C	5.05E	5043A	1409A	6451A
2	4.70C	9.65AB	6.23D	3742B	384C	3359B
3	4.85C	9.26B	6.25D	3498B	536C	2962BC
4	10.81B	7.84C	9.25C	1245C	1407A	2652C
5	13.82A	10.05A	11.92A	213D	16B	228D
6	12.68A	9.27B	10.95B	285D	51B	336D
7	12.72A	9.51AB	10.26B	250D	8B	433E

1 – conventional tillage (CT) rice and wheat; 2 – CT direct-seeded rice (CTDSR)–zero tillage (ZT) wheat; 3 – ZT direct seeded rice (ZTDSR)–ZT wheat; 4 – maize-fresh beds (FB); wheat–CT; 5 – permanent beds (PB); 6 – ZT in both the crops on flat beds; 7 – ZT in all the three crops on flat beds (source: Jat et al., 2020)

soil degradation processes (e.g., soil erosion). Extremes of weather can cause physical damage to productive soil activities. Finally, external inputs such as fertilizers, lime, and irrigation can help maintain the stability of the outlet in the face of climate change without compromising soil self-regulation. For this reason, detailed information on the type and quantity of external inputs should be used to establish a productivity-based assessment of soil resilience.

9 The Impact of Conservation Agriculture on Soil Properties

9.1 Physical Properties

Soil aggregate stability is defined as the soil resistance to alter due to natural or human activity. There is a high intermediate correlation between aggregate stability in water, compound size, and total organic carbon percentage (Liu et al. 2019). Most of the plant residues are left on the surface of the earth, which improves soil aggregation and aggregate stability. It also keeps the surface particles from eroding due to rain and splashes. Because it is dominated by no or minimum tilled and crop remains retention, CA is excellent for soil aggregation and aggregate stability (Li et al. 2011). It also keeps the surface particles from eroding due to rain and splashes. Expanding micropores into the soil also increases water retention capacity and reduces evaporation from the surface of the earth (Kassam et al. 2009; Palm et al. 2014).

9.2 Soil Moisture Content

CA allows conserving soil moisture by covering it with agricultural wastes and mulches. Agricultural residues left on the field have increased water intake and retention. Mulching helps to protect the earth from extreme heat changes and reduce evaporation, which is especially important in tropical and subtropical areas (Kodzwa et al. 2020). According to several researchers, CA saves 20–30% of irrigation water by reducing evapotranspiration losses from above when residues are used (Jat et al. 2012), and more water is available because soil moisture is retained.

9.3 Exchangeable Ca, Mg, and Micronutrients

Rahman et al. (2008) documented that exchangeable calcium, magnesium, and potassium were significantly higher in uncultivated soils than cultivated soils. The provision of soil nutrients and cycling improved with the organic crop leftover decomposition, which are essential for soil microbes. Compared to conservation tillage, micronutrients such as zinc, iron, copper, and manganese were available at higher amounts under zero-tillage with residues, especially near soil (Franzluebbers and Hons 1996). In distinction, Govaerts et al. (2007) found that tillage did not affect iron, manganese, and copper concentrations, but extractable zinc concentrations were considerably more remarkable in the upper surface layer in contrast to conservation cultivation with full residues. Similar outcomes were outlined by Du Preez et al. (2001) and Franzluebbers and Hons (1996).

9.4 Soil Microbial Biomass Carbon (SMBC)

Continuous application of CA-based management strategies lowers soil disturbance, which can promote soil microbial biomass (SMB) and improve microbial activity, leading to improved soil quality and higher crop output productivity (Hungria et al. 2009). According to Dong et al. (2009), the annual microbial biomass carbon (MBC) was significantly higher in zero tilled (ZT) with residual while lower in conventional tilled (CT) without residual. On similar lines, Silva et al. (2010) found consistently higher concentrations of MBC and microbial biomass nitrogen reaching more than 100% in no-tilled (NT) as compare to CT. The major factor influencing the amount of SMB in soil is widely thought to be the rate of organic C incorporation from crop biomass. The SMB is a measure of the soil potential to retain nutrients cycling (C, N, P, and S) and soil organic matter with a high turnover rate as compared to total soil organic matter (Dick, 1992; Carter et al. 1999). According to Spedding et al. (2004), residue management had a greater impact on microbial properties than tillage, and plots with residue retention had higher MBC and N concentrations than plots with residue removal. But, only 0–10 cm layer showed significant variations. Over conservation tillage, the NT practice increased total carbon by 45%, microbial biomass by 83%, and the MBC:total carbon ratio by 23% to a depth of 0–5 cm after 21 years. In surface soil, no-tillage boosted the rate of carbon and nitrogen mineralization by 74% when compared to conservation tillage systems (Zhang et al. 2018).

9.5 Soil Enzymatic Activities

CA-based farming system helps to increase the enzymatic activities in the soil, due to the vertical distribution of organic residues and microbiological activities, which positively affects soil enzymes that play a key role in catalyzing reactions required for organic matter decomposition and nutrient cycling, as well as energy transfer, environmental quality improvement, and crop productivity (Dick 1992). According to Roldan et al. (2007), ZT produced higher dehydrogenase and phosphatase activity in the 0–5 cm soil layer than CT. The dehydrogenase enzyme activity of soil under the permanent bed planting technique was substantially higher (62%) than that under conservation tillage, according to Singh et al. (2009). Hota et al. (2014)

discovered that organic residues combined with ZT resulted in higher acid phosphatase activity than control (i.e. without residues).

Results show that CA-based rice management boosted net profitability (NP) and energy usage efficiency (EUE) while reducing irrigation, i.e., water-saving, global warming potential (GWP), and system productivity (SP) when compared to current farmers' practice (FP), as shown in Fig. 6.2 (Jat et al., 2020). When CA-based maize was substituted for rice, similar mean profitability gains (16%) were achieved, but dramatic improvements in irrigation (84%), EUE (+ 231%), and GWP (95%) were found when compared to FP (Jat et al., 2020).

10 Conclusion

Extensive and resource-intensive traditional farming deteriorated soil, water, and environmental quality, as well as low profitability, which has threatened the viability of South Asia's foremost rice-wheat (RW) systems. Conservation agriculture-based management approaches have a lot of potential for increasing production, profitability, and mitigating climate change, but they haven't been widely adopted. To achieve a holistic shift in the conventional farming system, more evidence from other perspectives will be required. This chapter highlighted an overview of CA systems worldwide and an in-depth review of the Indian subcontinent. CA systems enhance productivity and profitability and offer strategies for resource conservation, particularly energy and water, carbon sequestration, and GWP reduction.

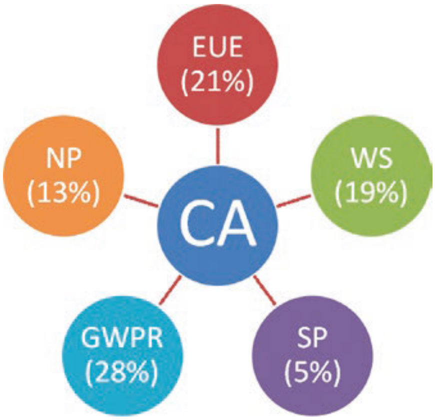

Fig. 6.2 Multidimensional outcomes of rice-wheat-based CA systems compared to conventional farming in Western IGP (adapted from Jat et al. 2020). *CA* conservation agriculture, *EUE* energy use efficiency, *WS* water-saving, *SP* system productivity, *GWPR* global warming potential reduction and *NP* net profitability

11 Future Prospects and Critical Areas of Research

- Need-based site-specific adjustments in CA systems will be required for higher adoption and scaling at mass.
- The gap of technology reach to farmers needs to be addressed, i.e., availability of the zero-till machine and seed cum fertilizer drill.
- Capacity development of agents of change (key farmers, extension agents, and officers of agriculture department).
- Networking of scientific community, agents of change, and policymakers in the decision system for higher adoption and broader outcomes.
- Bottom to top approach for refinement and redesigning of CA systems.
- Policy framework for transforming subsidy to ecosystem services.
- Paving ways for carbon credits to farmers for sequestering carbon and developing climate resilience.
- Recognition and incentivizing farmers for adoption of resource-conserving technologies.

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Chapter 7
Plant Molecular Farming: A Marvelous Biotechnological Approach in Agricultural Production

Abhishek Kumar, Ashutosh Singh, and Anshuman Singh

Abstract Plants have several advantages over the system for strategic production of useful biomolecules and proteins. Plant molecular farming is the genetic manipulations of the plants for production of desirable proteins and other useful biomolecules through various biotechnological approaches. Moreover, plants have been recognized as potential and natural sources of pharmaceutical products including various types of biomolecules including vaccines, proteins, antibodies, therapeutic entities, and essential blood substitutes. In addition, mammalian-derived recombinant DNA drugs, plant-derived antibodies, edible vaccines, and useful proteins are advantageous and are free of mammalian viral vector as well as other pathogens related to human. Plant-made biopharmaceuticals are safer, cheaper, can be commercially produced, and easily stored. In this article, we have described several plant diverse systems for the commercial production of useful proteins, enzymes, antibodies, and vaccines with desirable traits. Several advantages as well as disadvantages of the particular system of the plant molecular farming are also discussed. We have also described the product of plant molecular farming currently available in the market on commercial basis.

Keywords Plant molecular farming · Recombinant DNA · Pharmaceutical proteins · Biomolecules · Plant-derived antibodies · Vaccines

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1 Introduction

Plant molecular farming is a robust way for the production of beneficial biomolecules or valuable metabolites to industry in the plants and has been traditionally used in agricultural cultivation. Practical application of plant biotechnology and genetic engineering in order to manipulate and produce beneficial plant-derived metabolites and chemicals for commercial and pharmaceuticals are the major goals of plant molecular farming. Plant molecular farming in the agricultural sector has great potential in the production of biodegradable plastics, industrial chemicals, pharmaceutical drugs, foods, feeds, and fodders (Franken et al. 1997). The attempt of molecular farming has come into existence since the successful manipulation of the plants was reported by Fraley and co-workers in Fraley et al. 1983. Molecular farming in the plant system has great potential in the production of unlimited recombinant proteins for use as life sciences and proper health care. Plant suspension culture system has a broad spectrum for the production of protein and useful biomass through propagation of transformed plants (Kamenarova et al. 2005). Transgenic plants can produce mammalian proteins for long-term storage. Moreover, the expressions of various plants now have been successfully demonstrated and products have reached commercial utilization.

The use of plant extract for pharmaceutical and medicinal purposes flourished in the seventeenth century when scientific pharmaceutical treatment for the cure of human diseases and disorders was recommended. Nowadays, bioengineering has recently grew up new opportunities for using plants as production biopharmaceuticals of desirable products. In this contrast, human growth hormones were the first pharmaceutically proteins expressed in the transgenic tobacco. In addition, other plant systems and transgenics are capable of expressng a number of proteins, vaccines, antibodies, nutraceuticals, industrial enzymes, etc. In order to produce recombinant proteins, prokaryotic and eukaryotic systems have been successfully utilized. Prokaryotic systems of recombinant protein production are much superior and convenient in comparison to other mammalian systems. However, most of the mammalian proteins need post-transcriptional modification of the proteins for biological activities, and that cannot be possible by the prokaryotic system. Overall, the use of prokaryotic system for the expression and production of long-term storage recombinant proteins is therefore perhaps limited. The production costs of mammalian proteins are very high because of maintaining cell culture and their proper scaling (Ma et al. 2005).

In contrast, molecular farming from plant system is one of the cheapest and successful strategies for the manipulation of the pathway of protein synthesis into desirable recombinant proteins. Production of biopharmaceuticals and heterogeneous at a large scale from plant sources can be achieved at the lowest cost by avoiding the contamination of animal pathogens. The progress in the production of recombinant proteins and antibodies using plant systems with respect to several human disorders and diseases is illustrated in the Table 7.1.

Table 7.1 Year-wise progress in the field of plant molecular farming

S. no.	Years	Progress	Sources
1.	1986	First plant-derived recombinant proteins	Human growth hormones in tobacco and sunflower (Barta et al. 1986)
2.	1989	First plant-derived recombinant antibody	Full-sized IgG in tobacco (Hiatt et al. 1989)
3.	1990	First human protein production in plants	Human serum album in tobacco and potato (Sijmons et al. 1990)
4.	1992	First plant-derived vaccine candidates	Hepatitis B virus surface antigen in tobacco (Mason et al. 1992)
5.	1992	First plant-derived industrial enzymes	A-amylase in tobacco (Pen et al. 1992)
6.	1995	Secretory IgA production	IgA production in tobacco plants (Ma et al. 1995)
7.	1996	First plant-derived protein polymer	Artificial elastin in tobacco plants (Zhang et al. 1996)
8.	1997	Commercial production and characterization of avidin and their extraction and purification	Avidin from transgenic maize (Hood et al. 1997)
9.	1998	First clinical trial using recombinant bacterial antigen	Antigen delivered in transgenic potato crop (Tacket et al. 1998a, b)
10.	2000	Production of human growth hormones in tobacco chloroplast	High-yield production of a human therapeutic protein in tobacco chloroplasts (Jeffrey et al. 2000)
11.	2003	Expression and assembly of functional antibody in algae	Expression and assembly of a fully active antibody in algae (Mayfield et al. 2003)
12.	2003	Commercial production of bovine Trypsin in maize	Maize (Zea mays)-derived bovine trypsin: characterization of the first large-scale, protein product from transgenics (Woodard et al. 2003a, b)
13.	2016	Chloroplast genome: Diversity, evolution, and application in genetic engineering	Chloroplast genome (Daniell et al. 2016)

2 Plants as Production System of Plant Molecular Farming

Several kinds of plants are available on the earth and many of them have potential to produce human- and animal-related proteins and other useful edible vaccines. Large-scale multiplication and production is now simplified by increasing the area of plants under cultivation. The potential use of the plant system for the production of useful recombinant pharmaceutical was successfully established in the year 1990 with successful expression of proteins resembling the mammalian serum album. Later, the crucial advantages of the plant system come into existence after the successful expression of the functional antibodies in the plants in the year of 1989 (Hiatt et al. 1989).

Applied biotechnology is expanding the use of plant system in biopharmaceutical production across the other and medicinal boundaries. Nowadays, molecular farming through plant systems has covered the production area of pharmaceutical proteins suited with the mammalian antibodies, blood substitutes, and edible vaccines. The strategies that precise the plant genetic manipulation, expression of the recombinant DNA and proteins as well as convenient storage of the raw materials with reduction of the contamination of human or animal pathogens during the processing. The generalized models of the plant molecular farming through plant system are diagrammatically presented in the Fig. 7.1.

Moreover, recombinant protein production and expression are also successfully achieved from microbial system. The robust microbial systems are able to produce only 0.1% of the commercial proteins, i.e., very less than plant system (Giddings 2001). Economic advantages of the plant system with respect to strategic production of plant-derived recombinant proteins and their proper expression are very clear as comparison to the other older system. The production of pharmaceutical proteins from plant system is much safer than the microbial system and animal system because they lack human pathogens and oncogenic nucleotide sequences of the DNA (Commandeur et al. 2003). The biosynthetic pathways of protein are consequently conserved between plants and animals, so plants are able to fold and assemble the human recombinants proteins efficiently. This is a wonderful advantage over

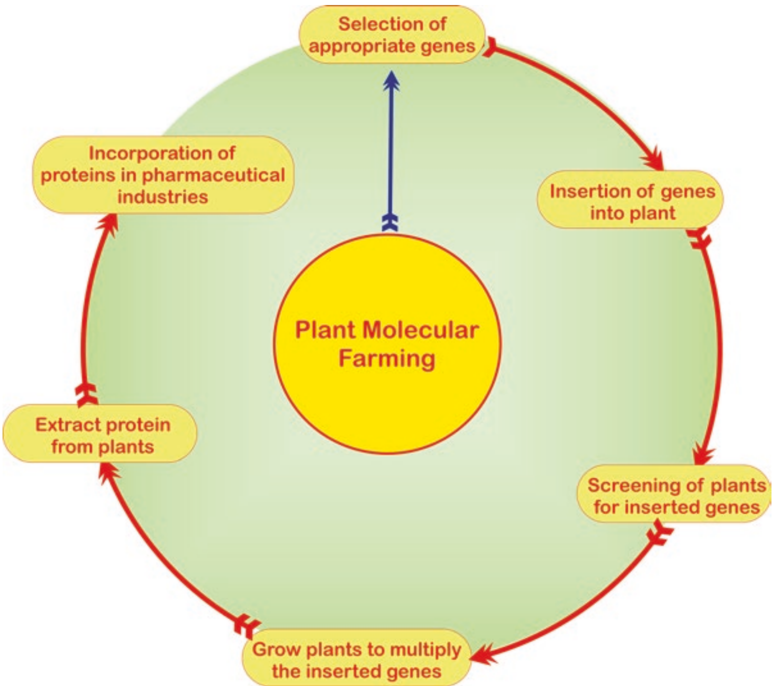

Fig. 7.1 Plant farming molecular approach of biomolecules production

the bacterial system expression of the proteins because many of the folds in bacterial proteins are fails to express. The ability of plant recombinant proteins with respect to folding and assembling is correctly demonstrated by their capacity to produce functional serum antibodies (Schillberg et al. 2002; Stoger et al. 2002a, b).

A number of crops including cereals, legumes, oil-yielding crops, vegetable, and fruit crops have been investigated for the production of desirable proteins and nutraceuticals (Hood 2002). Selection of crops for plant molecular farming is the important factors that include biomass per hectare, easy to transport, and scalability. Crops like rice, wheat, tobacco, and pea have been used to express single chain Fv-antibodies to compare the merits and demerits of the production system (Stoger et al. 2002a, b). The major advantages of the production of the proteins from vegetable and fruit crops are that the edible organs can be used as unprocessed or semi-processed materials (Tacket et al. 1998a, b). The idea for the production of nutraceuticals and edible recombinant vaccine is so much designated for application (Tacket et al. 2000). Potatoes are the major source among vegetable crops for edible vaccine production (Richter et al. 2000). Transgenic potato crops have been administrated to humans in three clinical trials carried out till date. Several reports describe the production of VP6 capsid protein in the transgenic potatoes for sufficient vaccination against several viral infections in the human being (Yu and Langridge 2003). Moreover, traditional and transgenic potatoes have also been used for the production of protein from human milk, antibody-fusion proteins, and glucanases (De Wilde et al. 2002). Other vegetable crops, like tomatoes, have several advantages in the production of nutraceuticals and recombinant edible vaccines over the potato (Schunmann et al. 2002). Tomato was first time used in the production of rabies vaccine and has also been used for the production of several types of antibodies (Chong and Langridge 2000). In fruit sources, bananas are the alternative and ultimate source of edible vaccine production (Mason et al. 2002). They are widely grown and consumed by human beings, mostly in Africa, where vaccinations are badly needed (Sala et al. 2003).

2.1 Suspension Culture of Model Plants

The plant cell culture and culture of other cellular compartments can help to increase the potential of target protein production in the plant system. Like microbes, plants cells are capable of carrying out many post-transcriptional modifications that occur in the mammalian cells. Plant cells are simply maintained in the synthetic media, and they are able to synthesize several classes of proteins and glycoproteins, like immune-globulin and interleukins (Valkova et al. 2013; Twyman et al. 2012). The glycoproteins synthesized in the plants as recombinant human glycoproteins show similarities with the N-glycon structure in comparison to the same proteins produced in other organisms such as yeast, fungi, and bacteria. Improvement in the yield of recombinant proteins is one of the important and countable factors which have significant impact on the economic value of the product.

Targeting the improvement of intercellular compartments and improvement of the downstream processing techniques through improvement in the development of novel promoters and their targeted signals can improve the recombinant protein stability (Schillberg et al. 2013). In addition, the intercellular compartment of the plan cell, such as endoplasmic reticulum, chloroplast, apoplasts, vacuoles, etc., is capable of synthesizing the targeted recombinant proteins in the culture plant cell under the suitable culture medium. The rough endoplasmic reticulum of the plant cell, i.e. bearing ribosomes on their surface, is the important route for the processing, proper disulphide bond formation, and glycolation. Chloroplasts and other plant pigments are also important sub-cellular components of disulphide bond formation and proper protein fold formation. Storage vacuoles and rhizomes of the plant root system can also be helpful in the downstream processing of the strategic secretion of the recombinant proteins (Drake et al. 2009). Several production and purification technologies such as transformation and cell suspension culture,and other transient systems related to plant molecular faring come into existence since the last two decades, and a large number of recombinant plant biomolecules and pharmaceuticals including vaccines, blood products, antibodies, and growth regulators hormones have been produced and some of them are commercialized at large scale.

2.2 Advantages of Plant System for Protein Production

Advantages of higher plants for strategic production of desirable biopharmaceuticals and recombinant DNA proteins are easy, fast, and cheapest rather than transgenic animal cells. Significantly, plants do not possess any known human pathogen that can contaminate the final biopharmaceutical products. Generally, higher plants synthesized proteins from eukaryotes with meaningful folding patterns, and they are directly suitable for the environment that reduces the degradation. Plant molecular farming is one of the success keys for the proper expression of recombinant protein products and their commercial production. This is one of the most important advantages with regard to the economics. Till date, large numbers of bioengineered recombinant proteins and biopharmaceuticals have been expressed in the plant system. Mostly, plant systems are capable of offering the cheapest and safest source of biopharmaceuticals and recombinant proteins production up to commercial scale. Furthermore, plants have over advantages as compared with the traditional system of molecular farming for pharmaceutical proteins production. The advantage of plant molecular farming over the traditional system includes cheapest cost of production, absence of human pathogen, and the ability to fold and assemble the complex recombinant proteins.

3 Biomolecules Production in Transgenic Plants

Transgenic plants are marvelous gifts toward the bioengineering sciences that pertain strategic and trustful production of biopharmaceuticals and recombinant proteins. The transformation of crop species through insertion of transgenes depends on the availability of the desirable recombinant plants. The bio-macromolecules produced in the living system are used for several diagnostics purposes and dietary supplements. Numbers of crops including tobacco, alfalfa, potato, canola, maize, Arabidopsis, rice, and cowpea have been successfully used in the production of pharmaceutical proteins, industrial enzymes, antibodies, and vaccines.

Tobacco mosaic viruses are one of the successful models which infect tomato plants and express the target proteins in the plant tissues. The transgenic tomato plants with tobacco mosaic virus can be easily manipulated in the production of the targeted proteins and can be easily obtained within months. Moreover, transgenic plant-derived protein products are commercially available.

Maize-derived trypsin protein is one of the recent introductions of transgenic plant-derived protein and has significant market value. Maize-derived trypsin is the protease and has a variety of applications as well as processing of the biopharmaceuticals. Bovine is another trypsin-derived recombinant molecule that helps in the commercial production of the desirable reagents. The maize-derived trypsin is proteolytic in nature and has been expressed in a variety of recombinant systems. The proper expression of such enzyme at commercial level in maize system was possible only through expression of enzymes in inactive zymogen form. However, the zymogen genes were inserted into plants and active form of enzymes was recovered in the extract from corn seeds (Woodard et al. 2003a, b).

In addition to exploiting transgenic plants with respect to plant molecular farming, the recombinant form of bovine aprotinin from transgenic maize seeds was first time reported by Zhong et al. (1999) using the particle bombardment method. Zhong et al. also reported that Agrobacterium tumefaciens-derived vector acts as seed-derived promoter deriving the corn bovine aprotinin gene. Later in Ruggiero et al. 2000, Ruggiero et al. reported the first human collagen produced in the transgenic plants. He incorporated the fibrillar collagen *1α3* and *α22* as cDNAs that code for complete human collagen chain into transgenic tobacco plants using agrobacterium with selectable marker gene *npt2*. Protein synthesized in the form of triple helix and was much surprising since plant farming system does not contain any particular post-transcriptional machinery that would be needed for collagen assembly. Several other evidences have been reported in plant molecular farming by using transgenic plants in the strategic production of the plant-derived pharmaceutical molecules and desirable proteins suited to humans and other animals (Table 7.2).

Table 7.2 Potentially produced proteins, enzymes antibodies, and vaccines from plant sources

S. no.	Details of beneficial plant molecular farming products		
1.	**Proteins produced in different plant host systems**		
	Therapeutic proteins	Commercial/potential use	Plant sources
(i)	Hirudin	Anticoagulant	Canola
(ii)	Protein C	Anticoagulant	Tobacco
(iii)	Calcitonin	Parathyroid gland, carcinoma, Paget disease, osteoporosis	Potato
(iv)	Human somatotropin	Hypopituitory dwarfism	Tobacco
(v)	Glutamate decarboxylase	Diabetes	Tobacco
(vi)	Epidermal growth factor	Mitogen	Tobacco
(vii)	Tuber growth factor	Mitogen	Tobacco
(viii)	Erythroprotein	Mitogen	Tobacco
(ix)	Human serum album	Blood substitute	Potato
(x)	α haemoglobin	Blood substitute	Tobacco
(xi)	β haemoglobin	Blood substitute	Tobacco
(xii)	α-trycosanthin	HIV therapy	Tobacco
(xiii)	α-interferon	Viral protection, anticancer	Rice
2.	**Industrial enzymes and proteins produced in different plant host systems**		
	Industrial enzymes	Commercial/potential use	Plant sources
(i)	*Cellulase*	Industrial use	Alfalfa, tobacco, potato
(ii)	*Phytase*	Commercial products and industrial use	Alfalfa, tobacco
(iii)	*Manganese peroxidase*	Industrial use	Alfalfa, tobacco
(iv)	*Avidin and avidinase*	Potential reagents in research purpose	Maize
(v)	α-amylase	Industrial use	Tobacco
(vi)	β -1,4 *xylanase*	Commercial products and industrial use	Tobacco
(vii)	*β -1,3-1,4 glucanase*	Industrial use	Tobacco, canola
(viii)	*Glucuronidase*	Potential reagents in research purpose	Maize
3.	**Antibodies produced in different plant host systems**		
	Potential use	Antigen used	Plant sources
(i)	Plant protection	Nematode antigen	Tobacco
(ii)	Research purpose	Human creatine kinase	Arabidopsis
(iii)	Phytoremediation	Atrazine	Tobacco
(iv)	Tumour associated antigen	ScFv–84–64 against carcino-embryogenic antigen	Cereals
(v)	HSV–2	Glycoprotein B of HSV	Soybean
(vi)	Colon cancer	Colon cancer antigen	Tobacco
(vii)	Tooth decay	*S.* mutant antigen	Tobacco
(viii)	Hodgkin's lymphoma	ScFv of IgG from mouse B-Cell lymphoma	Tobacco

(continued)

Table 7.2 (continued)

S. no.	Details of beneficial plant molecular farming products		
4.	**Vaccines produced in different plant hosts**		
	Antigen	Disease and causal organism	Plant sources
(i)	Malarial antigen	Malaria	Tobacco
(ii)	CT-B toxin	Cholera	Potato
(iii)	Spike protein	Piglet diarrhea	Tobacco
(iv)	LT-B toxin	Traveler's diarrhea	Potato
(v)	Capsid protein epitode	Mink enteritis virus	Cowpea
(vi)	c-Myc	Cancer	Tobacco
(vii)	Hemagglutinin	Influenza	Tobacco
(viii)	Mouth/foot disease antigen	Foot and mouth disease	Cowpea
(ix)	Gp41 pesticide	HIV-1	Cowpea
(x)	Norwalk virus antigen	Gastrointestinal disease	Tobacco, potato
(xi)	Hepatitis–B antigen	Hepatitis–B	Tobacco, potato
(xii)	Glycoprotein B	Human cytomegalovirus	Tobacco
(xiii)	Human cytomegalovirus	Human cytomegalovirus	Tobacco
(iv)	Rabies virus glycoprotein	Rabies	Tomato, tobacco, Spinach

3.1 Expression of Recombinant Biomolecules in Plant

The expression of the recombinant DNA biomolecules and desirable proteins in crop-plants has been reported and commercially produced in the industries. The biopharmaceuticals and desirable proteins that have been expressed in the plant system are categorized by Horn et al. in 2004. The broad areas are related to therapeutics and pharmaceutical intermediates; some of the proteins are directly used as plant-pharmaceuticals along with the desirable recombinant DNA proteins. The stable transformation of the desirable foreign DNA segments into the plant genome can be achieved by Agrobacterium-mediated gene transfer techniques. The insertion of such types of genes through Agrobacterium results in the proper expression of stable recombinant DNA proteins. In addition, polynucleotide transformation is possible to target the protein of interest into other sub-cellular locations such as plastids, cytoplasm, endoplasmic reticulum, vacuoles, apoplasts, and their post-transcriptional modification to be carried out on the expressed proteins.

Overexpression of the particular DNA sequences adjacent to the recombinant DNA motifs, presence of many times repeated homologous sequences, and methylation of the recombinant DNA and their co-suppression can also lead to the inactivation of the recombinant DNA. Most of the inactivation concern with recombinant DNA can be prevented by avoiding the line selection with proper insertion of the single transgenes, instead of using the repetitive homologous DNA sequences. Stability of recombinant DNA inside the plant genome sometimes undergoes inactivation and results in the prevention of their expression in the plant cells.

Optimization of the foreign DNA sequences for their proper expression in the plant system is much more complicated as comparison to the animals because plant systems have so many different codons than animal systems. However, introgressed foreign genes/DNA must be optimized for the proper expression in plant systems and must be able to increase the translation and result in the desirable protein yield. Expression of the proteins can be accelerated by using tissue-specific promoters. It has been also tested that the use of some tissue-specific promoters is also helpful in avoiding adverse effect on the proper growth and development of the engineered plants. The other protein accelerating systems of the expression like introns in the recombinant DNA molecules enhance the transgene translation by addition of untranslated leader sequences (Maas et al. 1991).

However, the transformations of the plants with multiple genes are desirable for the production of multi-protein complex and multi-biopharmaceuticals and can be achieved with improvement in the metabolic pathways as well as their biosynthetic routes. Insertion of multiple genes can also be achieved by other practices by using internal ribosomal sites for the strategic expression of genes in the form of bicistronic messengers. This is one of the novel approaches for the expression of the multiple genes because internal ribosomal sites are the polynucleotide sequences that recruit the eukaryotic ribosomes to mRNA to initiate protein translation in the middle of the messenger-RNA molecules needed for translation initiation (Houdebine and Attal 1999). The potential expression of proteins and biopharmaceuticals from the plant system has been reported from some plants such as tobacco, tomato, maize, and rice, mentioned in Table 7.2 and Fig. 7.2.

3.2 Antibody Production in Plants

Antibody production in the plant system is one of the important goals of plant molecular farming that can accelerate by proper and strategic utilization of bioengineering and recombinant DNA techniques. Most of the antibodies are multiple units of the glycoproteins produced by the mammalian immune system, which allows them for application in thediagnostics of several diseases in humans and animals. Plant molecular farming is one of the robust and alternate sources of antibody production for animals and humans. Bioengineered and genetically modified plants have been frequently used for antibody production against several human diseases, such as dental caries, rheumatoid arthritis, cholera, E. coli diarrhea, malaria, certain cancers, Norwalk virus, HIV, rhinovirus, influenza, hepatitis B virus, and herpes simplex virus (Schillberg et al. 2003). The antibodies have been produced from the plant systems, as mentioned in Table 7.2.

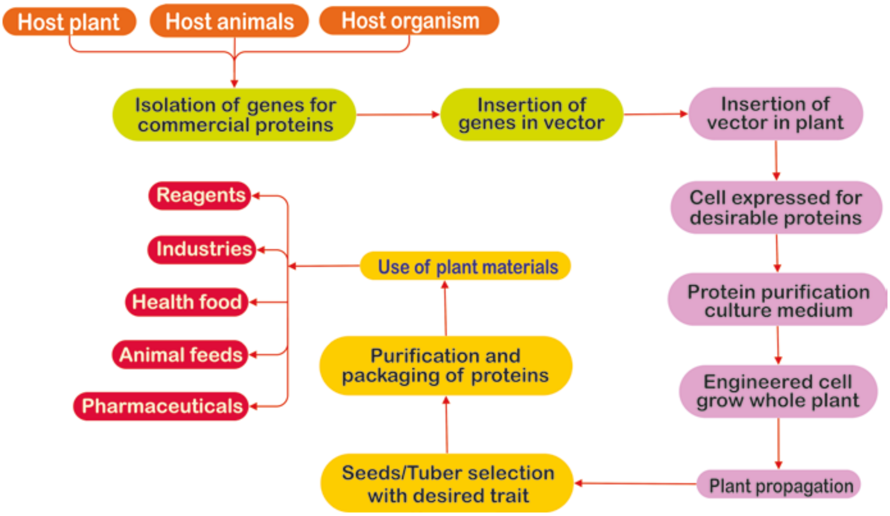

Fig. 7.2 Plant farming molecular approach for protein production

3.3 Edible Vaccine Production

Edible vaccines came into trends after the discovery and commercial production of the hepatitis B vaccines from tobacco plants and tomato tubers. Most of the plant-derived edible vaccines are either complete unit or sub-unit of the vaccine that introduced selectable genes into the plant system and facilitated the production of desired proteins. In addition, specific antigen inbuilt protein can be produced in plants with the ability to induce several hormonal responses when eaten by animals and humans. Protection studies have been shown on a broad spectrum when these oral vaccines are used. In most of the studies, it has been found that the protection was actually better with the edible vaccine than the edible vaccines commercially available in the market (Lamphear et al. 2004). Most of the edible vaccines are mucosal in nature and capable to stimulate systematic and mucosal immune response. Moreover, a number of edible vaccines from plant sources have been produced against hepatitis B, E. coli, V. cholera, rabies virus, human cytomegalovirus, and rotavirus. Most of the edible vaccines are also tested in many crops and successfully produced from potato, tomato, tobacco, canola, etc. (Table 7.2).

4 Commercial and Economic Opportunities for Plant Molecular Farming in Future

The commercial and economic prospects of the plant molecular farming products are quite high as compared to the traditional plant products. A large number of products with desired recombinant biopharmaceutical have been developed from the transgenic plants and are commercialized for the prevention of several pathogens. There is a huge demand for plant-derived recombinant proteins because protein productions from plants are stable molecular transformation of the crop species on earth. To achieve specific recombinant protein production in the plant system, DNA or polynucleotides which code for the desired proteins and their proper synthesis must be inserted in the plant cell and may increase the economic production of the plant products. Commercial molecular farming is now exposed to the strategic production of suitable products from plant sources. The high value biopharmaceutical products and many recombinant proteins owing to their high-profit potential are under development and some of them are under clinical trials from large and marginal industries. However, if the products of molecular farming from plant sources are to be commercially successful, definitely in the future they must be holding competitive advantages over alternative products. The commercial process of plant molecular farming is still much an immerging industry and has the opportunity to capture new markets for agricultural products.

5 Conclusion

A combination of the diverse group of plant system and advanced biotechnological tools and techniques may be helpful in the plant molecular farming strategy for the production of useful pharmaceutical proteins, antibodies, desirable nutraceuticals, and other edible vaccine for the nation. Molecular farming through utilizing plant systems is the attention of new era for shifting of traditional and basic research towards commercial exploitation of the plant system. Strategic and stepwise exploitation of the potential plant system for commercial drug development and development of pharmaceutical produce is the major objective of plant molecular farming. In this context, efforts have been done by researchers in the plant molecular farming area. Recently, in the last decade, a number of products have been developed with desirable nutraceuticals and recombinant proteins. However, some of the limitations have been observed in the plant molecular farming system which are due to the less or limited expression of the proteins in the human system from the plant system. Other challenges in plant molecular farming are various environmental impacts, biosafety regulations, and several types of risk assessment, which reflects the release and commercialization of transgenic agricultural crops. These crucial issues have major challenging impact on the successful and commercial production of plant molecular farming. Improvement in such types of challenges and alternative sources will be helpful in the production of novel products through the plant molecular farming system.

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Part III
Advanced Technology in Agriculture for Smart Faming

Chapter 8
Examining the Outcome of Coupling Machine Learning with Dual Polarimetric SAR for Rice Growth Mapping

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Abstract Agricultural applications of remote sensing have recently been extended to attempt detailed identification and mapping of rice growth stages. In terms of agricultural insurance, the information plays a critical role in the damage assessment as rice plants of certain ages cannot survive flooding or drought events. In this research, Phased Array-type L-band Synthetic Aperture Radar (PALSAR-2) data were evaluated in combination with machine learning techniques. Two forms of PALSAR-2 images were investigated, i.e., backscatter coefficients and their combination of textural and decomposition properties. The datasets were ingested into seven machine learning processes so that the accuracy of each combination of tools and datasets for identifying rice growth stages could be evaluated. Additional SAR properties provided a benefit to all machine learning processes, with at least 4% improvement. Random Forest was the best performing algorithm with 83% overall

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accuracy, while competing processes such as C5.0 and Extreme Gradient Boosting, followed closely with a margin of about 5%.

Keywords AdaBag · Extreme gradient boosting · GROWTH phase · PALSAR-2 · POLARIMETRY · Random forest · RICE · Support vector machine

1 Introduction

Rice is the most prolific food crop in many parts of the world, including Indonesia. Rice fields have been developed for centuries, and because they are essential for food security in many countries, they continue to be an issue of great importance for concerned governments. Due to their importance, rice fields must be thoroughly monitored. Since Indonesia's rice-growing regions are scattered throughout the country, a practical yet reliable monitoring system needs to be established.

Contributions of remotely sensed images for providing continuous data supply for environmental monitoring purposes, including agriculture, have long been established. Previous crop assessment has focused on the utility of multispectral data by taking advantage of its long-term, repetitive records (Son et al. 2016). A survey of the literature showed that initially, remote sensing data were exploited for mapping the extent of rice fields (Van Niel and McVicar 2004), and a variety of classification algorithms including supervised tree-based models (Panuju et al. 2021) and the autonomous Iterative Self-Organizing Data Analysis Technique Algorithm (ISODATA) (Nguyen et al. 2012) have been used to map rice field extents. Kamthonkiat et al. (2005) went beyond field extent mapping to distinguish between irrigated and rain-fed rice fields by exploiting time-series multispectral datasets. This approach allows more precise information retrieval about planting intensities. Irrigated rice fields could have up to three planting seasons per year, while rain-fed rice fields are usually planted only once. Detailed information extraction tends to involve more sophisticated image processing strategies; hence, geo-artificial intelligence techniques are typically employed. With the availability of diverse machine learning models, there is a need to understand the relative performance of different classifiers and regression techniques for crop monitoring applications.

Large-scale rice monitoring involves close investigation of drought water-related hazards since irrigation networks may be absent or not fully functioning. Drought has been a primary research focus using multispectral sensors by taking the advantage of vegetation indices and the thermal infrared waveband. Water deficiencies change the canopy structure of rice, creating conditions whereby vegetation indices can be exploited. Numerous vegetative-related remote sensing products have been presented (Sholihah et al. 2016), which have often been combined with thermal bands to elevate their sensitivity (Bhuiyan et al. 2017). Drought can also be evaluated through the estimation of moisture, using either plant or soil moisture as a primary proxy. Sensitivity of SAR waves to moisture has been proven as a good candidate for this task. Brisco and Brown (1990), for instance, found that C-band HH-polarized backscatter coefficients provided a good medium for detecting drought in wheat. For regional assessment, however, data and information fusion exploiting multispectral and microwave data can be more beneficial (Anderson et al. 2012).

The impact of drought severity on rice production depends on the growth phase of the plants. For example, juvenile plants do not survive prolonged drought or sustained flooding, which frequently occurs in many Indonesian rice field centers. Further information on growth status, preferably at the parcel level, would be a key benefit to improving the quality of agricultural datasets. The key challenge to using multispectral data for this task is the frequency of atmospheric disturbance. Clouds are almost persistent in rainy seasons, making data acquisition from optical sensors fairly difficult in the rainy season.

With the advent of X-, C-, and L-band Synthetic Aperture Radar (SAR) sensors, opportunities for data exploitation have improved. Using an X-band data series, Inoue et al. (2014) concluded that VV polarization was useful to estimate grain yield, although it was insensitive to growth phases. Abundant C-band data from Envisat and Sentinel-1 satellites suggested that discrimination of planting, vegetative, reproductive, and maturity phases is generally successful (Chen et al. 2007). The application of L-band, unfortunately, has been lacking in this domain, perhaps due to limited data available to public. A survey of the literature indicates that L-band data only work well for the identification of rice fields if they are combined with multispectral data, as demonstrated by Torbick et al. (2011) in the United States and Wang et al. (2015) in a Chinese site. The application of L-band SAR with the aid of machine learning should, therefore, be examined.

The main objectives of this article are two-fold. The first is to identify whether single-acquisition L-band SAR features have enough sensitivity to distinguish different growth phases of rice. The second is to explore augmented methods through adding the use of textural and decomposition features of L-band SAR and testing their performance using modern machine learning methods.

2 Methodology

2.1 Test Site

This research was situated in rice fields centered on Bojongpicung district, Cianjur regency, Indonesia (Fig. 8.1). The area has relatively flat terrain, with undulating and hilly terrain in the south. The soils are predominantly Grumusols, which are favorable for cash crop agriculture. According to the Köppen climate classification, the Bojongpicung area can be categorized as A-type, which is typical of tropical

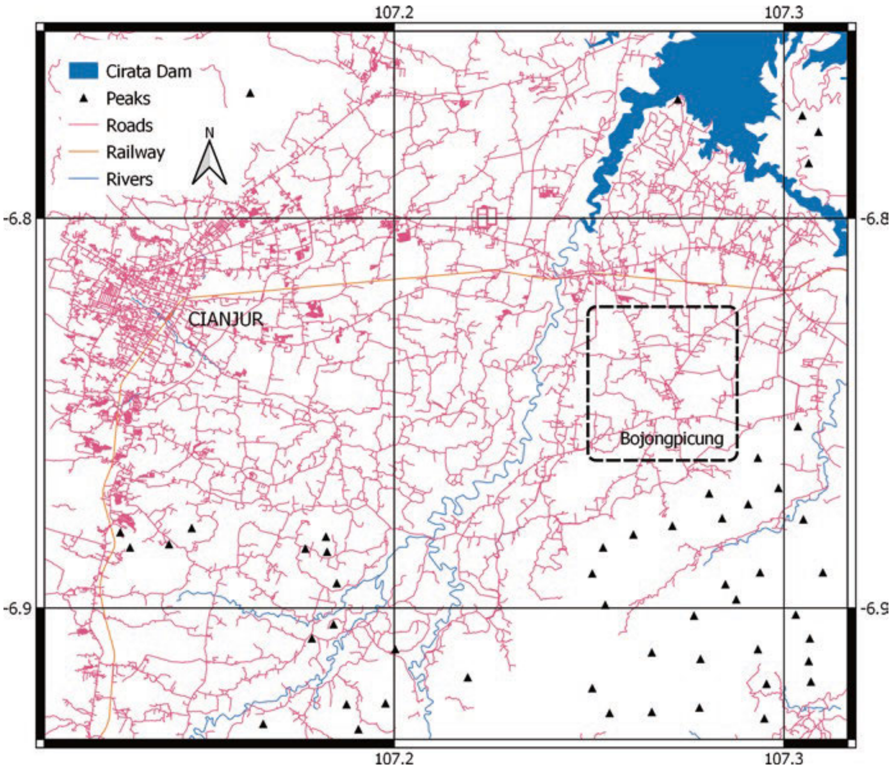

Fig. 8.1 Test site, Bojongpicung, Cianjur, Indonesia

regions with long wet seasons. This area has been one of the primary breadbaskets of West Java province and is supported by numerous rivers and streams. In addition, irrigation networks have been in use for decades and they have generally been well-managed. The northern part of the region is bordered by the Cirata dam, one of three major dams along the Citarum River.

2.2 Datasets

The primary earth observation data used in this research were Level 1.1, dual-polarized PALSAR-2 data, obtained from Japan Aerospace Exploration Agency (JAXA). The data were acquired on 8 November 2017 in ascending mode, with an off-nadir angle around 28.6 degrees. In order to assist the interpretation, a series of Sentinel-2 datasets, before and after the acquisition date, was available to this research. To support the analysis, ground datasets were collected and compiled in a database. This spatial database consisted mainly of rice field parcels with their respective block numbers, integrated with planting dates, the planted cultivar, and

Fig. 8.2 Field documentation during surveys. Top images: early vegetative phase. Bottom left: late vegetative phase. Bottom right: late vegetative phase with early indications of drought

field documentation when available (Fig. 8.2). This provided the baseline for the sampling procedure used in classifying growth stages.

2.3 Data Preprocessing and Analysis

PALSAR-2 data were preprocessed to retrieve backscatter coefficients in HH and HV linear polarizations using the SNAP software package, which is freely available from the European Space Agency (ESA) website. The image was calibrated into β^0 to allow subsequent processing of terrain flattening. This further removed artifacts due to undulating terrain. In this preprocessing step, the one arc-second digital elevation model (DEM) from the Shuttle Radar Topography Mission (SRTM) was employed. A Range-Doppler terrain correction was applied to the data and the output was registered to World Geodetic System (WGS) 1984, permitting the integration with existing baseline maps. In order to minimize the speckle effect, the image was filtered using a 5×5 Gamma MAP filter. Finally, linear-scaled backscatter coefficient images were converted to decibels (dB) for analysis.

Dual-polarized SAR images are often found inadequate to solve complex problems. Augmentation procedures, such as combining them with textural features, are popular options that can significantly improve classification outcomes (Panuju et al. 2019). In this research, extending backscatter data was performed using the grey-level co-occurrence matrix (GLCM) to describe textural features(Haralick et al. 1973). While several GLCM features exist in the literature, this research employed two robust textural features, i.e., mean and variance, as summarized in Panuju et al. (2019).

In order to further amplify the overall accuracy, dual polarimetric decomposition was applied. In this research, a dual-polarized entropy-alpha angle model (Cloude 2007) was investigated. Augmentation of backscatter data was implemented by inserting entropy, alpha angle, and anisotropy features. Entropy (H) quantifies randomness of surface scatterers and ranges from 0 (single-type scattering) to 1 (random-type scattering)(Cloude and Pottier 1997). Alpha angle deals with dominant scattering mechanism under a specific neighborhood definition (in this case 5×5 pixels). Generally, assessment of surface scattering is sufficient with these two decomposition features. Where complex conditions occur, an additional feature, the Anisotropy, is employed (Cloude and Pottier 1997). It aids interpretation when more than one dominant scatterer ($0 < H < 1$) is present. At the end of the preprocessing, the complete set of SAR data consisted of nine layers.

The field survey indicated that only five growth stages existed during PALSAR-2 data acquisition (Table 8.1). Forty-eight samples were available to this research and the training-testing ratio was set to 70:30. All analyses, including modeling and prediction, were done in the R programming environment. The 'raster' package was used for input/output procedures, while modeling was undertaken using the 'caret' package. In order to minimize bias, a ten-fold cross-validation technique was applied with three repeats. This approach, however, consumed a substantial amount of computing time. Parallel processing, both in the training and prediction steps, was done using the 'doParallel' package.

This research employed conventional, monolithic tree Classification and Regression Trees (CART) as the benchmark. The model is available from the 'rpart' package. To further investigate modern machine learners, the study also implemented the C5.0, Average Neural Networks (AvNN), AdaBag (ADAB), Random Forest (RF), Support Vector Machine (SVM), and Extreme Gradient Boosting (XGB) algorithms. These techniques were selected considering the robustness of these classifiers in previous research (Panuju et al. 2021; Trisasongko et al. 2019; Trisasongko and Paull 2020). The overall accuracy was computed using the testing dataset for each algorithm.

Table 8.1 Class targets. The ripening stage was absent from the study area during the SAR acquisition date

Code	Stage	Growth phase	Age (days after transplanting)
1	Vegetative	Pre-tillering	<35
2	Vegetative	Tillering	35–45
3	Vegetative	Stem elongation	46–56
4	Reproductive	Booting	57–67
5	Reproductive	Heading	68–78

3 Results and Discussion

3.1 Backscatter Characteristics

Figure 8.3 depicts pattern similarity among linear polarization states during the juvenile to mature growth phases. Young plants weakly return incident signals to the antenna, especially in HV polarization. The interaction between juvenile plants and cross-linear polarization like HV has been found to be disturbed by soil background (Trisasongko and Panuju 2015). As a consequence, incoming waves are mostly reflected away from the sensor. Hence, recorded signals from this type of interaction are usually low. This phenomenon is known as the specular scattering mechanism. While augmented backscatter coefficients have been found in regular planting patterns as shown in rice fields(Ouchi et al. 2006) or rubber plantations(Trisasongko and Panuju 2015), this research did not observe this distinctive condition in the research site.

The co-polarization (HH) backscatter coefficient in the early tillering stage was about –13dB, similar to previous findings(Wang et al. 2009). Rapid development of the plant canopy in the early growth phase minimizes soil background and the observed scattering process changes to diffuse scattering where a greater amount of the incoming signal is received by the SAR antenna. This research found that in the tillering stage, a dense and curved rice canopy significantly increased returning signals, even though the SAR look angle was quite steep. While previous findings showed very low HV returns (around –24dB) (Wang et al. 2009), this research indicated that HV polarization of the remaining vegetative stages would be around –16dB. This large discrepancy was most likely rooted in different types of cultivars, which determines plant vigor in a given set of site conditions. While Inpari 32 and Inpari 33 were among the popular cultivars at the research site, the Pajajaran and Siliwangi cultivars have also been introduced. Because the provision of new cultivars has caused further complexity in the backscatter patterns, models capable of distinguishing cultivars should be sought and developed in the near future.

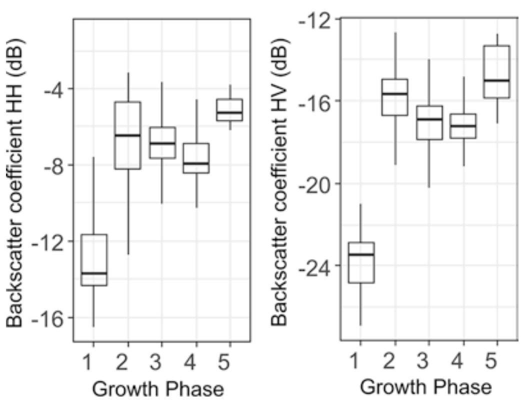

Fig. 8.3 Varying backscatter coefficients due to growth phase

Across the different vegetative phases, the behavior of backscatter coefficients remained similar either for HH or HV polarization. The early phase of the reproductive stage was indicated by a slight increase of backscatter coefficient, which was consistently shown in both HH and HV polarizations. This suggested that L-band SAR might be able to discriminate vegetative from reproductive stages.

3.2 Polarimetric Decomposition

Robustness of SAR data for classification or regression problems might be achievable through data augmentation. There are three different approaches to SAR data augmentation from a polarization perspective. The first is through applying arithmetic procedures to backscatter coefficients, including the Canopy Structure Index (CSI), Volume Scattering Index (VSI), and Biomass Index (BI) as proposed by Pope et al. (1994). Second, derivation of textural properties from specified backscatter coefficients has also been reported. Although several texture filters are available, GLCM has been the most commonly used.

With the advent of polarization diversity in SAR remote sensing, a third alternative to the aforementioned approaches has been introduced as an aid to improve model accuracies. SAR polarimetric features can be derived through polarimetric decomposition techniques applied to phase-preserved data. In general, fully polarimetric SAR data are ideal for data augmentation experiments or implementation (Trisasongko et al. 2019; Trisasongko and Paull 2020). Nonetheless, this type of data has been very rare and might not be available for regular monitoring schemes. With that condition in mind, single look complex format dual polarization SAR data show the greatest potential among other SAR data types.

Figure 8.4 presents the Entropy-Alpha angle plot for the data used in this experiment. It shows that classes generally overlap, suggesting that discrimination solely based on both decomposition features is likely to fail. While the distribution of Entropy is shown to be feasible, the dynamic range of the Alpha angle is extremely low, i.e., from 0 to around 30. This suggests that odd-bounce dominated in the interaction between the signal and rice plants. Although ground data showed the existence of a heading period, the figure demonstrates that dipole/volume scattering (Alpha angle around 45°) was not met. This condition indicates strong penetration of L-band SAR through the rice canopy, although dense canopy was observed during the field survey in the heading stage. Despite little indication of their contribution to the model, detailed observation of Entropy features suggests that juvenile plants behaved purely as single-bounce scatterers. Maturing plants would behave as random scatterers, with the growth of scattering objects like leaves and panicles.

The less successful discrimination based on Entropy and Alpha angle may be improved by incorporating Anisotropy. However, as shown in Fig. 8.5, Anisotropy provided trivial separation between the classes. High levels of Anisotropy designate that a secondary scattering mechanism could be observed, summarizing the complex wave-plant interaction when L-band is employed. The importance of

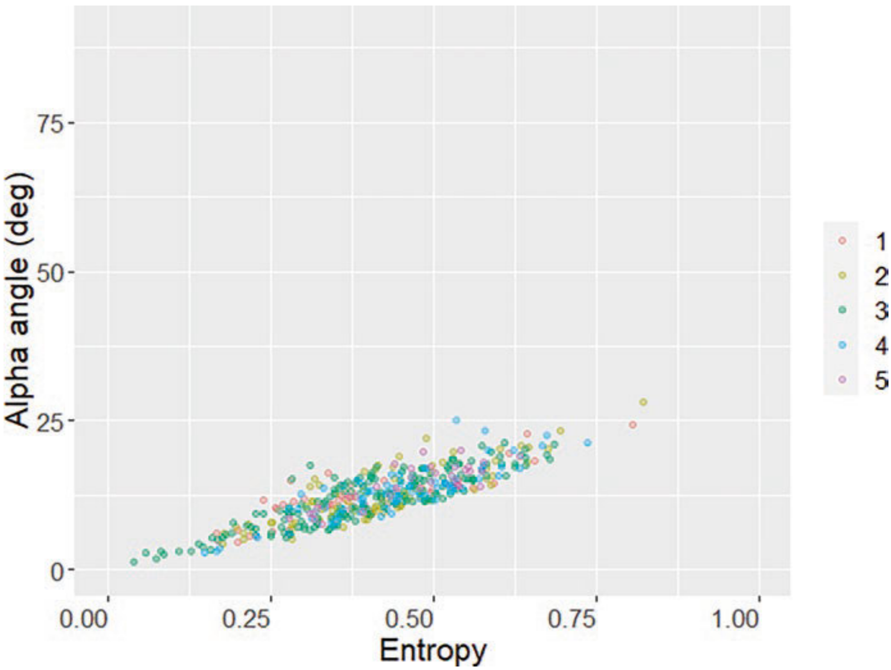

Fig. 8.4 Entropy-alpha angle plot

secondary scattering mechanisms, however, is slightly diminished with growing plants. This could be linked to the increasing domination of volume scattering among the rice canopy, which was shown to have a high level of Entropy (Fig. 8.4).

3.3 Baseline Accuracy

With the specific target of providing detailed information on growth stages, this research explored contemporary machine learning models to further investigate their performance and utility. Table 8.2 presents a summary of each machine learner's capability to distinguish five growth stages. The research found that SVM performed best when dual-polarized data were used. In addition to its high overall accuracy, the algorithm also yielded the best class-based accuracy.

It appears that monolithic, tree-based models such as CART performed poorly with limited predictors (only two in this case) and with sufficiently large targets to be resolved. This finding, alongside one previously reported (Panuju et al. 2021), suggested that the monolithic tree was most likely to be ineffective during modeling and for producing cropping maps. Interestingly, their improved versions, ensemble tree learners including C5.0 and RF, provided a little improvement. In this experiment, as a competing model to SVM, RF was found to be less able to discriminate

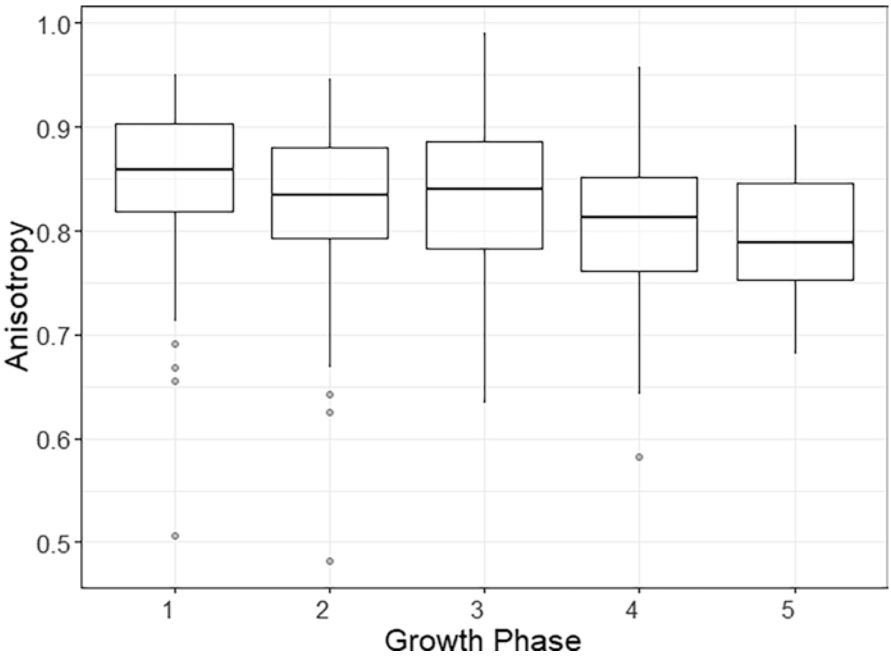

Fig. 8.5 Distribution of Anisotropy over plant growth phases

Table 8.2 Overall and class-based accuracies (in %) using the backscatter dataset

Method	Overall accuracy	1	2	3	4	5
CART	54.5	94.5	70.5	61.7	50.0	50.0
C5.0	55.5	99.4	58.7	64.5	60.9	75.3
AvNN	53.5	95.6	50.0	59.2	50.0	50.0
ADAB	61.4	95.6	73.6	67.5	50.0	62.5
RF	58.4	95.6	55.7	70.2	64.2	83.2
SVM	68.3	96.2	59.7	81.3	75.3	66.6
XGB	65.4	96.2	63.7	74.6	72.0	77.5

complex classes, with about 10% difference between them. It appears that RF requires a larger number of predictors to work as expected, while SVM may be more suitable when there are only a few independent variables. Nonetheless, another type of ensemble tree-based learner, XGB, showed an ability to separate growth phases similar to that of SVM. Gradient boosting was reported to have a better classification accuracy than SVM (Trisasongko et al. 2020). Having access to a variety of machine learning approaches would be beneficial to better understand the performance of contemporary classifiers. This research indicated that when the number of predictors is severely limited, tree-based models, either monolithic or ensemble, may not work well.

3.4 Accuracy Based on the Augmented Dataset

In practice, a threshold of 80–85% overall accuracy is typically required for reliable monitoring purposes (Panuju et al. 2019). Since the results reported in the baseline experiment did not reach that level, data augmentation using textural and polarimetric decomposition features was implemented. Table 8.3 indicates that this strategy was fairly successful in elevating both overall and class-based accuracy levels.

SVM, as the best performer in backscatter-based data feed, slightly dropped the overall accuracy with this augmented dataset. In contrast, ensemble tree learners were highly responsive to additional datasets. The greatest improvement from baseline backscatter data was achieved by RF(ca. 24.8%); C5.0, with the second largest improvement (around 24.7%), was only slightly less improved. The latter, in general, provided the best option to predict all pixels, with around 83% accuracy, followed by the C5.0 model. This suggests that tree-based learners benefit from access to more predictors to be able to discriminate complex problems such as detecting vegetative growth phase or estimating woody vegetation biomass (Trisasongko et al. 2019). Nonetheless, it is also acknowledged that the information contained in the additional data is also critical and should be regarded when data augmentation is considered. Insertion of weak variables may impose diminishing returns that could be ineffective during modeling and prediction.

The predicted growth phase map from the RF model is shown in Figure 8.6. As shown, all blocks are nearly homogenous as their planting date was fairly similar. We noticed, however, that a few blocks could be considered outliers to the general trend. The reason for this is unknown and this deserves further investigation in future research.

The overall accuracy obtained by this research was at the same level as the research conducted in China using SVM (Zhang et al. 2009). It should be noted, however, that this research employed five class targets, in comparison to only three growth stages used in the Chinese study. Finding comparable outcomes to this research in the literature is somewhat difficult as the diversity of cropping patterns, sampling sites, classification methods involved, etc. complicate the comparison.

With this achievable level of accuracy, L-band SAR should be useful for baseline monitoring of rice fields. The paucity of L-band data should be reevaluated to overcome the data gap in fine scale studies. Although regular provision of L-band data

Table 8.3 Overall and class-based accuracies (in %) using the augmented dataset

Method	Overall accuracy	1	2	3	4	5
CART	62.4	96.2	67.8	71.9	80.3	50.0
C5.0	80.2	98.9	89.0	83.5	86.4	87.0
AvNN	62.4	95.6	49.4	70.6	80.7	50.0
ADAB	65.4	96.2	64.6	73.7	80.9	62.5
RF	83.2	98.9	89.0	86.7	90.3	87.0
SVM	65.4	95.0	76.3	69.4	66.0	68.8
XGB	79.2	99.4	78.5	85.2	89.7	79.6

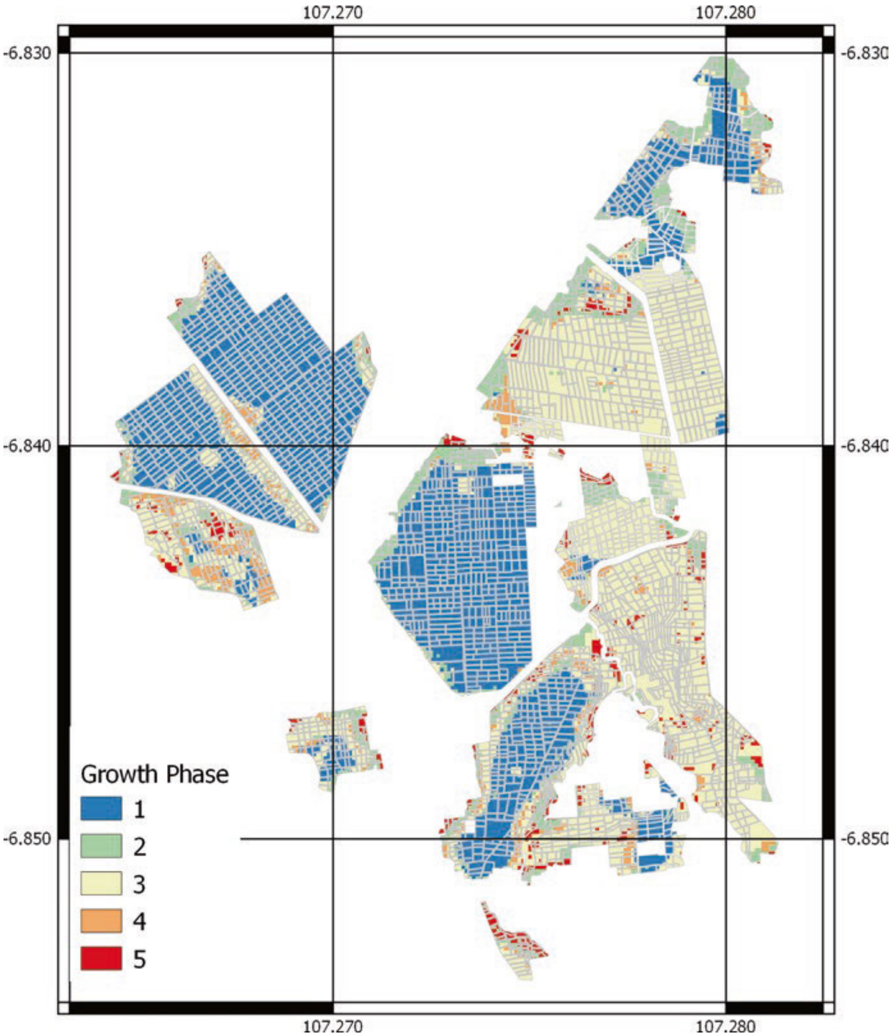

Fig. 8.6 Growth phase map derived from the Random Forest model

has been achieved by JAXA, the ScanSAR mode of PALSAR-2 does not fully suit the nature of small-scale rice patches in Indonesia, or perhaps also in many tropical regions, due to coarse spatial resolution. In addition, the stability of the statistical models investigated in this research should be reevaluated to investigate the model's transferability as suggested by Trisasongko et al. (2019).

4 Conclusion

Spatially scattered rice production and a need for identifying the most suitable machine learning methods to map rice growth phases have motivated this research. Employing L-band SAR supported by Sentinel-2 for interpretation, the robustness of contemporary machine learners to map rice growth phases was explored. A significant upsurge of returned signals occurred in the tillering stage. Both HH and HV showed similar patterns in describing growth phases and were capable of differentiating vegetative from generative stages. Augmenting backscatter datasets with texture layers improved the overall accuracy by about 8% – 27%, depending on the machine learning method used. The greatest increase was for C5.0 at 26.7%, followed by Random Forest at 24.8%. Meanwhile, the highest accuracy using the augmented data was generated by Random Forest at 83%. This research demonstrates the robustness of machine learners, which, together with suitable datasets, yields an overall accuracy >80%, the commonly used threshold for mapping purposes.

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Chapter 9
Mapping Prominent Cash Crops Employing ALOS PALSAR-2 and Selected Machine Learners

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Abstract Monitoring crops area is essential in achieving food security. The production coverage, crop types, and their growth phases are the key for monitoring food supply. Remote sensing plays a critical role to provide reliable data on regional basis supporting food production monitoring. In this research, we evaluated the use of Phased Array-type L-band Synthetic Aperture Radar (PALSAR-2), coupling with selected machine learners to map crop areas in the South Burnett, Queensland, Australia. Feature amendments onto dual polarimetric of ALOS PALSAR-2 were then assessed by means of variable importance to improve classification performance. Four machine learners were selected based on previous research and evaluated through classification accuracy. The best performer was Random Forest followed by C5.0, which generated accuracy at 82% and 81%, respectively. The response of data amendment varied over different classifiers. Random Forest and C5.0 seem to produce the highest accuracy at the best data-subset, while additional

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features with contribution less than 20% tended to reduce the accuracies of the two classifiers. Meanwhile, extreme gradient boosting tree and support vector machine kept increasing their accuracies, although additional features contributed trivially.

Keywords C5.0 · Crops mapping · Extreme gradient boosting tree · PALSAR-2 · Polarimetry · Random forest · Support vector machine

1 Introduction

A number of 7.8 billion population with the average growth rate of 2015–2020 at 1.09% are presently in need of consumption (United Nations 2019). Monitoring crop production and distribution is required to manage supply and demand for food provision. Valid data for both sides are crucial for realizing food security. Remote sensing plays a vital role for inventorying and monitoring crops area, which are the basis for managing food production (Courault et al. 2016). The technology may inform spatial distribution of production area (Rembold et al. 2019), indicate the stage of growth (Chosa et al. 2010; Panuju et al. 2021), map cropping pattern (Sianturi et al. 2018), and identify cropping intensity (Chen et al. 2012; Gumma et al. 2014; Liu et al. 2020) and has been employed to estimate yield (Zhang et al. 2017; Zhou et al. 2017). All are core data for managing food supply.

Various imageries, including optical and microwave sensors, have been explored to provide reliable data for securing food supply. To deal with the challenge of generating such information, understanding the suitability of data to produce targeted figures is necessitated (Erasmi and Twele 2009; Panuju et al. 2020b). One should consider spatial and temporal resolutions to opt for appropriate imageries for delivering the information. A few options are available for indicating growth stages of seasonal crops (Panuju et al. 2020a), generally from optical sensors, such as SPOT Vegetation (Khan et al. 2010), PROBA (Haerani et al. 2018b), MODIS (Panuju et al. 2021), Landsat, and Sentinel-2 (Chen et al. 2012; Liu et al. 2020). In another instance, medium to high spatial resolution images are required to map crop production areas which enable accurate estimation of food supply (Shi et al. 2014; You and Dong 2020). Nevertheless, cloud cover may limit the ability of optical sensors for monitoring those areas, especially in tropical regions (Ngo et al. 2020). Microwave sensor is an option for such cases.

The employment of microwave sensor has been pivotal for mapping crop areas in cloud-prone regions. The exploration of synthetic aperture radar (SAR) for crop monitoring covers various aspects, including delineating rice fields (Bouvet and Le Toan 2011; Ngo et al. 2020), identifying waterlogged field (Trisasongko 2019), mapping cash crops (Li et al. 2020; Veloso et al. 2017), estimating yields (Zhang et al. 2017), identifying pest infestations (Westbrook and Eyster 2017), etc. Nonetheless, using radar data also faces challenges, i.e., speckles that have been handled by several techniques, such as speckle noise model (Sumantyo and Amini 2008), improved sigma filter (Lee et al. 2009), or extended sigma filter (Lee et al. 2015). Another challenge is limited bands of SAR data which are between 1 and 4 that constrain the capability for mapping heterogeneous spaces. To deal with such circumstances, some researchers fused the data with optical images or their derivatives (Cai et al. 2019; Guo et al. 2019) and added decomposition or texture layers (Panuju et al. 2019). Additional layers have substantiated the increase of accuracies.

To date, advancing machine learning algorithms have progressed mapping capability when implemented on either optical or SAR data. Yet, a few have discussed the response of combining SAR amendment with various machine learners (Küçük et al. 2016; Panuju et al. 2019; Wei et al. 2019). This chapter aims to document an experiment which compares selected potential machine learners, i.e., C5.0, Extreme Gradient Boosting Tree (XGB), Random Forest (RFO), and Support Vector Machine (SVM) implemented on amended SAR data with Cloude decomposition and texture layers for mapping prominent cash crops in the South Burnett, Queensland, Australia.

2 Methodology

2.1 Research Site and Dataset

This research was conducted in Kingaroy, South Burnett, Australia. Kingaroy is situated in eastern Queensland, having a total area of 8381.6 km^2 with subtropical climate, average daily temperature between 12.2°C and 25.7°C, and precipitation about 769 mm annually (South Burnett Regional Council 2020). The area is known as a high quality producer of agricultural products, such as peanut, navy bean, and corn (Sorby and Reid 2001). Figure 9.1 describes the research site with the distribution of training and testing data for the experiment.

We employed ALOS PALSAR-2, taken from RA6 JAXA Project, with acquisition date on 10 March 2016, to suit ground data. The Fine Beam Dual (FBD) mode of PALSAR-2 Level 1.1 was used to comprehend the impact of additional synthetic layers for improving the accuracy of crop mapping. The original SAR data comprised of horizontal transmitting and receiving signals (HH) and cross polarization (HV) and were provided in the form of single look complex (SLC) with slant-range geometry at ascending mode. The swath width was 70 km and the range resolution 3 m (Rosenqvist et al. 2004). Moreover, Shuttle Radar Topography Mission (SRTM) 1 arc-second HGT was used for terrain correction, while Google Maps were employed to situate research site.

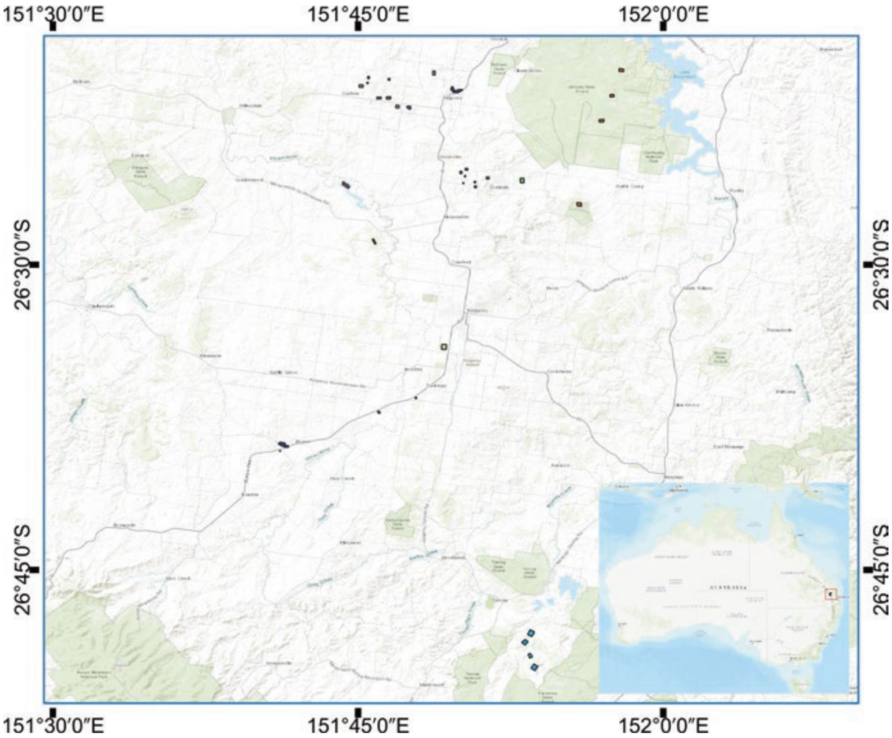

Fig. 9.1 Research site in South Burnett, Queensland, Australia (Courtesy of Google Maps)

2.2 Procedure of Analyses

In general, the procedure started from image preprocessing, followed by texture analysis, ground sampling, classifying images with selected machine learners, identification of variable importance, selecting the best model, and generating predicted map prediction. Figure 9.2 describes the flow of analyses from preprocessing to producing the final map of crop area employing dual polarimetric ALOS PALSAR-2. The data were preprocessed by performing calibration, terrain correction, decomposing SLC data by using dual polarimetric Cloudetheorem into Entropy, Anisotropy, and Alpha angle components, and transferring the sigma-0 into decibel (dB). Dual polarimetric ALOS was terrain-processed with pixel spacing at 10 m assisted by SRTM. The use of dual band ALOS synthetic aperture radar data may limit the capability to differentiate various crops for mapping purposes. Following the works of D. R. Panuju et al. (2019) the amendment of the data was implemented to improve the accuracy. Five texture layers were generated for each HH and HV, including Grey Level Co-occurrence Matrix (GLCM), i.e., Mean, Variance, Correlation, Entropy, and Maximum Probability (MAX) for the amendment. Whole processing

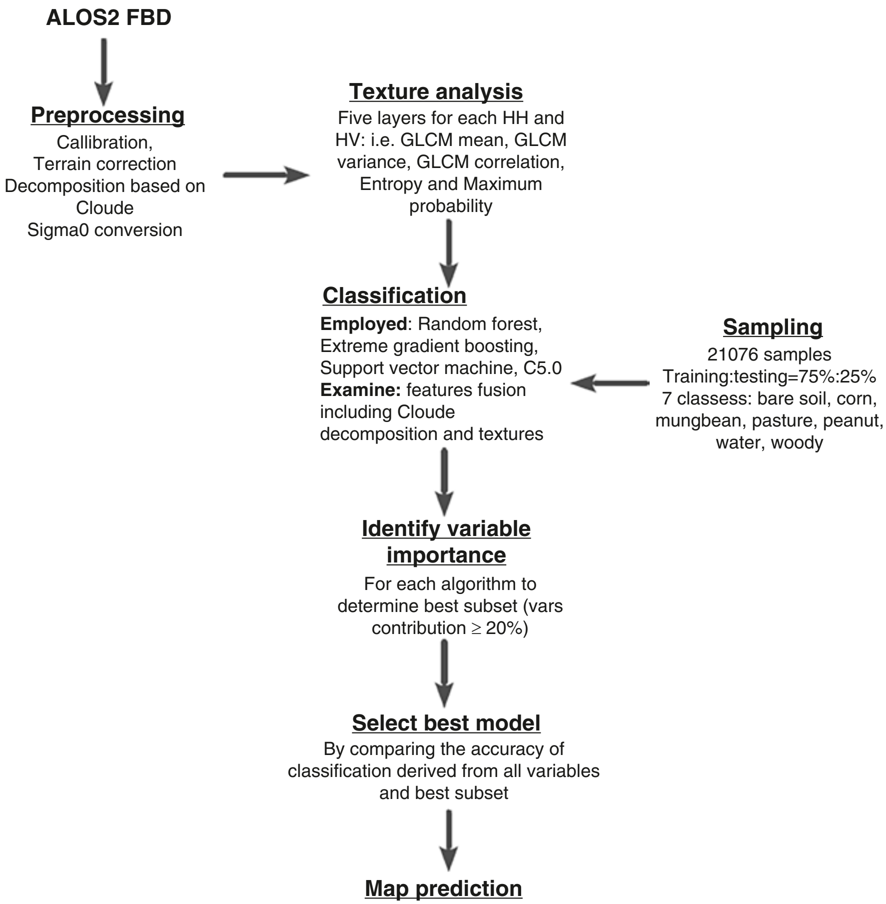

Fig. 9.2 Procedures to map crops area employing ALOS-2 FBD and feature fusion and four algorithms of machine learning

steps were performed in Sentinel Application Platform (SNAP) software version 8.0, freely available from European Space Agency (ESA) website.

All layers were then utilized for classifying crop areas employing four selected classifiers, i.e., C5.0, RFO, SVM, and XGB. Random forest was selected due to the superiority in terms of accuracy to map area (Chan and Paelinckx 2008; Panuju et al. 2019). The classifier was often compared with SVM and some showed SVM outperformed RFO (Trisasongko et al. 2017), while others demonstrated comparable performance between the two (Dalponte et al. 2013; Duro et al. 2012) for mapping purposes. C5.0 is an improved version of C4.5 which has potential for comparison (Fu et al. 2019). Last, the use of extreme gradient boosting tree has grown, being comparable to random forest (Naghibi et al. 2020; Panuju et al. 2019), which indicates its capability for crop mapping. All classification, accuracy assessment, and spatial prediction were coded in open access R statistical software, mainly using ‘raster’ in handling remote sensing and GIS data and ‘caret’ packages for modeling. In order to minimize bias, we performed ten-fold cross validation. Parameter tuning for each machine learning algorithm was performed automatically using ‘caret’ package.

Sampling was taken from the South Burnett region of Queensland, Australia, with a total of 28099 pixels. The samples were separated into 75% training and 25% testing for mapping seven classes, including (1) bare soil, (2) corn, (3) mungbean, (4) pasture, (5) peanut, (6) water, and (7) woody vegetation. Pictures of the ground truth taken during field surveys are presented in Fig. 9.3. We then compared four selected algorithms and selected the best performer to generate crop maps. Algorithms’ selection was based on the accuracies of classification being presented in several articles including Trisasongko et al. (2017)and Panuju et al. (2019). Data amendment was assessed by comparing the overall accuracy, examining variable importance, and selecting between the best subset and all employed variables. The use of variable importance to identify the best contributor for classification was discussed in Breiman (2001), Verikas et al. (2011), and Belgiu and Drăguţ (2016). The best subset composed of all variables having contribution more than 25% to variable importance (VI). Maps were then generated from the best and second best algorithms.

Fig. 9.3 Pictures representing four prominent cash crops and other land cover classes. From left to right: top: corn, mungbean, pasture; bottom: peanut, water, woody vegetation

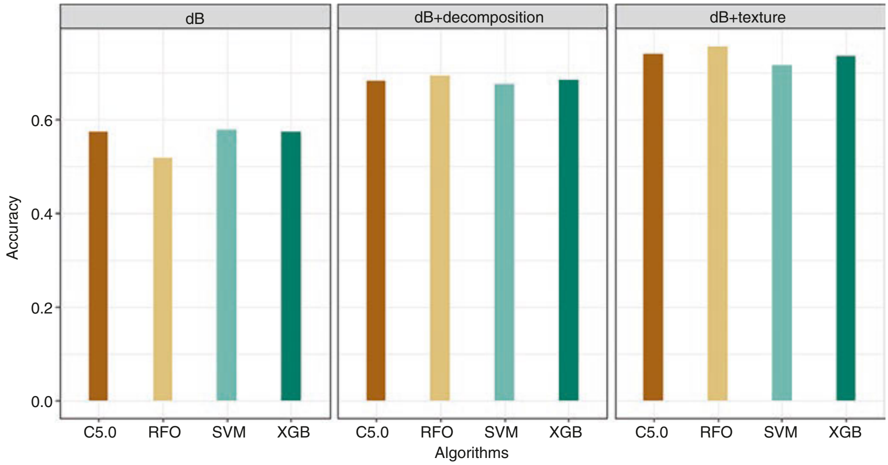

Fig. 9.4 Accuracies of classification derived from dual polarimetric layers (dB), dB + Cloude decomposition, and dB + textures

3 Results

An initial result was performed to evaluate the accuracy of dual polarimetric layers of ALOS PALSAR-2 and augmented datasets. Figure 9.4 describes the improvement of accuracy by feature fusion. As expected, dual polarimetric layers generated quite low accuracy, ranging from about 51% to 58% by all four algorithms. This demonstrated that limited layer inputs would not be able to gain sufficient outcome, although modern machine learning tools have been applied. Adding three features from dual polarimetric Cloude decomposition improved the accuracy by about 10% to 17%, with the highest improvement given by RFO. More accuracy improvement was generated by amending textures layers, by about 14% to 24%. Again, the highest increase was performed by RFO, followed by C5.0 and XGB. It appears that SVM responded sluggishly to layer amendment.

3.1 Variable Importance

Variable importance signifies the contribution of each variable to differentiate classes (Breiman 2001). Each algorithm presents different levels of importance on the same datasets. To some degree, Fig. 9.5 shows similarity of important variables resulting from random forest and extreme gradient boosting tree. A few similarities were shown by SVM. Nonetheless, C5.0 tended to not differing contribution of various variables, except for maximum probability of either horizontal or co-polarization layers which were very little or negligible.

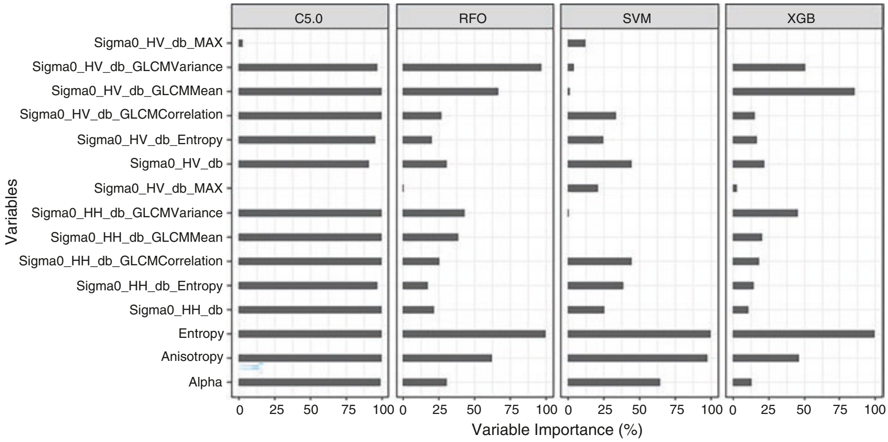

Fig. 9.5 Variable importance of four algorithms, C5.0, Random Forest (RFO), Support Vector Machine (SVM), and Extreme Gradient Boosting Tree (XGB)

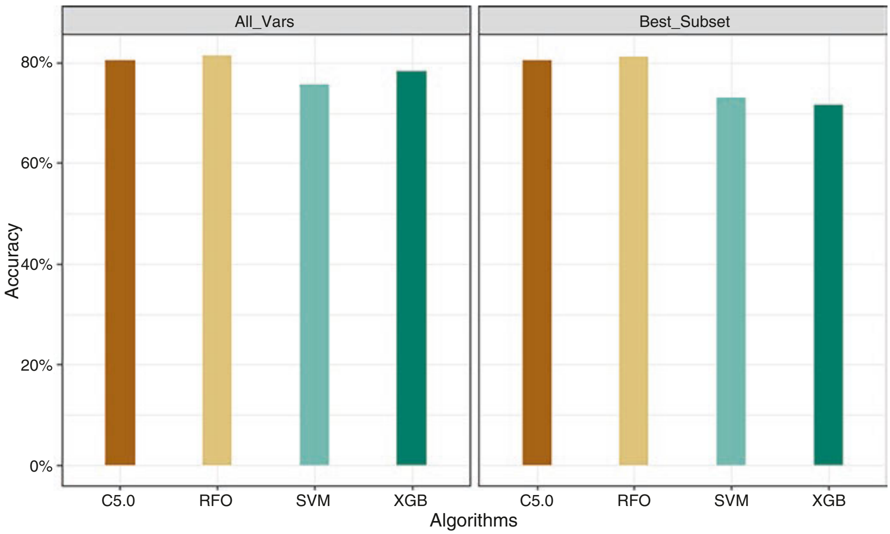

Fig. 9.6 Comparing Accuracies resulting from Best Subset and All Employed Variables by using Four Algorithms

3.2 Comparing Accuracy of All Variables and the Best Subset

The very last step to get the best combination of datasets and algorithms for mapping the research site was by examining the accuracy of all employed features compared to the best subset in which the selection was guided by variable importance. Figure 9.6 describes the comparison between those two datasets. In general, C5.0

and RFO produced somewhat higher accuracies with less variables, whereas more variables might generate a better accuracy for SVM and XGB. It implies that variable selection was essential when employing RFO and C5.0. Meanwhile, the accuracy of SVM and XGB may be improved by inserting additional features.

Tables 9.1 and 9.2 present the confusion matrix from the two highest accuracies derived from RFO and C5.0, respectively. The overall accuracy of RFO was 81.8%, the highest compared to other algorithms. From the user accuracy, it was shown that the best separation was for the water body at 99.7%. Woody vegetation and bare soil were the next land cover types relatively well-separated with accuracies at 92.1% and 87.5%, respectively. The two weakest objects within the context of class separability were mungbean (66%.2%) and peanut (69.8%).

Table 9.2 shows the overall accuracy of C5.0 at 80.4%. Generally, the pattern of accuracies for all land covers was similar to RFO result. Again, according to user accuracies, the best separated land cover was waterbody at 100%, while the two least accuracies were for peanut and pasture at 61.9% and 68.1%, respectively**.**

3.3 Map of the Best Algorithms

From the previous evaluation, we generated two best maps derived from random forest and C5.0. The spatial distribution of classes is presented in Fig. 9.7. In general, two maps depicted similar spatial distribution. Pasture predominates the extent, followed by woody vegetation. The classifiers accurately identified natural parks that were dominated by woody vegetation at the top right and top left of the figure.

Table 9.1 The accuracy of classification generated by the best subset employing random forest

Prediction	Reference							User accuracy
	Bare soil	Corn	Mungbean	Pasture	Peanut	Water	Woody vegetation	
Bare soil	1516	29	46	104	36	0	1	0.875
Corn	28	865	84	65	6	0	34	0.799
Mungbean	41	32	775	104	131	0	87	0.662
Pasture	64	14	58	440	31	0	5	0.719
Peanut	20	3	51	32	367	0	53	0.698
Water	1	0	0	0	0	387	0	0.997
Woody vegetation	2	7	52	3	55	0	1394	0.921
Producer accuracy	0.907	0.911	0.727	0.588	0.586	1.000	0.886	
Overall accuracy								0.818

Table 9.2 The accuracy of classification generated by the best subset employing C5.0

Prediction	Reference							User accuracy
	Bare soil	Corn	Mungbean	Pasture	Peanut	Water	Woody vegetation	
Bare soil	1517	25	50	121	31	0	4	0.868
Corn	35	875	98	63	7	0	33	0.788
Mungbean	36	16	658	92	96	0	57	0.689
Pasture	59	13	82	419	36	0	6	0.681
Peanut	24	7	96	42	391	0	72	0.619
Water	0	0	0	0	0	387	0	1.000
Woody vegetation	1	14	82	11	65	0	1402	0.890
Producer accuracy	0.907	0.921	0.617	0.560	0.625	1.000	0.891	
Overall accuracy								0.804

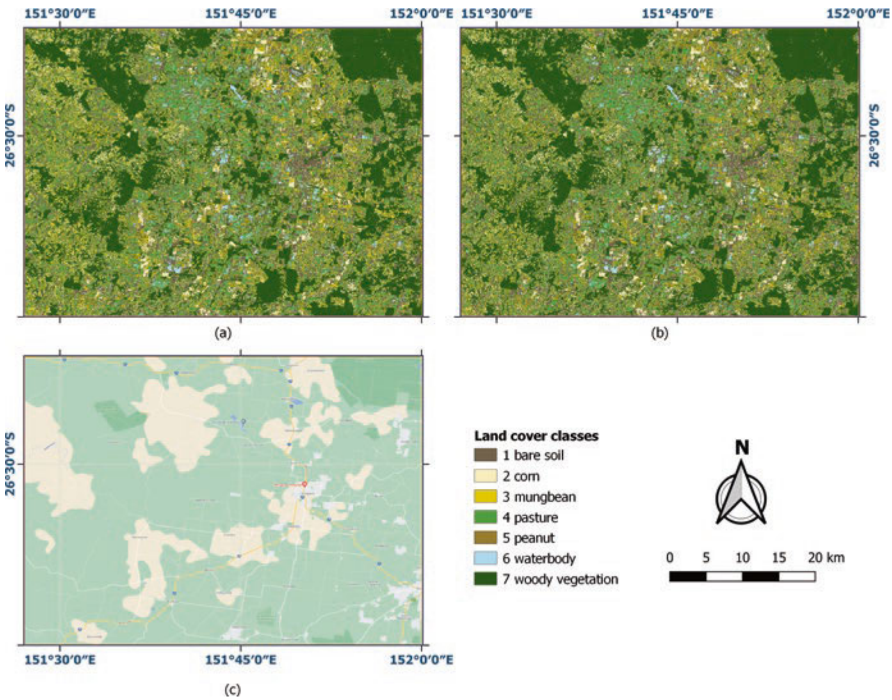

Fig. 9.7 The maps derived from (**a**) Best Subset of Random Forest, (**b**) Best Subset of C5.0, and (**c**) The Google Maps

4 Discussion

As eradicating hunger is the second goal set by the United Nations-Sustainable Development Goals (UN-SDG), all related measures related to food production and distribution need to prepare technologies to accomplish the SDG. Mapping crop has widely been explored, the area that remote sensing communities signify their contribution onto data and information provision for managing food production. This research explored and assessed nominated machine learning algorithms for mapping various crops while improving performance of SAR data by features amendment.

This research demonstrated that limited input layers were a key drawback in utilizing SAR data for agricultural crop mapping. Ingesting synthetic data layers onto dual polarimetric ALOS PALSAR was proven effective in improving the accuracy of crop mapping with spatial resolution at 10 meter. The result was parallel with previous experiments in land cover mapping (Ngo et al. 2020; Panuju et al. 2019). However, a 10% reduction of accuracy was noticed in comparison with coarser spatial resolution (PROBA at 100m) used in an earlier experiment (Haerani et al. 2018a). Interestingly, additional features may not always improve the overall accuracy, particularly for random forest and C5.0. This may relate to challenges when implementing feature fusion employing machine learners, such as data correlation, inconsistency, and confliction (Meng et al. 2020). Redundant information indicated by correlation is often unwanted in statistical analysis, since it may reduce the goodness of fit of a model (Whitley et al. 2000). Meanwhile, less consistent and conflicting information may complicate the decision, which in turn may diminish the overall accuracy. The experiment showed that additional features with contribution less than 20% may even reduce the accuracy of classification on specific classifiers, particularly the RFO. The C5.0 model resulted in the same accuracy for the best model and all variables. Support vector machine and extreme gradient boosting tree handled amendment quite efficiently, although the contribution of added features was less than 20%. The accuracy of the best subset and all variables depicted the small increase between two datasets.

Variable importance (VI) has been an effective measure to assist in the selection of features that contribute to the result in the classes. RFO, SVM, and XGB algorithms in R have been equipped with the VI to indicate each contribution of ingested features in differentiating classes. C5.0 could not differentiate the contribution like the others. It tended to only suggest that a variable was either having or not having a share to the classification problem. The performance of algorithms themselves may be improved by other strategies like tuning parameters. The discussion can be found in Trisasongko et al. (2017).

The result offers an insight regarding classifiers' performance on feature fusion such as the response towards data amendment and efficient contribution for differing classifiers. The responses of four machine learners on features ingestion need further exploration, especially on the reaction of potential learners on various datasets or environmental settings. By and large, variable importance seems an effective measure for selecting variables in order to obtain the best accuracy for machine learning algorithms.

With the upcoming hybrid polarization data from several SAR missions like Indian RISAT-1 satellite (Kumar et al. 2017) and Canadian Radarsat Constellation Mission (RCM) (Touzi and Côté 2019), supports to agricultural mapping are expected even greater. Hybrid polarization allows in-depth characterization of surface objects through polarimetric decomposition (Raney et al. 2012); hence, the dataset may be an option for future investigation. An initial result of this effort was presented (Trisasongko 2019), suggesting that the acquisition mode has a potential for agricultural applications in cloud-prone areas. In addition, taking benefits of dual-frequency antennas, a joint US and India mission (NISAR, NASA/ISRO Synthetic Aperture Radar), (Rosen and Kumar 2019) would also be an excellent opportunity to develop a better monitoring system for agriculture.

5 Conclusion

We explored the use of phase-preserved, dual polarimetric ALOS PALSAR-2 and the response of Cloude decomposition and texture layers for crop mapping. This research investigated four contemporary machine learners, i.e., C5.0, extreme gradient boosting tree, random forest, and support vector machine, and observed varying overall accuracy using all and the best subset of datasets guided by variable importance.

The research found that random forest outperformed other classifiers and generated the overall accuracy of crop map at 82%, followed by C5.0 at 81%. Coupling dual polarimetric decomposition features onto dual polarimetric data may not always produce a better classification accuracy. This study indicated that random forest generated the best accuracy at selected variables based on variable importance, while other variables either remained constant or slightly increased with each added feature. This research suggests that analysis employing RF should consider VI as a tool to optimize the outcome.

The amendment of SAR data with other feature extraction or with optical sensors and its derivatives coupled with the employment of various machine learners should be explored in the future to assist agricultural monitoring. In addition, further exploration should also investigate the potentials of hybrid polarization and the upcoming dual-frequency SAR.

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Chapter 10
Crop Assessment and Decision Support Information Products Using Multi-sensor and Multi-temporal Moderate Resolution Satellite Data

Swati Katiyar

Abstract The current study is focused on the crop inventory and crop assessment of agricultural fields of Madhya Pradesh state, with Taluk as a spatial unit using decision support information product because it gives precise information about the condition of crop in any area in terms of health or stress condition and biodiversity analysis and helps in monitoring crop management activities such as rehabilitation and abiotic factors like temperature and rainfall. The aim of this research is to improve methods for quantifying and verifying inventory-based carbon pool estimates for the tropical dry deciduous forests. In future, other methods and techniques will be found out to perform the analysis. The current study uses the satellite remote sensing data of LANDSAT-8 and RESOURCESAT-2 to generate the objective and study about Rabi season (November-December to April- May) in the year 2015–16. The study deals with crop yield estimation, spatial distribution, crop assessment, crop inventory, and developing decision support information product in the districts of Madhya Pradesh, i.e., Hoshangabad. Crop yield estimation and crop assessment of these districts are studied at the village as well as taluk level. The major Rabi season crops under study are wheat, jowar, and mustard. Spectral response-based model identifies different crop conditions of sensitive areas.

Keywords Crop inventory · Crop assessment · NDVI · LANDSAT-8 · RESOURCESAT-2

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1 Introduction

India is an agriculture-dependent country and one of the principal wheat producing and consuming countries in the world. Almost two-third of the employed class in India are surviving upon agriculture as their means. Agriculture, one of the oldest economic practices, plays a vital role in the context of Indian society. Remote sensing data can also be used for the estimation of crop area. Remote sensing techniques have demonstrated their potential in providing information on the character and distribution of various natural resources. Possible application areas related to agriculture are management of land and water resources, crop acreage and production forecasting, and crop condition. Agriculture is the backbone of the Indian economy, contributing about 40% towards the Gross National Product (GNP). So, for a primarily agriculture-based country like India, reliable, accurate, and timely information on types of crops grown and their production is important (Sukhatme and Pause 1951; Singh et al. 1992, 1993). Crop monocultures vary from place to place in India. Using single-date imagery, it's very difficult to generate the spectral response and calculate the statistics. With the invention of remote sensing technologies in the 1970s, the study, keeping an eye on agricultural practices and improvement in global agricultural monitoring system, has gone a step ahead. Studying the seasonal crop variability, *i.e.,* crop yield, crop acreage estimation, and crop growth, became an easy task. As per the data of Ministry of agriculture, the total coverage of area under Rabi crops as of February 13, 2015 is 615.74 lakh hectares (Singh et al. 2000; Ayyangar et al. 1980a, b). Wheat's sowing area is 306.35 lakh hectares and the Gram sowing area is 85.91 lakh ha, while the last year's digits were 102.25 lakh ha. Monitoring and management of these crops would greatly help in ensuring food and nutritional security of the country. The following papers have been reviewed during this research.

The agricultural crop production of principal agricultural crops in the country is usually estimated as a product of the area under the crop. The estimates of the crop acreage at a district level are obtained through complete enumeration, whereas the average yield is obtained on the basis of crop cutting experiments conducted on a number of randomly selected fields in a sample of villages in the district (Tyagi et al. 2000; Mendelsohn et al. 1994; Deschenes and Greenstone 2007). Agriculture, one of the oldest economic practices, plays a vital role in the context of Indian society. Therefore, there exists a need for timely and reliable information on crop statistics generation. Crop area estimation is the foremost requirement in any crop monitoring program (Sakamoto 2009; Fuhrer 2003; Bausch 1993; Benefetti and Rossini 1993; Deering and Haas 1980; Dejong 1994; Dymond et al. 1992).

Verma et al. (2011) used remote sensing techniques in crop acreage assessment. In the study, crop acreages were estimated using particular seasonal imageries from satellite. For crop acreage estimation at district level, stratified random sampling and supervised classification of the data is the approach that is used. Ground-based observations were collected in prospect with satellite data and various crops and other vegetation were identified and their respective spectral signatures were drawn.

The sample segments were classified using these spectral signatures and crop acreages in the district are estimated using standard statistical aggregation procedures. Esfandiary et al.'s (2009) This chapter was based on the study of multi-date medium resolution AWiFS data and explained the methodology as well as results obtained on national level wheat production in India during forecasting. The radiometrically and geometrically corrected multi-date Resourcesat-1 AWiFS data were classified using decision-based rules, which generated the various spectral profiles of winter season crops. Wheat acreage estimation was done by the aggregation of strata in stratified random sampling and wheat yields were predicted as well for meteorological subdivisions using fortnightly temperature by correlating it with weighted weather regression model. Production forecast and preharvest acreage estimation of wheat were made with the crop growth performance and analysis of previous and normal season study. Meng et al. (2007) explained that crop damage assessment can provide decision-making information for the working out of agricultural policy and financial aid to the affected farmers. Remote sensing helps in the detection of crop growth and effect if they are affected by too dry or wet climate, affected by insects, any fungal infestation or weed, or any other weather-related damage. Pre and post-dates' qualitative assessment of satellite images was done in the study of crops if they are affected by hail storm, unseasonal heavy rainfall, or any untimely weather conditions. The images of crop damage generated using multi-date satellite imageries, against the damage report generated by concerned authority, are used to study the severity and extent of crop damage. Rembold and Maselli (2006) integrated remote sensing-derived parameters in local crop simulation model (Rotask) to forecast yield of wheat at regional level in southeast France. The acreage estimation statistics calculation includes finding representative sites of various crops and land-cover features on image with respect to their ground truthing data and generation of spectral signatures for different classes and classification of image. Oza et al. (1996) explained that from the last two decades, numerous methods involving remote sensing data were developed for crop assessment and condition monitoring, varying from countries and the effectiveness in the results of crop growth and monitoring conditions are improved greatly as well. Among these methods, some are direct monitoring method with remote sensing indices; in this, on the bases of the values of NDVI and LAI indices, we monitor crop condition and estimated that the higher the indices the better is crop condition. Image classification method, on which we first do the supervised or unsupervised classification and then with the observed data of growing status of seedling having some spatial and temporal attributes, certain growth labels are assigned to each category. By same-period comparing method, we compare the remote sensed data of crop growing status of certain period with the data of the same period in the past (mostly for consecutive year study is done). Difference and ratio indices are most commonly used in this method.

Jianping (2002) described that the filed reports of regional crop growth status estimation are often quite expensive to study and prone to a large number of errors and cannot provide real-time update as well. Remote sensing satellite system provides continuous global data cover. Along with the advancements in the remote sensing field and application, temporal satellite data become the most important data source to monitor crops. USDA of U.S. and VI of EU, as well as FAO, all are working upon their own remote sensing-based crop monitoring system. Agarwal et al. (2001) used MODIS EVI multi-temporal imagery for major winter Australian crops and to determine broadacre crop area. Multi-temporal approaches use Harmonic analysis of time series data (HANTS); principal component analysis (PCA), multi-date MODIS EVI (MEVI), and two curve fitting procedures (CF1,CF2) are the functions that are derived and applied. These results of these approaches were validated against the traditional single-date approach. The crop area estimation of early season was derived through development and application of a metric, that is at different periods before flowering collecting consecutive 16 day EVI values which are greater than or equal to 500. Czaplewski and Catts (1992) stated the condition of the crop is affected by factors such as availability of water and nutrients, pest attack, disease outbreak, and weather conditions. Monitoring crop condition with remote sensing can get the condition of crop seedling as well as the status of their growth in that duration. By this, we can also get an idea about crop production. Having the database of crop condition at early age is more fruitful then acquiring information at the harvest time about exact production; especially on large scale, statistics are considered.

1.1 Significance of Wheat in Indian Economy

World economy's role in wheat production is significant both in terms of cultivated land and food supply, feeding, and commerce. Around 80% of the area under wheat is irrigated. The total production of wheat in India is about 70 million tons. From a global view, the wheat area in India accounts to 11% of the total area under wheat cultivation across the globe and about 12% of the global wheat production (Sinclair and Seligman 1996). At present, India is the second largest producer of wheat in the world. Nationally, about 18% of the net cropped area is planted to wheat. Uttar Pradesh holds the position of having the largest share in wheat production counting 36% of production, followed by Punjab with 19% and Haryana with 11%. These three northern states together contribute two thirds of the production of wheat. (Rossini and Benedetti 1993; Delecolle et al. 1992).

1.2 Crop Inventory

The discrimination of crops and identification as per remote sensing concepts are based on the terms like having unique spectral signatures and growing period. Different crops have different spectral signatures which is the main basis of crop discrimination, and they are influenced by specification of sensor characteristic and pattern recognition technique as well. The crop inventory procedure includes identifying the representative site of various land cover feature/crop classes in the image and then validating it with ground truth collected data. Results of the study showed that crop identification and discrimination cannot be done with single-date data as the crop has different growing stages. Within this context, classification of multi-date data gives identifiable results with added phenologic information (Murthy et al. 1998, 2003; Gregory 2002). The acreage estimation procedure includes identifying the representative site of various land cover feature/crop classes in the image and then validating it with ground truth collected data.

1.3 Crop Forecasting and Acreage Estimation

One of the earliest applications of remote sensing for crop acreage has been reported in LACJE and AGRISTARS experiments conducted in the US using land sat data. The first systematic attempt in India directed towards crop inventory through remote sensing technique was carried out under a joint ISRO-ICAR experimental project named Agricultural Resources Inventory and Survey Experiment (ARISE) during 1974–75. Satellite data for crop acreage and crop production estimates for various major crops in the country have been made under the crop Acreage and Production Estimation (CAPE) project (Deschenes and Greenstone 2007). Under this approach, representative training sites of known class are selected. Using appropriate classification algorithm, each unknown pixel is assigned to any one of the number of classes. Crop acreage is a prominent factor in determining crop production. Crop production forecasts and monitoring is done so that food demand and supply should meet the needs of population and we can balance social security in society as well. During the period of food shortage or surplus, the outcome shows that crop acreage estimation is not done properly; hence, monitoring and estimating crop acreage is a long-term process with long-term study and efforts. Crop acreage estimation is a hierarchical step-by-step process that involves developing a crop inventory-based mathematical model and differentiating different crops as different classes and calculating the yield and crop area (Dadhwal et al. 2002).

The current study uses the satellite remote sensing data of LANDAST 8 OLI and Resourcesat-2 to generate the objective and study about Rabi season (November-December to April- May) in the year of 2015–16. The study deals with crop yield estimation, spatial distribution of wheat area, integrated NDVI, season maximum NDVI, crop assessment, crop inventory, and developing decision support information product in Hoshangabad district of Madhya Pradesh. Crop yield estimation and crop assessment of these districts are studied at village as well as taluk level. The major Rabi season crop taken under study is wheat. The study analyzed the multi-temporal images of LANDAST 8 OLI and Resourcesat-2 LISS III, LISS IV for classifying different crops in the selected districts in the year of 2015–16 and to carry out spatial analysis of crop yield within the district in relation to the yield affecting indicators and generate the information products on crop performance.

2 Location of Study Area

Hoshangabad is a municipality in Hoshangabad district in the Indian state of Madhya Pradesh. It is located on the south bank of the Narmada River and is the administrative center of Hoshangabad District. Hoshangabad district lies in the central Narmada Valley and on the northern fringe of the Satpura Plateau. Hoshangabad, located at 22° 46″ N and 77° 44″ E, is picturesquely placed along the southern bank of Narmada River, while north of the river stretch to the Vindhyan hills (Fig. 10.1). Madhya Pradesh has a good air connection with the other states. The major airports are Bhopal, Gwalior, Jabalpur, and Indore. For train route, the major stations of the

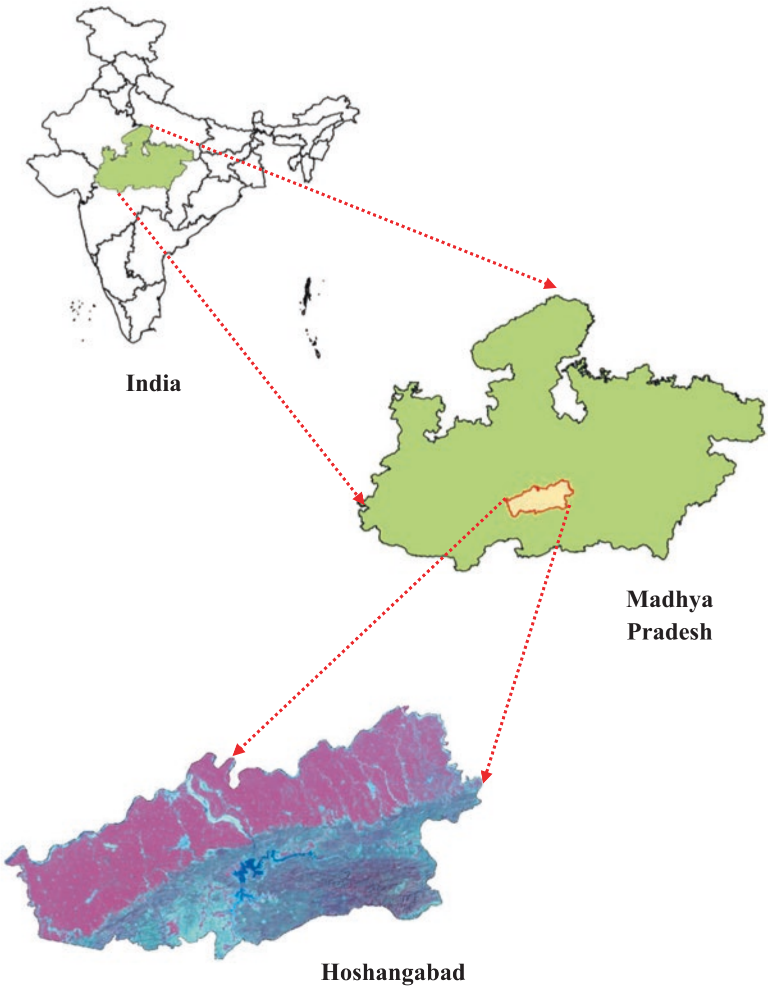

Fig. 10.1 Location of study area

state are: Jabalpur junction; Bhopal junction for west central railways; Ratlam junction for western railways; and Gwalior and Jhansi for North central railways. Maharashtra has Chhatrapati Shivaji international airport for reaching Mumbai. And many domestic airports are: Santa Cruz domestic airport, Nagpur, Pune, Kolhapur, and Aurangabad from where flights circulate on daily basis.

3 Material and Methodology

The current study uses the satellite remote sensing data of LANDAST8 (OLI) and Resourcesat 2 (LISS-III, LISS IV and AWiFS) to generate the objective and study about Rabi season (November-December to April-May) in the year 2015–16. The study deals with crop yield estimation, spatial distribution, crop assessment, crop inventory and developing decision support information product in the districts of Hoshangabad, Madhya Pradesh. Crop yield estimation and crop assessment of these districts are studied at the village as well as taluk level. The major rabi season crop taken under study is wheat.

3.1 Data Used

3.1.1 Remote Sensing Data

The aim of the study is to extract the maximum possible information about the crop growing year. The multi-temporal satellite data used for cropping system mapping were from Resourcesat-2 and LANDAST 8 Sensors. LANDAST 8 sensor has the capability of providing data at 16-day interval and the spatial resolution of LANDAST 8 is 30 m, whereas AWiFS provides the data at every 5-day interval with spatial resolution of 56m.

3.2 Indices Generation

3.2.1 Normalized Difference Vegetation Index (NDVI)

Spectral response characteristics of healthy vegetation can easily be characterized in different parts of the electromagnetic spectrum. NDVI is most widely used for operational crop assessment because of its simplicity in calculation, easiness in interpretation, and also its ability to partially compensate for the effects of atmosphere, illumination geometry, etc. The Normalized Difference Vegetation Index (NDVI) is expressed as shown in the following equation

$$NDVI = \frac{NIR_{ref} - R_{ref}}{NIR_{ref} + R_{ref}}$$

where:

NIR_{ref} = Near-Infrared band = Band5 in L8 = Band4 in R-2 LISS-III
R_{ref} = Red band= Band4 in L8= Band3 in R-2 LISS-III

The NDVI values for vegetation generally range from 0.1 to 0.6, the higher index values being associated with greater green leaf area and biomass.

3.2.2 Normalized Difference Water Index (NDWI)

The Normalized Difference Water Index employs the near-infrared band and a band in the short-wave infrared (SWIR) (Gao 1996). Instead of using the red band, the reflectance at which is affected by chlorophyll, a short-wave infrared band in the region between 1500 and 1750 nm is used, a region where water has high absorption. The near-infrared band is the same as with NDVI, as water does not absorb in this region of the electromagnetic spectrum. The NDWI index is expressed with the following equation:

$$NDWI = \frac{NIR_{ref} - SWIR1_{ref}}{NIR_{ref} + SWIR1_{ref}}$$

where:

NIR_{ref}= Near-Infrared band = Band5 in
$SWIR1_{ref}$ = Short-Wave Infrared band 1 = Band 6 in L8

There is only one SWIR band in R-2 LISS-III, i.e., Band 5

3.2.3 Land Surface Water Index (LSWI)

Short-wave Infrared (SWIR) band is sensitive to moisture available in soil as well as in crop canopy. In the beginning of the cropping season, soil background is dominant, hence SWIR is sensitive to soil moisture in the top 1–2 cm. As the crop progresses, SWIR becomes sensitive to leaf moisture content. SWIR band provides only surface wetness information. When the crop is grown up, SWIR response is only from canopy and not from the underlying soil. The LSWI index is expressed with the following equation:

$$LSWI = \frac{NIR_{ref} - SWIR2_{ref}}{NIR_{ref} + SWIR2_{ref}}$$

where:

NIR_{ref}= Near Infra Red band = Band5 in L8
S$SWIR2_{ref}$ = Short-Wave Infrared band 2= Band7 in L8

Higher values of LSWI signify more surface wetness.

3.3 *Crop Classification*

3.3.1 Supervised Classification:

Crop classification in our study is done using LANDAST 30m data. In order to perform crop classification, we need to perform crop inventory and extract the crop pixels. Vegetation from False Color Composite images is compared with its corresponding NDVI pattern to develop decision rules. By applying these decision rules on NDVI images in the ERDAS Imagines' Model Maker tool, we extract the crop pixels. Thus, different dominating crops in the study area for 2015–16 Rabi seasons are extracted and crop classification is done to estimate acreages (Figs. 10.2 and 10.3).

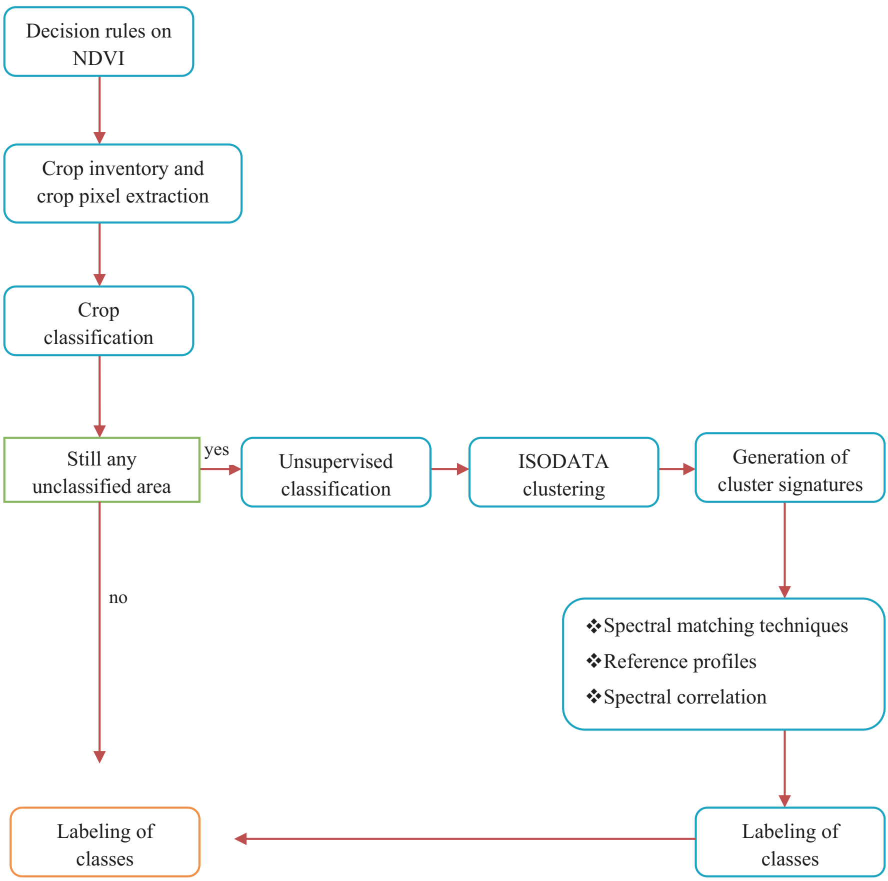

Fig. 10.2 Methodology for crop classification

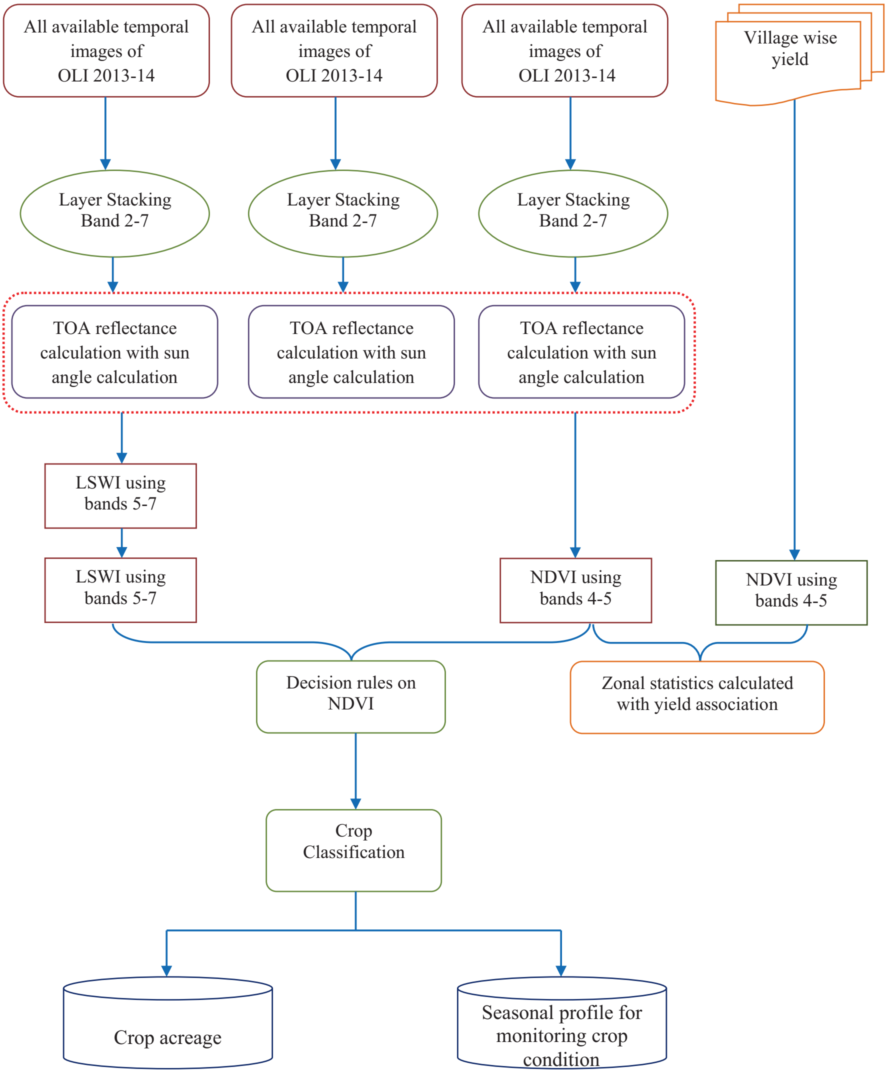

Fig. 10.3 Seasonal profile for monitoring crop and crop acreage

3.3.2 Unsupervised Classification:

Unsupervised classification is based on Iterative Self-Organizing Data Analysis Technique (ISODATA) clustering method. It is an iterative method. Unsupervised classification is done from stacked NDVI image with 36 number of classes. The number of clustering is based on the number of classes. The more number of classes assure homogeneity of pixels in the class and help in post-classification stage to interpret the features more visually in feature space image. The temporal profiles of each class are derived from the NDVI time-series data of a class. Single-date imagery cannot provide a temporal profile of a class, so it is advantageous to have time-series imagery.

3.4 Spectral Matching Techniques (SMTs)

Spectral matching techniques match the class spectra derived from classification with an ideal spectra-derived LANDAST 30m. Time series data, such as the monthly OLI NDVI data, are similar to hyperspectral data. These similarities imply that the spectral matching techniques (SMTs), applied for hyperspectral image analysis, also have potential for application in identifying agricultural land use classes from historical time series satellite imagery. The qualitative Spectral Matching Techniques can be used to identify and label Historical Time Series (HTS) LULC classes. The identification and labeling process begins with qualitative spectral matching technique which visually matches the time series NDVI spectra of known Recent Time Series-LULC classes and/or ideal end member classes with time series spectra of HTS-LULC classes. This helps identify classes of similar spectral characteristics in terms of shape and magnitude over time. This study is aimed at evaluating the possibility of remotely sensed data to estimate crop acreage, monitor crop condition, and assess crop damage. Combination of digital image processing and classification techniques, namely, unsupervised classification, extraction of crop by ISODATA clustering, acreage estimation, and study of NDVI and LSWI timeseries profiles for crop condition monitoring, is performed in this study.

4 Results and Discussion

4.1 Wheat Mapping with Finer Resolution

LISS IV data, which are in 6m spatial resolution, were used to map the wheat crop in rabi 2015–16 season. The district is covered by two paths of LISS IV with one scene in each path. One data sent in November, i.e., in the beginning of the season, and the other in Feb/March were procured as shown in Fig 10.4. Decision rules for classification are shown in Table 10.1. Considering the time difference between the two paths and crop stage differences, the decision rules are slightly changed in path 2.

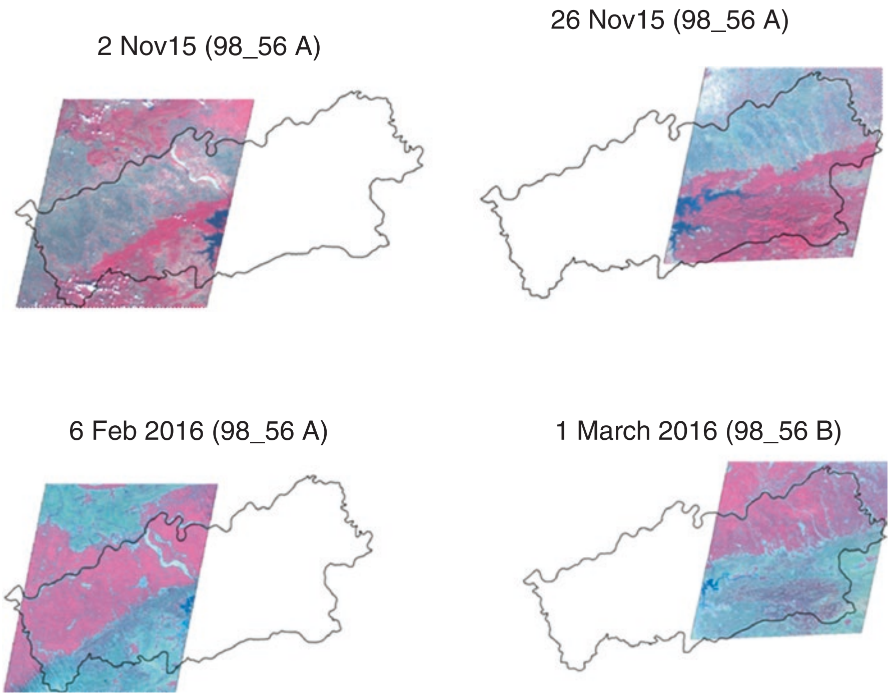

Fig. 10.4 RESOURCESAT 2 LISSIV 2015–16

Table 10.1 Decision rules for classification

	DATE	NDVI
Path 1	02 November 2015	<=0.2
	06 February 2016	>=0.55
Path 2	26 November 2015	<=0.25
	01 March2016	>=0.5

4.2 Wheat Crop Distribution Among the Villages

Value addition is made to the wheat maps of the three years by generating the maps of wheat crop distribution among the villages of the district in all three years, as shown in Fig. 10.6. These maps indicate the villages where the wheat cultivation is intense and the villages with very less wheat area. These maps are useful planning related to canal water management. These maps also are extensively used in crop insurance and crop damage assessment-related tasks.

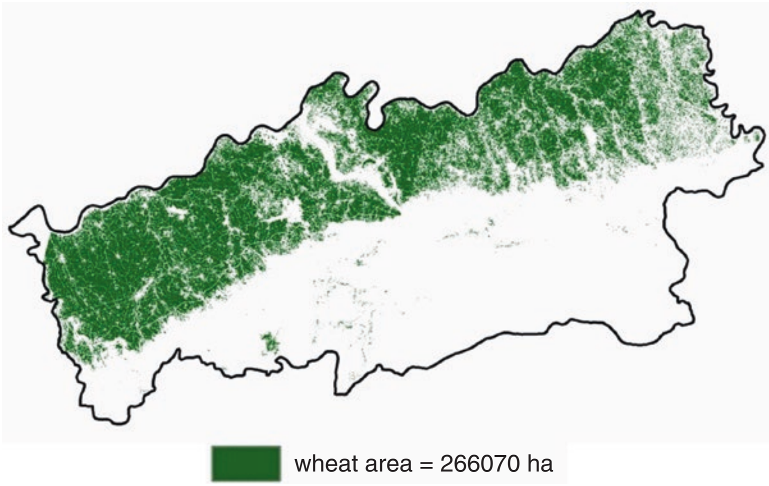

Fig. 10.5 LISS IV-based wheat crop area delineation, Rabi 2015–16

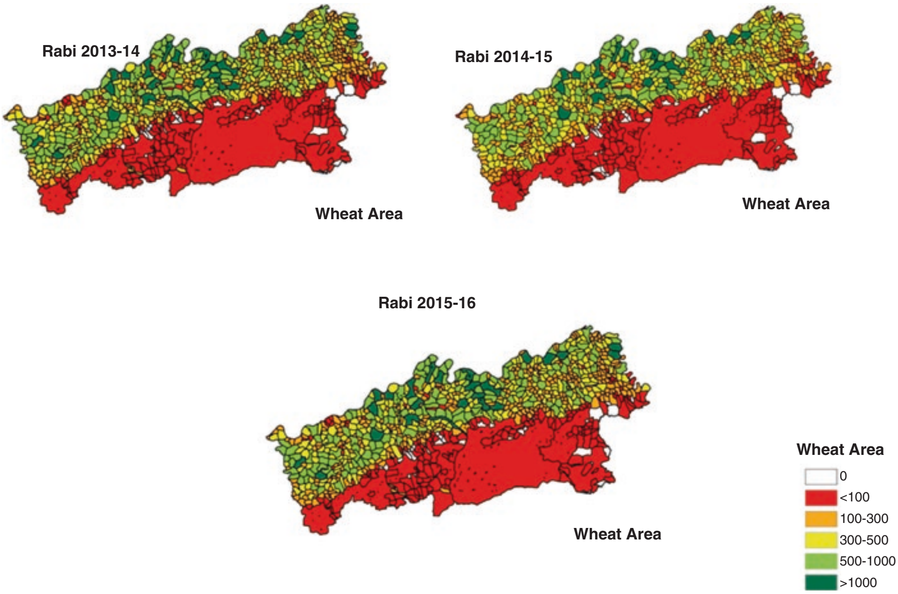

Fig. 10.6 Wheat crop distribution among the villages

4.3 Mapping Early Sown and Normal Sown Wheat Area

Wheat crop mapping during the season has many uses - related to crop management, water management, food security, etc. Detection of spatial differences in the phenology brings value addition to any crop map. Such information – early sown crop, normal, and late sown crop, if available for the command area of an irrigation system, has many other added advantages like achieving equity and reliability of irrigation service, improving irrigation efficiency, etc. Spectral indices derived from satellite data have been used to map rice areas and to study rice phenology. Murthy et al. (1998) mapped the staggering in rice transplantation, using peak NDVI derived from time-series NDVI profiles of IRS LISS-1 data. Raju et al. (2008), used 5-day interval AWiFS data over the command area of an irrigation system in India and detected the staggering in rice transplantation based on time of occurrence in peak NDVI. Motohka et al. 2009, used EVI data from MODIS to detect the phonological stages of rice crop. Xiao et al. 2005, used LSWI, NDVI, and EVI for mapping rice areas, starting from 40 days after transplantation. In this study, wheat crop area classified from satellite data was further grouped into two groups – early sown wheat and normal sown wheat. LANDSAT 8 OLI data of overpass dates of November (beginning of the season), December (growing stage of crop), and February (peak vegetative phase of crop), along with NDVI and LSWI for three rabi seasons (2015–16), are presented in Fig. 10.7.

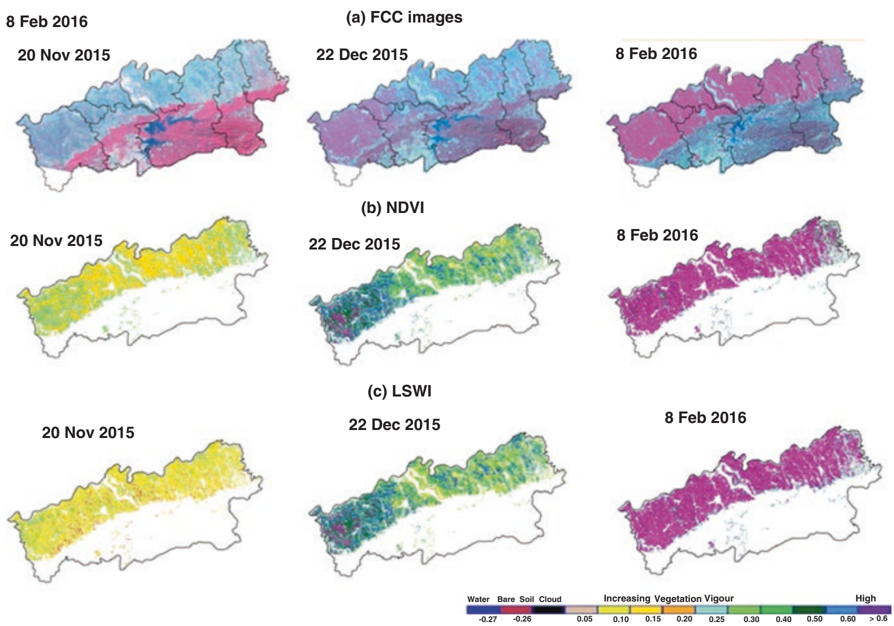

Fig. 10.7 Multi-temporal LANDSAT OLI data showing the early sown wheat crop area, Rabi 2015–16

In the FCCs of December images of all the three years, it is evident that south-western part of the district shows higher vegetation vigor compared to the rest of the district. NDVI and LSWI in this part of the district remain higher, indicating high crop vigor in this month. These pixels with high NDVI and LSWI in December correspond to early sown wheat crop. Interestingly, the NDVI and LSWI images of February month, in all the three years, do not show significant differences between the early sown and normal wheat crop. Seasonal NDVI profiles of six overpass dates from 06 Dec, 15 to 11 March, 2016, for the pixel locations of early sown and normal sown wheat. It is interesting to observe that on 22 Dec 2015, the two wheat groups show large differences. During February, when the crop is in maximum vegetative phase, the two groups converge due to overlapping NDVI/LSWI. Village average NDVI and LSWI values of wheat crop for the rabi 2015–16 with seven overpass dates are shown in Fig. 10.8. The spread of NDVI and LSWI in December is very high followed by convergence in February. Thus, early sown and normal wheat crop pixels are best discriminated in December images. After studying the NDVI/LSWI-based signatures, among the wheat pixels, the NDVI and LSWI thresholds representing early and normal wheat crop are arrived as given in Table 10.2.

By applying the above thresholds, wheat crop map was grouped into two classes, namely early sown and normal sown (Fig. 10.8). These maps are validated with secondary data and general crop calendar information available from various records in the districts.

4.4 Wheat Crop Condition Analysis

Spatial variability in wheat crop condition was analyzed using the metrics derived from NDVI. Use of remote sensing technology for assessing the response of agricultural crops to weather variations has been well-recognized. Satellite-derived vegetation indices, particularly NDVI, have been successfully used for monitoring crops, agricultural areas, stress detection, etc. Satellite-derived phonological metrics were used to evaluate the terrestrial ecosystems (Sakamoto 2005). Wu et al. (2008) investigated the phenology over crop lands in China, using time series NDVI data sets, and concluded that significant changes took place at the start of the growing season in the past 20 years. Time series phenological parameters over agricultural areas represent the impact of inter and intra-seasonal variations of climate. Phenological observations measure the response of vegetation to meteorological and environmental factors.

Table 10.2 NDVI and LSWI thresholds of early sown and normal sown groups among the wheat pixels

S. no	NDVI/LSWI of December	NDVI/LSWI of February
Early sown wheat	>=0.35	>=0.6
Normal sown wheat	<0.35	>=0.6

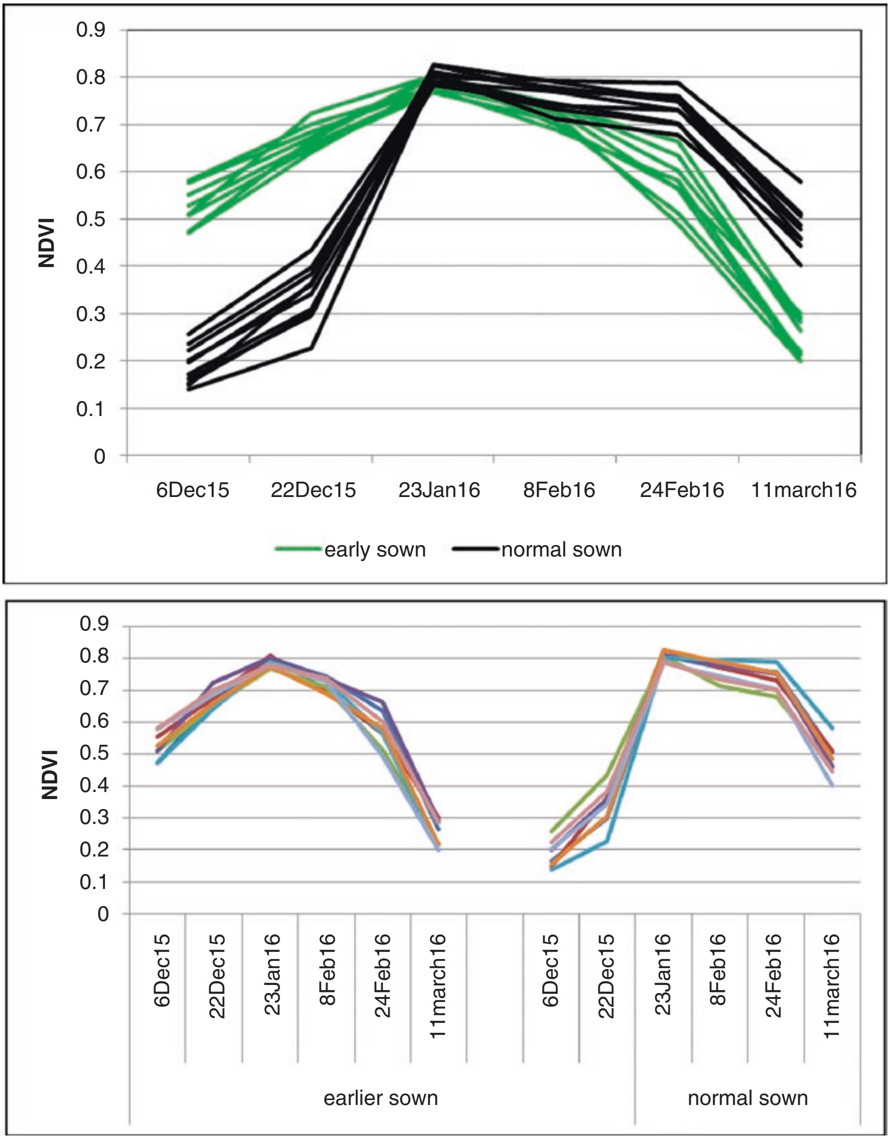

Fig. 10.8 Comparison of temporal NDVI of early sown and normal sown wheat (Rabi 2015–16)

4.5 NDVI and LSWI Profiles of Wheat Crop

Typical profiles of NDVI (chlorophyll-based indicator) and LSWI (moisture-based indicator) corresponding to wheat crop of rabi 2015–16 season are shown in Fig. 10.9, which reveal the phenology of wheat crop. The start of the season, growing phase, and peak vegetative phase with stable and high vigor followed by decreasing vigor in senescence phase are clearly seen in these profiles. The trajectories of NDVI and LSWI are almost close to each other.

Seasonal profiles of NDVI and LSWI for a randomly selected group of villages in Fig. 10.10 bring out the spatial differences in wheat phenology and crop condition, and hence, its performance in the district, which is very valuable information for various planning purposes.

Resourcesat 2 AWiFS data covering the study area, during the rabi season 2015–16, were also analyzed (Fig. 10.11) to enhance the frequency of observation. AWiFS NDVI profiles of wheat crop are shown in Fig. 10.12, which are clearly depicting the phenology of the crop. Thus, 16-day frequency 30 m OLI data and 5-day frequency 60m AWiFS data have the potential for capturing the phonological information on wheat crop.

Supplementary use of AWiFS with OLI to fill the gaps was also attempted in this study. In Rabi 2014–15, no OLI data were available in January 2015 due to cloud cover problem. AWiFS data of three passes 15 Jan, 20 Jan, and 25 Jan were composited to generate cloud-free NDVI. This NDVI is adjusted to get its OLI equivalent, through inter-sensor normalization technique described in subsequent sections. The seasonal OLI NDVI profiles of wheat crop for selected villages for the rabi season 2014–15 are shown in Fig. 10.13. In these profiles, January data are drawn from AWiFS data. Thus, the trajectory of these profiles indicates perfect supplementation of AWiFS data into the OLI temporal data.

Two metrics, namely, Season's Maximum NDVI and Season's Integrated NDVI, were derived for each year using multi-date NDVI of wheat pixels. These two metrics adequately describe the biomass and vigor of the wheat crop in the study area. These metrics act as proxies to wheat yield. Spatial distribution of these two NDVI metrics for the three rabi seasons reveals insignificant spatial differences in the condition and vigor of wheat crop. Excepting a few villages, all villages show a narrow range of variability. These maps are useful to plan for sampling strategies for measuring yield for crop insurance purposes. Murthy et al. (2007), proposed a sampling design for crop yield estimation in irrigated command areas using satellite-derived crop area and crop yield. In similar way, the wheat crop condition images could be affectively used.

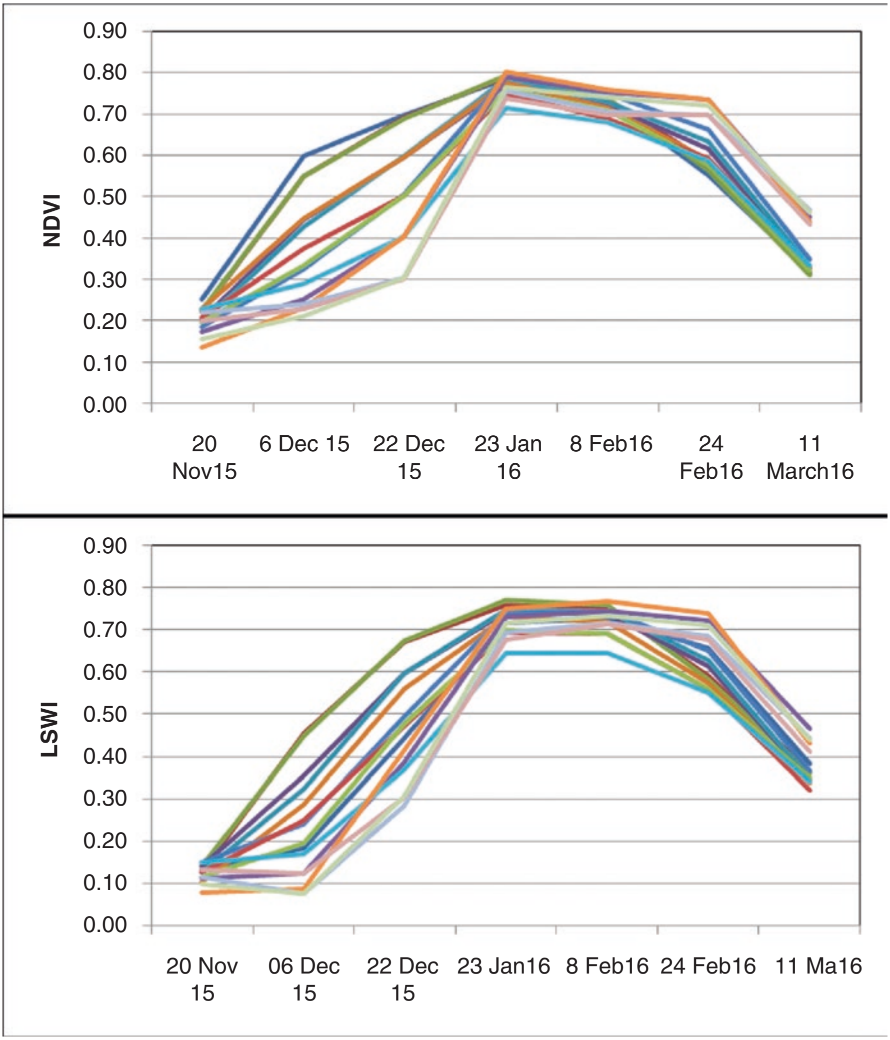

Fig. 10.9 Typical seasonal profiles of NDVI and LSWI over wheat crop

5 Conclusion

Detailed analysis of moderate resolution satellite data from multiple sensors, multiple overpass dates in a season, and multiple years was performed in this study for wheat crop mapping, wheat crop condition analysis, and wheat yield variability analysis. The study area is a prominent wheat-growing Hoshangabad district of Madhya Pradesh. Rabi seasons of three years 2015–16 are involved in the analysis. Landsat 8 OLI data have been primarily used followed by Resorcesat 2 AWiFS and LISS IV. Normalized Difference Vegetation Index (NDVI) which represents the

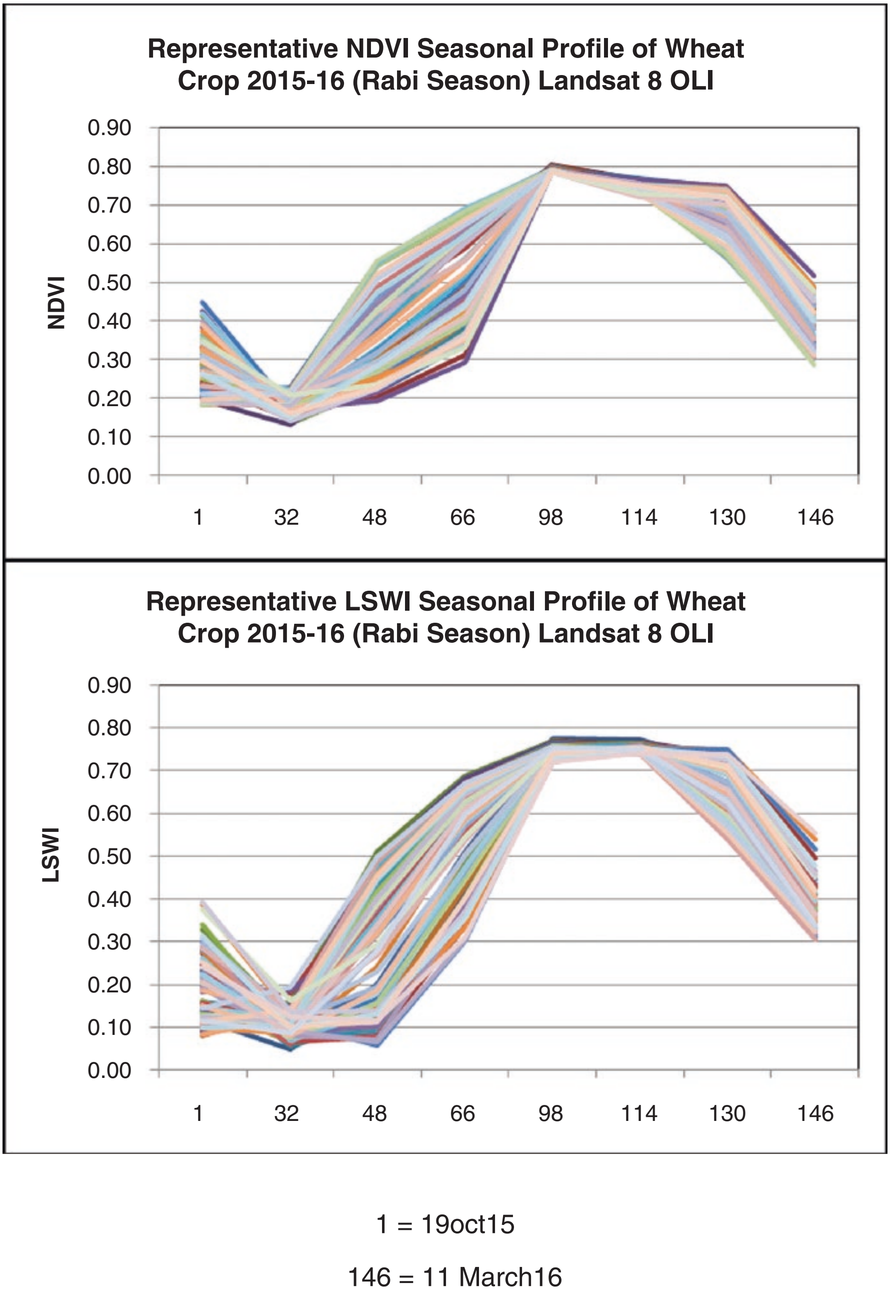

Fig. 10.10 Seasonal profiles of NDVI and LSWI of wheat in rabi 2015–16 of different villages

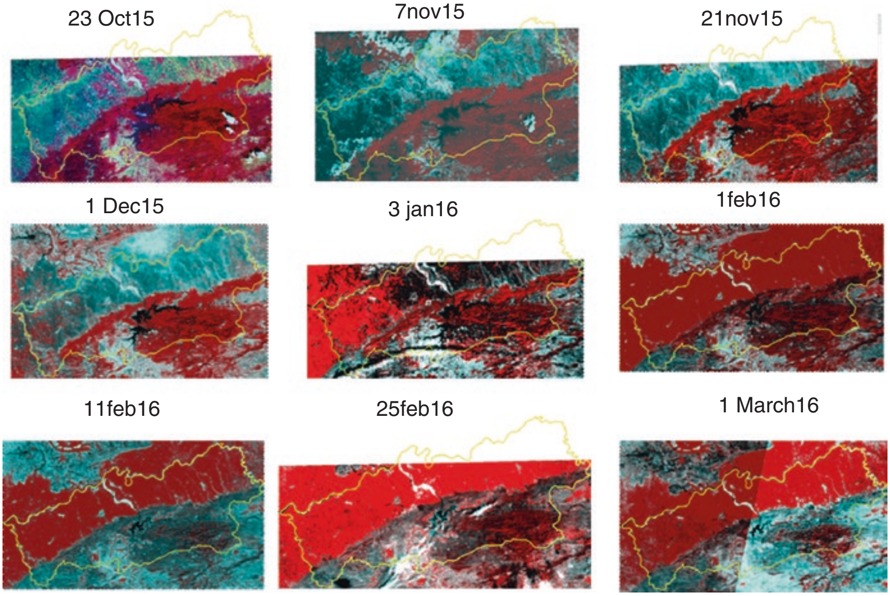

Fig. 10.11 Multi-temporal data of RESOURCESAT 2 AWiFS covering Hoshangabad district, Rabi Season 2015–16

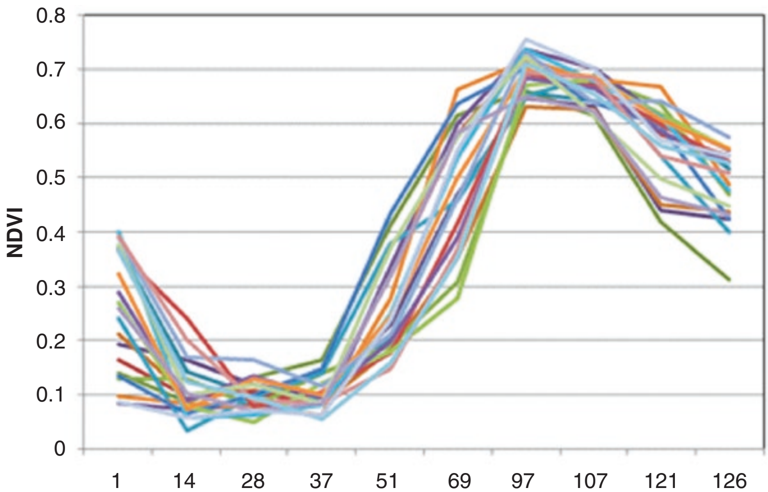

Fig. 10.12 Seasonal profiles of wheat NDVI of AWiFS for different villages, rabi 2015–16

vigor of crops and Land Surface Wetness Index (LSWI) which represents the moisture status of crops were used in the analysis. Crop classification was performed by proven techniques of decision rules analysis. The crop area estimates were validated with secondary data from the respective State departments. Crop classification

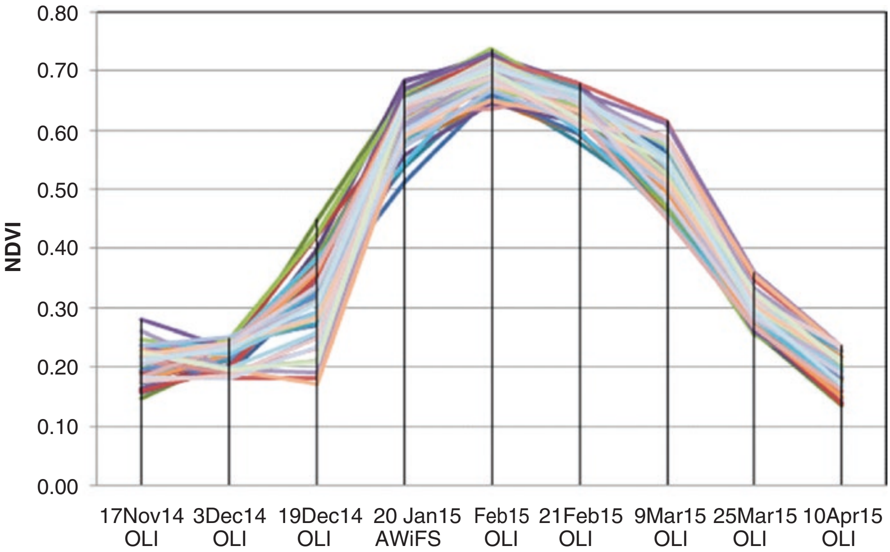

Fig. 10.13 Seasonal NDVI profiles of wheat with cloudy OLI data supplemented by AWiFS

needs more rigorous validation. Wheat mapping with 30m OLI data and 6 m LISS IV data showed consistency. There was no significant difference between the two area figures. Segregation of wheat area into early and normal sown categories was successfully done using NDVI. The study has proved that end of December NDVI better separates the early and normal sown wheat pixels than any other NDVI. During January and February months, the NDVI of these two groups of wheat tends to be overlapping, reducing the separability. Using the satellite-derived wheat maps, crop distribution analysis among the villages of the district in the three rabi seasons was carried out. With multi-temporal NDVI, early sown and normal sown wheat crop could be identified. By intersecting the wheat layers of three rabi seasons, spatio-temporal changes in wheat distribution were brought out. It was found that geographic distribution of wheat is consistent between the three years, with 80% of wheat fields located at the same place. Wheat crop condition analysis was performed with the metrics of NDVI and LSWI. Seasonal profiles of NDVI and LSWI of OLI and NDVI of AWiFS data have revealed the spatial differences in the wheat phenology. AWiFS data utilization leads to increased frequency of observation. AWiFS can also be used to fill the gaps in OLI data availability due to cloud cover problem. Using two metrics, namely, Season's Maximum NDVI/LSWI and Integrated NDVI/LSWI, spatial maps of wheat crop condition for the three rabi seasons were generated. The wheat yield of Crop Cutting Experiments (CCE) for rabi 2014–15 representing about 450 villages and 2000 plots was analyzed. Wheat yield distribution analysis revealed the yield patterns and yield gap in the district. Association between NDVI/LSWI and yield at village level and Taluk level is found to be insignificant. The variability of NDVI/LSWI among the villages/Taluks is very less, whereas the yield variability is high, thereby indicating that NDVI/LSWI alone could not capture the wheat yield variability. Analysis of detailed weather data such as temperature and irrigation water supplies data and its integration with satellite indices may explain the yield variability to a larger extent. The current study thus showcased the capabilities of routinely available LANDSAT 8 OLI images for crop mapping, crop distribution analysis, crop condition monitoring, spatial and temporal analysis within the districts, change detection with historic perspective, identification of homogenous areas with respect to crop performance, detection of hotspots, etc. All these spatial information products on wheat have direct relevance to crop management, crop insurance, and water management in irrigated command areas. These reliable information products enable more effective planning and implementation of different strategies that would strengthen agribusiness chain and bring stability and sustenance to crop farming. A statistically robust relative radiometric normalization developed in this study with large sample of observations has shown very strong correlations between the red, NIR, and NDVI of (a) OLI and LISS III and (b) OLI and AWiFS. More than 90% of R^2 values suggest that OLI and LISS III data can be used synergistically to enhance the frequency of observation. Thus, OLI and LISS III can be supplemented to increase the frequency of observation. Similarly, AWiFS NDVI can supplement the OLI NDVI and can be used to fill the gaps in OLI data. Correction for atmospheric differences in the multi-temporal data of the same sensor (OLI) was performed using regression approach with the data's pseudo-invariant features. The study has thus brought out a comprehensive analysis of multi-sensor data to generate a variety of information products on wheat crop in a district. These information products are useful for a variety of needs in crop management.

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Part IV
Livestock Production: Technology Development, Transfer and Opportunities

Chapter 11
Application of Information and Electronic Technology for Best Practice Management in Livestock Production System

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Abstract The demand of food, either plant or animal origin, is rising with the increase of human population. Due to limitation of land, water, and other natural resources, farming by manual processes may face challenges in near future. It is thus the need of the hour to find alternatives that will help to accomplish greater productivity and return in farming. Through the fourth industrial revolution, we are already in the age of digital technologies and computers and high-speed internet; tab and smart phone are now the most common modern technologies. Several advanced technologies such as computer programming, Information and Communication Technologies (ICTs), Internet of Things (IoT), Wireless Sensor Networks (WSN), cloud computing, big data analysis, Artificial Intelligence (AI), Machine Learning (ML), Drone technology, and Robotics have already transformed our everyday life with greater gains and efficiencies. These technologies have already reached real farms from research labs. The livestock farm industry is now

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the hotspot for the application of these advanced technologies to monitor farm animals in real-time basis, optimize food intake, predict diseases, and improve animal health. Digitalization has made possible shifting of agriculture from input-intensive to knowledge-intensive system. There are many digital technologies for smart and precision livestock farming. However, the question puts forward which digital technologies could presently be practiced in the management and operations of livestock farm. Of particular interest is to illustrate advanced digital technologies available for use rationally to achieve greater efficiencies in livestock farming and make livestock enterprise profitable.

Keywords Wireless sensor networks · Artificial intelligence · Machine learning · Drone technology · Smallholder farming

1 Introduction

Farming holds a vital position in national economy, since nutritious food availability is continuously rising with the increase of the world population. The demand for nutritious foods has already been increased for enhancing immunity during the pandemic situation of Covid-19. One projected data indicate that the global population will be 8.6 and 9.8 billion in 2030 and 2050, respectively, and thus the food requirement will be increased by 70 percent to keep the pace (Alexandratos and Bruinsma 2012). Besides, wherever global populations and their incomes have increased, per capita consumption of animal-origin food has also augmented. According to Alexandratos and Bruinsma (2012), the demand for livestock products is expected to increase by 62% for milk and by 77% for meat by the year 2050 as compared to 2005-07 and the global livestock production needs to be doubled by 2050 from the present levels. To meet this growing demand, it is required to produce more products from livestock.

In the world, the livestock sector is the major livelihood for one billion of the poorest population (Hurst et al. 2005). About 90% of them are found in Asia and sub-Saharan Africa. It is also the fact that about twothirds of the rural people in developing countries are smallholder farmers having agricultural lands smaller than 2 hectares (Lowder et al. 2014). In the world, the smallholder farmers represent the largest proportion of 570 million farms (Lowder et al. 2016). India is a land of smallholder farmers, constituting more than 85% of the country’s farmers (Agricultural Census 2015–16). Nearly 98% of the farmers in China, 90% of the farmers in Ethiopia and Egypt, and 50% of the farmers in Mexico are smallholders (Rapsomanikis 2015). In the world scenario, the smallholder farmers produce and supply a considerable quantity of food to the global population. However, farming by manual processes is now facing enormous challenges due to limitation of land, water, and other natural resources. Hence, it is the need of the hour to find alternatives that will help to accomplish greater productivity and return in farming.

The fourth industrial revolution has brought several advanced technologies such as ICTs, IoT, WSN, cloud computing, big data analysis, AI, ML, Drone technology, and Robotics (Ilyas and Ahmad 2020). These powerful technologies have already transformed several areas of our daily life with greater gains and efficiencies, and there is no exception in agricultural field (Wolfert et al. 2017). The application of these advanced technologies plays a crucial role in the value chain of agricultural production. Various computer-based programs have already addressed numerous issues in agricultural field, such as plant disease discovery (Mohanty et al. 2016), insect detection (Larios et al. 2008), farmland management (Adebiyi et al. 2020), and crop yield analysis (van Klompenburg et al. 2020). Currently, the application of data analytics in agriculture has helped to store, share, and analyze huge data for the generation of valued information that has made possible shifting of agriculture from input-intensive to knowledge-intensive system (Basnet and Bang 2018). The livestock farm industry is now the hotspot for the application of these advanced technologies to monitor farm animals in real-time basis, optimize food intake, predict diseases, and improve animal health. Advanced digitalization technologies for smart and precision livestock farming are surely the key solutions for a shifting from experience-driven livestock farm management practices to data-driven farming approaches to trim down the drudgery of repetitive farming jobs, optimize cost-effective contribution per animal, and justify animal welfare and environmental sustainability (Klerkx et al. 2019). Thus, the concept of precision livestock farming (PLF) has come into play in the management of livestock farm following the principles of process engineering (Wathes et al. 2008). These smart and precision technologies have enabled watching animals in real-time (Wolfert et al. 2017), optimizing food intake (Nikoloski et al. 2019), predicting diseases (VanderWaal et al. 2017), look up animal health (Fu et al. 2020), etc. The present interest is to figure out how these advanced technologies can be used rationally to achieve greater efficiencies and gains in livestock farming for the survival and profitability of the livestock enterprise. Therefore, the objective is to illustrate the scopes of application and explore the opportunities of using ICTs, IoT, WSN, big data analysis, AI, ML, Drone technology, and Robotics in livestock farming in the days to come.

2 Information and Communication Technologies

The Internet has become now an indispensable tool for communication, education, entertainment, shopping, and many other purposes. At present time, ICTs play a central role in every sphere of day-to-day life. Agricultural extension services are also progressively employing ICTs to deliver information and advice with newer approaches to the farmers and all stakeholders of agricultural activities (Baumüller 2018). It is a cost-efficient method to share information for improving smallholders' knowledge of current best agricultural practices and enhancing productivity and sustainable livelihoods (Afroz et al. 2014). ICT services enable us in broadcasting meteorological, technical, and market-oriented information to the vast farming community in a timely and cost-effective way using computers, telephones, televisions, radio, networks, mobiles, email services, SMS messages, WhatsApp messages, software tools, distance learning software tools, and video conferencing and other applications (Aker 2011; Deichmann et al. 2016; Baumüller 2018). Nowadays, access to cyberspace is not a luxury any longer, but a necessity (Warf 2019). For example, the use of different e-platforms for online training, seminar, and video conferencing could enable agricultural extension services to keep regular communication between the farmers and the experts in this crisis situation of pandemic Covid-19. The increase in internet access and the availability of user-friendly smartphones due to their affordability have resulted in fast growth of internet use that went beyond 500 million in 2019 with 40% active internet user base in rural India (ICEA 2020) and thus created huge scope for e-agriculture in developing countries like India. However, some constraints like poor literacy rate among women in developing countries and least-developed countries (UNESCO 2017), lack of infrastructure, and poor internet connectivity in rural areas in accessing ICT in developing and underdeveloped countries (Lekopanye and Meenakshi 2017) need to be addressed properly and urgently. Access to ICTs has already put forward huge opportunities to small and marginal farmers and many rural businesses by providing online training, planning, finance, and legal services as well as allowing users to contact markets and customers (Trendov et al. 2019). There are several expert systems and ICT-based self-learning modules for easy understanding and information systems worldwide.

2.1 Dissemination of Information on Livestock Farm Management

There are several web-based platforms for disseminating information on livestock farm management. DairyMAP is such a web-based dairy management analysis program for dairy herd producers to evaluate and improve the producer's herd (Chellapilla 2003). Similarly, Herdman is software for swine management platform which permits collecting data from the herd and summarizing the data into standard report and plan of actions for better farm operations (Anonymous, 2021). Different other softwares are Farmbite for livestock record keeping and management system; Ranch Manager Open for detailed livestock records; EasyKeeper for goat herd management; Farm Matters for cattle, sheep, crops, medicines, and farm management; Bovisync for dairy and beef operations; and DairyCOMP 305 for an on-farm dairy management program (Anonymous 2020a). There are several self-learning modules for livestock farmers and extension workers such as dairy cattle management system (Ravisankar et al. 2014), animal fertility management system (Ghasura et al. 2012), buffalo reproduction information system (Singh and Singh 2013), etc. GOPALA app developed by National Dairy Development Board, India, is helping the farmers in buying and selling of cattle and buffaloes, choosing proper animal feeds and fodders, guiding for diagnosis and treatment of the animals, and sending alerts for deworming, vaccination, etc., and also updating farmers about different government schemes (Anonymous, 2020b). Common Service Centre Scheme, one of the mission mode Digital India programs, helps in disseminating information, advisories, and timely solution in agriculture and allied sectors through direct contacting the Krishi Vigyan Kendra (KVK)'s experts through video calling (Anonymous 2019).

2.2 Dissemination of Livestock Health Information and Disease Surveillance

Information systems can play a vital role in risk analysis and making information to take preparedness. Livestock disease surveillance is vital for quick data analysis including risk analysis and generation of information, detection of disease or infection, monitoring disease trends, early warning, and prevention of the spread of disease or infection (Merianos 2007; Kshirsagar et al. 2013). Computer-based geographical information system (GIS) has improved animal disease surveillance through spatial data management, spatial statistical analyses, and graphical display for knowing disease incidence, prevalence, mortality, morbidity, transmission pattern of diseases, or infections on the farm, region, or national levels (Yong et al. 2006; Siddiqui et al. 2018). Internationally, the World Animal Health Information System (WAHIS) broadcasts information on the outbreak of animal diseases through its web-based e-alert system (Ben Jebara 2007). At the national level, many countries have owned Web-GIS-based information systems by which the veterinary service providers can visualize and analyze geographic distribution of diseases on the Internet and make plan for the inspections and disease control measures at farms where outbreaks occur (Colangeli et al. 2011; Di Lorenzo et al. 2019). Livestock disease surveillance and information systems can potentially forecast the risk of disease outbreaks and eradication plan of theileriosis, trypanosomiosis (Rogers 1991), East Coast fever (Lawrence 1991), avian influenza, Rift valley fever (Kshirsagar et al. 2013), and vector-borne bluetongue virus in ruminants (Legisa et al. 2014; Rizzo et al. 2021). In Australia, livestock disease surveillance and information systems provide animal disease outbreak warning, disease management, and reporting facilities at the regional, state, and national levels (Garner 2011). Some self-learning modules for livestock farmers and extension workers such as dairy animal health information system (Phand et al. 2013), goat health management information system (Roy and Tiwari 2016), etc. are important for disseminating information developed by different organizations in India. NADRES v2, an interactive and vibrant web application developed by the National Institute of Veterinary Epidemiology and Disease Informatics (NIVEDI) of Indian Council of Agricultural Research (ICAR), provides two months' prior warning and alert of disease occurrence for 13 important livestock diseases for all the 700 districts in Pan India (Suresh et al. 2019). Thus, preventive health measures such as vaccinations, deworming, and stress reduction management may be followed at right time in the right location to control the outbreak of diseases or infections.

2.3 Telemedicine Services

The application of ICT in telemedicine services ranging from telephone to internet service is now guiding healthcare professionals as well as livestock owners for the treatment and management of livestock at a distant place (Mort et al. 2003). Veterinary telemedicine services have been started in the 1980s in New York (Robertson 1999). Nwagwu and Soremi (2015) reported that livestock farmers in Nigeria used mobile phones for feed formulation and also got the right information in emergencies about animal healthcare services from a veterinarian without any time lapse. The telemedicine service may effectively be used in the developing countries, where there is still huge shortage of veterinary doctors and veterinary service in animal health care and treatment in remote areas. However, the efficacy of telemedicine in veterinary service needs to be figured out (Mars and Auer 2006).

2.4 Early Warning System for Disaster Management

The effect of weather and natural calamities on farming is enormous. ICTs can make more effective communication by providing real-time information and action-oriented timely advice to different stakeholders for taking certain preparedness and management of disaster to reduce the risk during emergency situations (Mohan and Mittal 2020). An early warning system can offer near real-time information to the governments so that emergency services can be provided to the people immediately and also give the alert to the public so that the people become aware and can take action according to preparedness (Siddhartha 2017). According to the India Meteorological Department (PTI 2021), a total of 115 people and more than 17,000 livestock were lost in India in 2020 because of consecutive 5 cyclones (i.e., Amphan, Nivar, Gati, Nisarga and Burevi). But, the causalities among human beings and the livestock would have been manyfolds if early warning wouldn't have been received well in advance with the use of ICT.

2.5 Food Safety and Traceability System

Traceability is frequently applied from food safety point of view to export markets where it is essential to track and keep record of a product in the agricultural value chain system. In the European Union, it is mandatory for cattle, sheep, and goats to have unique low-frequency ID tags (ISO 1996a; ISO 1996b). Even the meats of the carcass (Dabbene et al. 2013; Comba et al. 2013) as well as the meat cuts (Barge et al. 2013) need to have high frequency or ultra-high frequency ID tags for traceability purposes. In Southern Africa, Botswana Animal Information and Traceability System (BAITS) is available for the farmers who can register their own cattle, effect ownership transfer, submit application for movement permit, report mortality, and record arrivals and departures of all cattle (Phokoje 2016). BAITS provides security for beef export market, accurate cattle census information, correct disease management information, and easy identification of stray cattle and also furnishes a linkage between cattle ownership records and the national registration system (Ntokwane and Dibeela 2016). Agricultural and Processed Food Products Export Development Authority (APEDA), Government of India, has developed an internet-based traceability platform named as TraceNet. This platform contains a centralized database and various components or techniques of sampling, testing, certification, and packing right from the farm to the retail shelves in the supply chain. TraceNet can also expedite dissemination of guidelines to agriculture sector stakeholders for facilitating process certification of organic products which comply with the National Programme for Organic Production (NPOP) standards in India (APEDA 2013). India has as many as 24 certifying agencies accredited by APEDA (Sood 2013). The Jamaica Broilers' Group installed a computer-based inventory management system, Mobile Enterprise Mobility Solution, which allows it to use barcoding and scanning technologies to track the dressed chicken and its products in the value chain (Motorola 2008). Time has come to implement an animal traceability system by the developing countries for reliability, maintaining quality, and confirming consumer's safety of the products in the value chain market (Mwanga et al. 2020).

2.6 Enhanced Access to Market

ICTs serve a big role in the agricultural marketing system. Many web-based trading platforms like DrumNet in Kenya, Tradenet.biz in West Africa, Foodnet in East and Central Africa, and MACE in Malawi have made easy trading of agricultural produces (Munyua 2008). In India, electronic National Agriculture Market (eNAM) trading portal has been launched for trading agricultural commodities across the nation (GoI 2021).

2.7 Financial Insertion

Digital financial services in agriculture cover digitization of land record and effective use of all available data resources. Successful operation of ICTs can bring a revolutionary change in the system of subsidy for the farmers and access to different schemes, insurance schemes, and financial services (Singh and Parakh 2017).

3 Animal Identification and Traceability System

Identification of animals is of immense importance in scientific and profitable animal husbandry practice. Animal identification facilitates registration of animals, keeping record of animals covering date of birth, breed information and production record, animal ownership record, insurance claim, tracing diseased animals, etc. (Bowling et al. 2008). Individual identification of animal is also useful for precision farming and implementation of different governmental schemes and policies to animal farming.

Branding, tattooing, ear notching, ear tagging, toe clipping, etc. are well-known traditional identification techniques, but have risk to tissue damage, loss, or steal (Edwards et al. 2001; Gosalvez et al. 2007). Radio frequency identification devices (RFIDs) have recently been proposed for traceability purpose (Sahin et al. 2002; Regattieri et al. 2007). External RF devices have risk of tissue damage, tampering, or steal, while internal devices are invasive and difficult to maintain. DNA-based identification technique is perfect (Loftus 2005), but it is time-consuming and expensive technique. Some animals have characteristics to identify individuals like eyespots on the wings of butterflies, belly patches in geese, and body markings in zebra (Bugge et al. 2011). Fins, which display curves, notches, nicks, and tears, are used to identify bottlenose dolphins (Bugge et al. 2011). The cattle can be identified by their nose prints (Awad et al. 2013). The pigs can be identified from auricular venation patterns (Harrell 2009). As traditional identification systems have some limitations, image-based identification and deep learning systems have been used recently not only for individual identification, but in breed identification within the same or different species. These technologies are cheapest, noninvasive, and easy to deploy both at farm and field.

3.1 Traditional Identification System

Animal identification techniques using permanent or temporary marking are classified according to characters used and to their permanence on the animal. Ear notching is an everlasting cheap individual identification system mostly used in the swine industry. Both ears are scratched into “V” shape in a certain fixed place and each location has predefined number. The individual animal id is determined by adding the number based on position of the cut in the left and right ear. However, this method of identification is less intensively used in the cattle industry (Caja et al. 2004). Ear tags are most commonly used for identifying livestock species. Ear tags, either electronic or nonelectronic, may be numerous in design, but these require perforation of the ear flap. Some tags have prenumber, others are supplied blank and can be numbered with permanent ink markers which have several color choices to increase coding possibilities. Branding is the procedure where marking in visible body part of the animal is done permanently. Freeze branding or chilled branding generally uses liquid nitrogen or dry ice, whereas hot branding is applied by heating the branding iron. Tattoo is another method of permanent identification of animals when they die with sharp, needle-like projections secured on animal's body.

3.2 Visual Biometric Identification System

Some species have unique coat patterns or markings which are used not only to classify one particular breed in same species like snakes but also for individual identification like zebras, dolphins, etc. within the same population. The patterns are captured in an almost controlled environment, preprocessed, extracted unique features from them, and matching them for individual or breed identification (Karanth and Nichols 1998; Burghardt et al. 2004; Lahiri et al. 2011; Duyck et al. 2015). Zebras and tigers have natural stripes like human fingerprints. The stripes have unique features like distances among the stripes, angle, etc. (Karanth and Nichols 1998). The patterns are captured and used for individual identification in Figs. 11.1, 11.2, and 11.3.

The fins of dolphins have a unique shape in adult stage. The shapes of fins of all dolphins are same in childhood and unique shapes are formed due to damage of fins from childhood to adult stage. It is formed due to attacks by other dolphins, accident

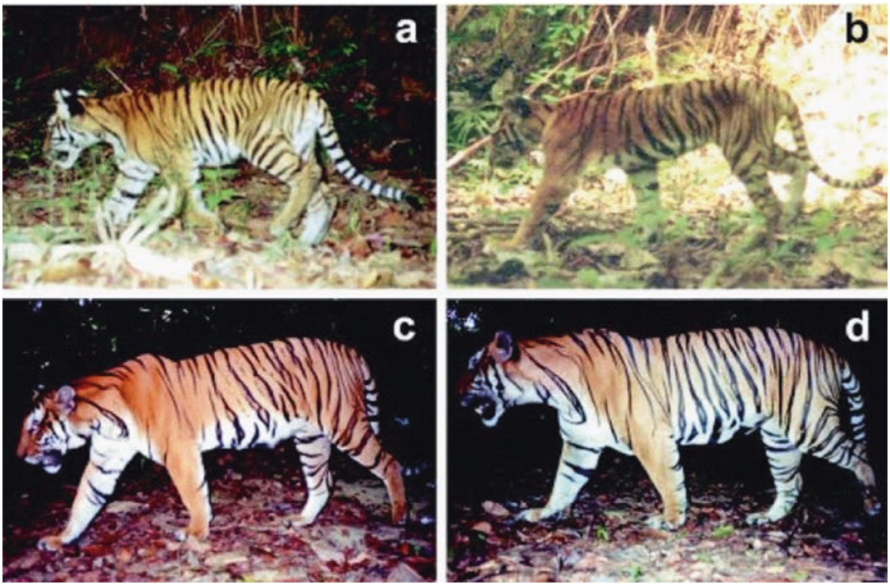


Fig. 11.1 Stripe patterns captured by infrared sensor camera are used for the identification of individual tiger cubs (**a**, **b**) and adults (**c**, **d**). (Source:https://www.researchgate.net/publication/289771762_Camera_trapping_the_Indochinese_tiger_Panthera_tigris_corbetti_in_a_secondary_forest_in_Peninsular_Malaysia)

Fig. 11.2 Stripes of Zebra. (Source: http://grevyszebratrust.org/stripe-recognition.html)

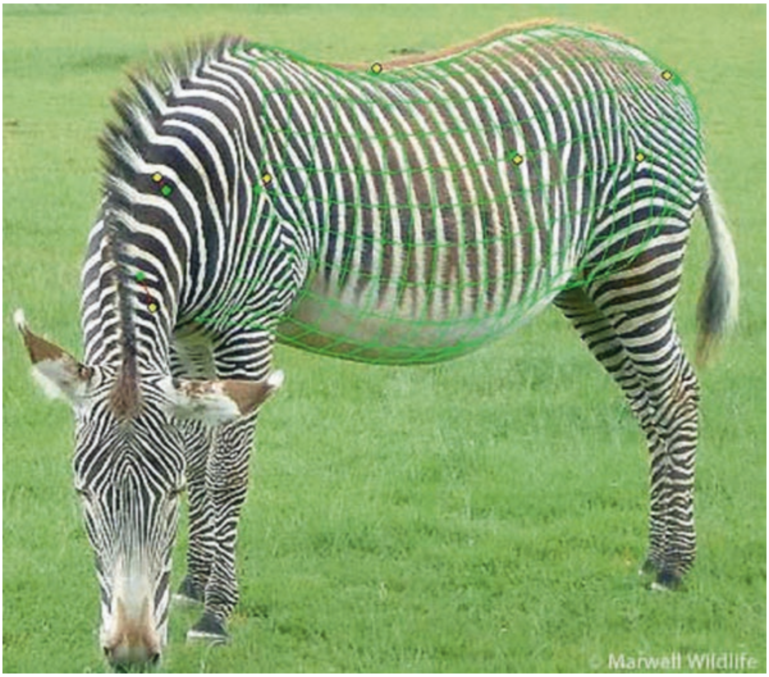


Fig. 11.3 Pointing for identification. (Source: http://grevyszebratrust.org/stripe-recognition.html)

with obstacles, or other various reasons. The damaged fins of dolphins are used as individual identification mark. The fin of dolphin is captured, the centroid is located, and lines are drawn from the centroid to the periphery with some angular differences. The lines are used as codebook for individual identification. The fin of the same dolphin is recaptured and a new codebook is developed. The matching is done between captured codebook and stored codebook in the database (Duyck et al.

Fig. 11.4 Fins of dolphins. (Source: https://www.americanscientist.org/article/computing-dolphin-fin-photo-ids)

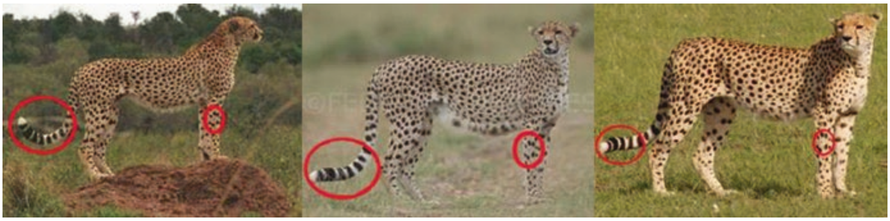


Fig. 11.5 Cheetah (Resy) in 2001 (left), in 2008 (Middle), and 2011 (right below). (Source: http://marameru.org/eng/project/cheetah-identification/)

2015). The dolphin gets identified based on matching score (Burghardt et al. 2004). The fins of dolphin are shown in Fig. 11.4.

Someway, Cheetahs based on tail rings and limbs spots and African penguins based on black spots on their chests were identified as presented in Figs. 11.5 and 11.6.

Fig. 11.6 Black spotson Penguins chests. (Source: Burghardt et al. 2004)

3.3 Image-Based Animal Identification System

In image-based animal identification, different trait(s) which may be given unique pattern-like trait(s) used for individual human identification have been captured using different cameras in different lighting conditions keeping animal free or restrained. Each trait has been preprocessed, segmented from the images. The features have been extracted and analyzed for individual animal identification. The faces, nostril, and inside the tail and ears have been captured by mobiles and camera (DSLR). The face images have been taken from different angles and some points have been marked like human detection using 22 points marked in the face (Kazimov and Mahmudova 2014). But most of the time, the animals do not repeat pose and hence the ratios of measurements of different trait(s) may be varied at different times for the same animal. Some dots have been found on the nostrils of some animals, like the goat. The dots are stable and have been tested for individual identification, but the dots of nostrils have not been found in kids and young goats. Many wrinkles have been found inside the tail of mature animals. They may be used for finding unique patterns for individual identification, but wrinkles are formed due to age and not available in all animals. The vein distributions of ears of some animals like pig, rabbits, and rats have been given a unique pattern and may be used as a trait for individual identification (Bugge et al. 2011). Ear vein distribution of some animals may not be captured due to hair inside of ears. Recently, Dan et al. (2021) have developed individual pic recognition system based on ear images. It has been proved that retina blood vessel or vessel tree is used for individual goat identification (Mustafi et al. 2021). The retinal vessel tree has been found unique for individual animal. The structure or architecture of the eyes of all animals is not similar like in human, and retinal cameras have been developed for capturing the human retina in a control environment. The eye has to be dilated using atropine and retina images have been captured using retinal cameras made for capturing retina images for human. The animal retinal pictures have to be captured in a natural environment and retinal images have been used for individual identification purpose (Mustafi et al. 2021). Iris recognition is one of the most dependable biometric techniques for

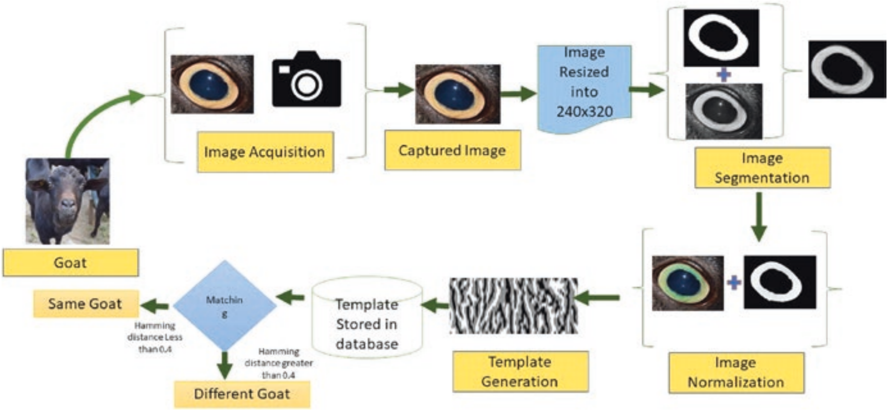


Fig. 11.7 Iris image-based goat recognition

individual identification purposes. J. Daugman (2002) is the pioneer in the field of iris recognition. Iris can be scanned quickly and images can be obtained digitally. The iris recognition system is already used in humans (Daugman 2007; Feng et al. 2008). The iris recognition has been done for cow identification (Zhang et al. 2009; Lu et al. 2014). The iris pattern matching has been proposed for recognition of goat recently (De and Ghoshal 2016; Roy et al. 2021). The photographic images of the iris were captured using a specialized iris identification camera. Algorithms already developed for human recognition using iris were not usable for recognizing animals like goat due to differences in the anatomical structure of their eyes. Unlike the iris of human, goat iris is rectangular in shape and cannot be set in any standard shape. Thus, iris segmentation algorithms of human would not be useful to section iris image of goat eye. A software iGoat developed by Roy et al. (2021) was applied to position the rectangular iris area in the eye and thus segment iris. The segmented iris was normalized and the template was generated and stored in Iris_template_database. Hamming distance (Daugman 2002) was used as a metric for iris pattern matching and recognition. It has been observed that matching scores among the iris images from same goat are significantly different from iris images from other goats. The goat identification system using iris is given in Fig. 11.7.

3.4 *Feature-Based Animal Breed Identification*

The classical neural network is not efficient for image classification. The fully connected layers have a huge number of parameters and each image is composed of a huge number of pixels. To avoid such problems, the statistical properties have been extracted from images and the extracted properties have been used as input of network for classification. The classification model has been used mainly on breed classifications. Mandal et al. (2019, 2021) have proposed one model consisting of

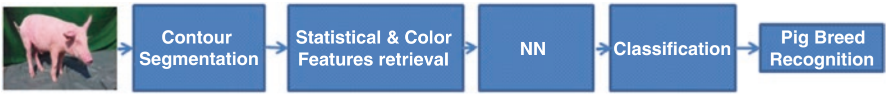


Fig. 11.8 Features-based pig breed identification

four sub-modules as layered structure (Fig 11.8). The captured images of different pig breeds have been preprocessed, images have been segmented based on hue-based algorithm, and finally color-based features have been extracted from each segmented image. The features have been processed in Neural Network for the prediction of pig breed. The suitable training has been chosen for better performance of network.

3.5 *Deep Learning-Based Animal Identification System*

Recently, different supervised deep learning frameworks have been used for breed identification within the same species. The frameworks have also been used in and between breed classifications. The individual identification framework has also been developed using supervised deep learning. Deep learning frameworks have already been developed recently for pig and goat breeds identification (Mandal et al. 2020; Mukherjee et al. 2020; Ghosh et al. 2021). In these frameworks, goat or pig breed identifications have been performed with Convolutional Neural Network (CNN) using individual goat or pig image. Two CNN architectures (Inception-v3 & VGG-16) have been compared and the better performing model was selected for goat breed prediction. In the third framework, goat breed prediction with localization has been done by using an object localization algorithm called Region Proposal Network (RPN) on top of the CNN feature extraction backbone combined known as Faster R-CNN. With the success of the proposed frameworks, it can be confidently stated that either one can be used for solving the animal breed identification problem with high accuracy as well as intelligent livestock management.

4 Internet of Things

Internet of things (IoT) comprises of a complex interconnected network of things that intermingle each other at any given time and place, data collection, data exchange, and placing them in the cloud for further processing by intelligent algorithms to accomplish collective targets. "Things" mean any physical devices like computers, cameras, cell phones, sensors, etc. that are attached to each other through the internet (Mattern and Floerkemeier 2010; Ma 2011; Qutqut et al. 2018).

IoT provides potential opportunities for using a stirring set of technologies that can be applied in every spare of life (XuDa et al. 2014; Li et al. 2015). Nowadays, with modern technological progress, a number of smart devices, such as sensors, smart phones, tablets, smart wristbands, and Radio Frequency Identification (RFID), have made IoT versatile and popular. Recent advances in IoT have made huge development in industry and agriculture for collecting and processing data in various situations, such as environmental monitoring, human healthcare, livestock healthcare, precision agriculture, and tracing (Djedouboum et al. 2018). With the ever-increasing demand for livestock and livestock products across the globe, challenges of processing a huge data become inevitable and thus IoT can help in the systematic and successful processing and real-time availability of the data which allow the users enormously for use of the basic information involving procurement of input, livestock management and production, livestock disease surveillance, market trend of livestock products, etc. In fact, the breakthroughs in IoT have made paradigm of prospects for livestock stakeholders. IoT is becoming an indispensible component of the farming society in the development and extension of the livestock sector to give better solutions and augment livestock production (Fig. 11.9).

A comparative study on cow population and milk production in different countries worldwide is presented in Table 11.1. The table shows India ranks first in cow population; however, India contributes roughly twothirds of milk that is contributed by the USA annually. The dairy cow population in Brazil is more than the cow populations present in USA or China, but cow milk production is less than the cow milk production recorded in USA or China. In the world scenario, the small farmers in developing and underdeveloped countries rear 80% of dairy cows (Kino et al. 2019). These small farmers practice traditional farming and they are not aware of

Fig. 11.9 IoT application for remote monitoring of livestock (Source: https://www.fareasternagriculture.com/live-stock/cattle/sas-iot-analytics-target-cold-chain-logistics-and-livestock-wellness-challenges)

Table 11.1 Comparative studies on cow population and milk production in different countries worldwide

Category	Country	Worldwide dairy cow population (%)	Worldwide cow milk production (%)
Developed	USA	3.4	14.6
	Germany	1.6	4.9
	France	2.0	3.9
	New Zealand	1.8	2.8
Developing	India	16.5	8.4
	China	4.7	6.0
	Brazil	8.7	5.3
Underdeveloped	Pakistan	3.8	2.1
	Bangladesh	1.5	2.0

Source: Akbar et al. (2020)

such modern digital technology. Thus, the use of such modern technology needs to be promoted to address the rising demand of the world.

SmartHerd management has been proposed by Taneja et al. (2019) for studying animal behavior and monitoring health in regard to increase milk productivity. Because of high initial investment, the ability of the small farmers is limited; in such conditions, open-source hardware may be an alternative option (Ngo et al. 2020). Arduino has opened opportunities for its open applications in greater ranges, such as collection of environmental parameters (Mesas-Carrascosa et al. 2015), data mining (Patil et al. 2016), automated watering systems (Rahman 2020), IoT-based platforms (Saqib et al. 2020), or information monitoring systems (Trilles et al. 2018).

The use of nanotechnology in IoT-based wireless sensor networks was conceptualized first by Bhargava et al. (2015) for the application in precision dairy farming. Kröger et al. (2016) reported sensors and network communication nodes for data recording and monitoring of livestock. Crowe et al. (2018) suggested an IoT-based semantic model for automatic heat detection and controlled direct fertility programs. Neethirajan et al. (2017) suggested an IoT-based implant device for recording all sorts of medical information of an animal at a particular location. Zhang et al. (2018) suggested a real-time data collection system for generating momentum information on agroecological conditions of a particular grazing land. Germani et al. (2019) recommended a long-range Low Power Wide Area Network (LoRa LPWAN)-based IoT technology for monitoring environmental variables as well as health-related various parameters of cattle. On the other hand, Maroto-Molina et al. (2019) put forward an IoT-based low-cost communication system consisting of Bluetooth tags and Sigfox network for identifying the position of a whole herd.

IoT technology was used for livestock tracking and geofencing (Ilyas and Ahmad 2020). Geofencing is a particular area-based technique in which a location-aware device like GPS, RFID, or Wi-Fi can trigger an alert when an animal attached with a location-specific device goes in or goes out of a particular virtual geographical boundary, considered as a geofence. Geofence is a concept of monitoring the movement of animals within a particular virtual boundary of a farm or pasture land. Geofence allows monitoring the animal remotely. GPS network, Wi-Fi nodes, and Bluetooth beacons are used to construct a geofence around a specific location; then the geofence is paired with sensors attached with the animal collar, and when an animal comes out of the particular virtual boundary, it gives alert signal to a device kept by the farmer (Akbar et al. 2020).

5 Wireless Sensor Networks

Wireless sensor networks (WSNs) consist of different networks of many devices and sensors which are interconnected wirelessly and communicated with one another every second. Chong and Kumar (2003) have described in detail the evolution of WSNs. World War II ended with the rising of competition between the USA and the USSR, mostly the present-day Russia. Such rebellion was known the Cold War. In the early 1950s, the USA marked the USSR submarines as the most dangerous to its defense. Hence, the USA focused research and development on underwater acoustics for detecting submarines leading to the development of a sound surveillance system (SOSUS). In the late 1970s, the Defense Advanced Research Projects Agency (DARPA) of the USA discovered distributed sensor network (DSN) followed by the development of WSNs.

Martin and Islam (2012) have defined WSNs as self-configured and wireless networks that collect data on the physical or environmental conditions and then leave the collected data to a particular location where the data are processed, analyzed, and displayed. WSNs commonly include Bluetooth, wireless mobile communication, wireless broadband, Wi-Fi, WiMax broadband, ZigBee, LoRa LPWAN, Sigfox, etc. A satellite navigation system plays a central role in WSN communication system. As of now, there are four satellite navigation systems to provide global coverage: (i) Global Positioning System (GPS) of the United States, (ii) Galileo of Europe, (iii) GLObal NAvigation Satellite System (GLONASS) of Russia, and (iv) BeiDou of China (Fig. 11.10).

The development of WSN technology has given opportunities to use it in many fields, such as industries, medical care, agriculture, livestock farming, transportation, environmental monitoring, and military defense (Minaie et al. 2013; Srivastava and Sudarshan 2013; Wang et al. 2016). The setup of livestock farms is generally found in remote locations. In such cases, data transmission through a wired network is not possible because of high cost, trouble in connecting power lines, or problem in signal transmission due to long lines. Hence, a network of wireless nodes technology has become popular to monitor farm environmental parameters and livestock as well (Llario et al. 2013; Wang et al. 2014; Murphy et al. 2015). Chen and Chen (2019) developed an automatic monitoring system using WSN technology that includes programmable logic controllers (PLC), analog-to-digital converter modules, RFU-400CR wireless device, and human-machine interfaces (HMI) in both dairy and pig farms. This WSN system removed manual data collection system

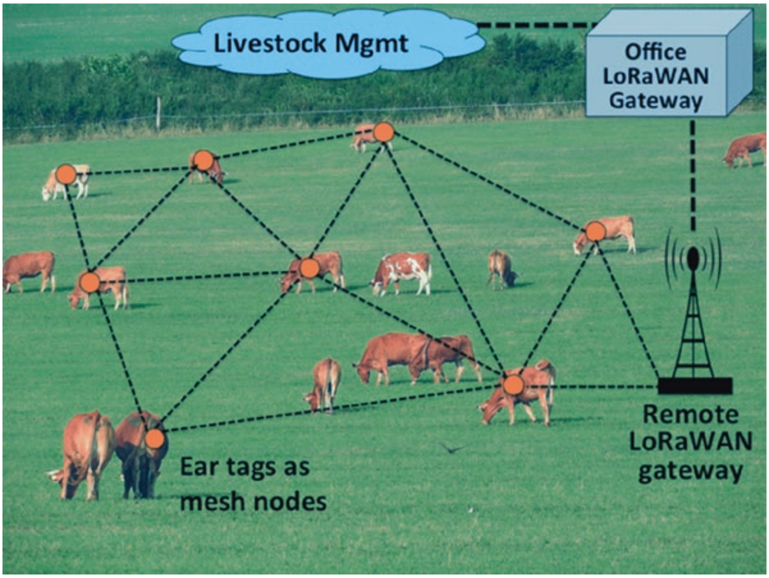


Fig. 11.10 WSN communication technologies application in livestock farming. (Source: https://data-flair.training/blogs/iot-applications-in-agriculture/amp/)

of the environmental conditions and manual controls of fans and water control valves in livestock farms as shown in Figs. 11.11 and 11.12.

5.1 Biometric Sensors

A sensor is a device that detects a physical, chemical, or biological thing (Neethirajan 2020a). A sensor collects real-time data which are processed by big data analytics systems to generate real-time information for further decision-making (Neethirajan and Kemp 2021). The available biometric sensors may be noninvasive or invasive.

5.1.1 Noninvasive

Stationary Sensors in the Farm Area

Animals in the farm have a daily routine like feeding and milking which are repeated. So, the stationary sensors placed at a particular place of the farm can capture those activities of the animals. The stationary sensors are surveillance cameras, microphones, and closed-circuit cameras for identification and monitoring of activities like lying time, feeding time, watering time, etc. Some other sensors include temperature measurement of the udder and recording of sound in the farm (Ferrari et al.

Fig. 11.11 Aerial photo of livestock farm. (Source: Chen and Chen 2019)

2008; Exadaktylos et al. 2014; Berckmans et al. 2015; Broom and Fraser 2015; Kim et al. 2015). Certain other sensors like thermometers, gas sensors, and pressure sensors are commonly used to monitor animals' health conditions, rumination, core body temperature, etc. for efficient management of each animal (Helwatkar et al. 2014). The advantages of these stationary sensors are that a few sensors are needed to monitor the animals in the farm. However, the behavioral activities are limited with this sensor and longer times of exposure to the sensor are needed.

Mobile Sensors Attached to the Bodies of the Animals

The noninvasive sensors commonly used in livestock management are thermometers, accelerometers, pedometers, magnetometers, RFID tags, etc., which are attached to the bodies of the animals to monitor an animal for a whole day in the most reliable way. The smart collars attached with wearable sensor systems are often used for animal tracking and activity monitoring of animals in an outdoor setting as shown in Fig. 11.13 and 11.14. Løvendahl and Chagunda (2010) suggested pedometers attached with readily available low-cost sensors which recorded the activities of the animal, like lying time, standing time, and oestrus behavior with highly efficient forecasting abilities. Nowadays, low-cost GPS positioning sensors are attached to the neck collars of the animals so that the different positions of animals and activities like seeking for their feed, eating, lying, and standing can be

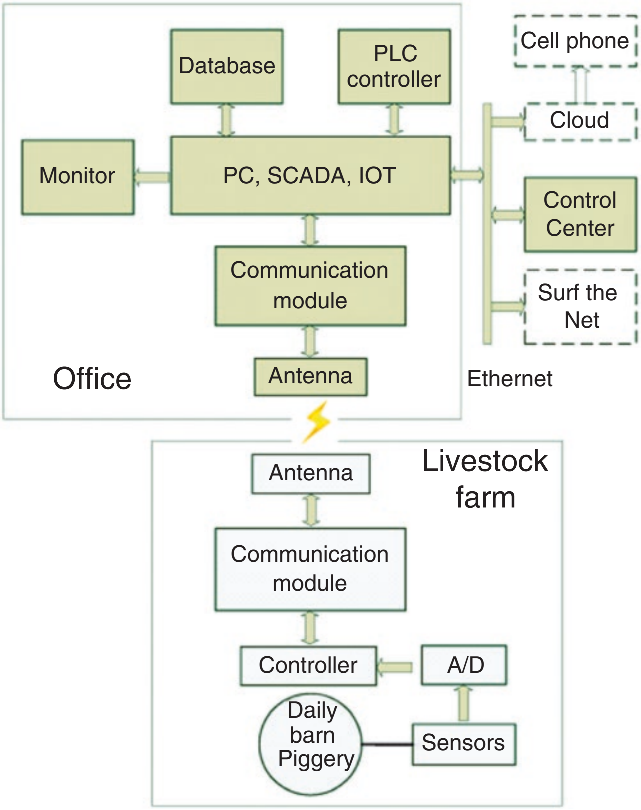


Fig. 11.12 The conceptual planning of system architecture including hardware devices for automatic monitoring system in livestock farms. (Source: Chen and Chen 2019)

monitored. But the success rate in classification is low as 85%; therefore, they are incorporated with other sensors like accelerometer, etc. for better results in the field (Godsk and Kjærgaard 2011). Other noninvasive sensor includes micro-electro-magnetic system (MEMS). MEMS-based accelerometer is more reliable for monitoring the activity of animals. This system is efficient for carrying more data than a normal accelerometer in low power conditions and at a lower cost (Marchioro et al. 2011; Helwatkar et al. 2014). Noninvasive, self-powered RFID-based digital thermometers have been developed for recording real-time body temperature in goats (Debnath et al. 2016), cattle (Debnath et al. 2017), and Murrah buffaloes (Debnath et al. 2019). The advantages of these sensors are that all the physiological as well as the behavioral activities of the animals can be monitored in and off the farm. However, the sensors may be lost like neck collars and can be damaged due to wear and tear of the device, etc.

Fig. 11.13 Data collector on the forehead of cattle. (Source: https://www.precisionag.com/in-field-technologies/sensors/using-iot-to-increase-efficiency-productivity-for-livestock/?amp)

Fig. 11.14 Wearable sensor system on the forehead of grazing animals for continuous monitoring. (Source: Ngo et al. 2020)

5.1.2 Invasive

The study on invasive sensors in livestock is limited. Invasive sensors are generally swallowed by or implanted in an animal for precise measurements of physiological parameters. It was as early as 1970 when electronic transponders were used for automatic recording of data on individual feeding of cows. The first-generation transponders were attached to a collar around the neck of the animals and these were further miniaturized and decided to be injected under the skin. Some classical examples of these types of sensors include RFID microchips, rumen bolus, and thermometer. RFID technology allows the user to track and identify the animal with specific tracing systems like disease tracing, vaccinations, medications, etc. RFID microchips implanted subcutaneously or embedded in ear tags and collars are used to monitor general activity, eating, and drinking behaviors (Neethirajan 2017). When the RFIDs are incorporated with GSM or mobile SIM cards, the inbuilt GPS can also send alerts to the farmers or the competent authorities whenever there is a case of theft or smuggling across borders. With these wireless sensors, a huge data of the animal can be stored in the memory of the pc or a mobile phone and thus these stored data can be used later or be referred to for tracing out any kind of information like disease outbreaks in a region and others. These sensors could be embedded on animals for detecting the presence of viruses and pathogens (Posthuma-Trumpie et al. 2009; Ayyar and Arora 2013; Mungroo and Neethirajan 2014; Kizil et al. 2015), measuring body temperature (Nogami et al. 2014; Sellier et al. 2014; Jensen-Jarolim and Flaschberger 2016), internal physiological measures (Helwatkar et al. 2014), observing animal's behavior and movement (Jaewoon et al. 2015), detecting stress (Lee et al. 2015), detecting pH (Kim et al. 2016), and estimating sweat constituents of animals (Garcia et al. 2016; Glennon et al. 2016; Heikenfeld 2016). Invasive sensors are advantageous for their reliable measurement values that are not affected by conditions prevailing outside the animal's body. Besides, continuous observation of the animals is possible.

5.2 Applications of Various Sensors

5.2.1 Image Capturing Sensors

Cameras can be used as image capturing sensors to collect actionable information. Cameras can be placed easily in barns to collect video images. These images can be further processed to generate algorithms that can indicate changes in animals' posture for the diagnosis of lameness and other morbidities, if any (Jorquera-Chavez et al. 2019). Video images can be further processed to create algorithms that can help in the identification of individual animals, monitoring of animal gait, water intake, feed intake, and aggression (Norton et al. 2019). Aggression of indoor-housed pigs and/or overall activity patterns of group-housed pigs can be tracked using an automated video imaging technology (Wurtz et al. 2019). Aydin (2017) proposed to use 3D vision camera and image process algorithm to detect lameness of broiler by examining locomotive behaviors. Zaninelli et al. (2017) used sensor-based infrared technology to monitor a flock of more than 500 hens under free-range extensive system of management. Benjamin and Yik (2019) suggested using 3D image technology to estimate the body weight of pigs. Facial recognition technology can also be applied to investigate any change of facial expression and recognize several behavior patterns of animals using machine learning computer algorithms (Camerlink et al. 2018; Marsot et al. 2020).

5.2.2 Sound Capturing Sensors

Microphones can easily be installed in farms to capture sounds exhibited by the animals. The sounds captured by microphones can be used for acoustic analysis in relation to monitoring vocalizations and coughing of the animals (Carpentier et al. 2018; Friel et al. 2019; Norton et al. 2019). Rottgen et al. (2020) concluded that automated detection of the vocalizations of an individual cow could be a prospective means for monitoring the estrus of dairy cows. Automated sound detection algorithms can also be utilized in poultry farms to figure out thermal stress (Du et al. 2018) and diagnose respiratory illness (Carpentier et al. 2019), feather pecking, or disease (Du et al. 2020; Mahdavian et al. 2020). Ngo et al. (2020) reported a low-cost, portable Wireless Location Acoustic Sensing System (WiLASS) for smallholder farms in rural areas to generate health information of farm animals.

5.2.3 Biosensing Sensors

The development of biosensors allows the farmers for rapid biomarker detection to monitor animal health leading to the improvement of dairy cattle health and welfare. Ketosis is a serious health problem in dairy animals. In ketosis, there is often an increase of betahydroxybutyrate (BHBA) level which can be identified by a quantum dots-based biosensor (Weng et al. 2015), ruthenium dye-sensitized graphene oxide (GO) nanosheets biosensor (Veerapandian et al. 2016), and 2D MoS2 nanostructure-based electrochemical immune sensors (Tuteja et al. 2017). A portable diagnostic reader has been developed by Jang et al. (2017) to detect progesterone in milk. Various biosensors have been reported to detect fowl adenovirus (Ahmed et al. 2018), avian corona virus (Weng and Neethirajan 2018), and ruminant Johne's disease (Chand et al. 2018) which may cause huge economic losses for the farmers. Recently, RFID tags and accelerometers as biosensing sensors have been used for capturing drinking behavior and water intake of grazing cattle with 95% accuracy (Williams et al. 2020) (Fig. 11.15).

5.3 Big Data Analytics

The application of various sensors generates huge data, called big data, which need to be stored, processed, and analyzed to figure out various important insights for better care and management of livestock. The big data are often considered as the

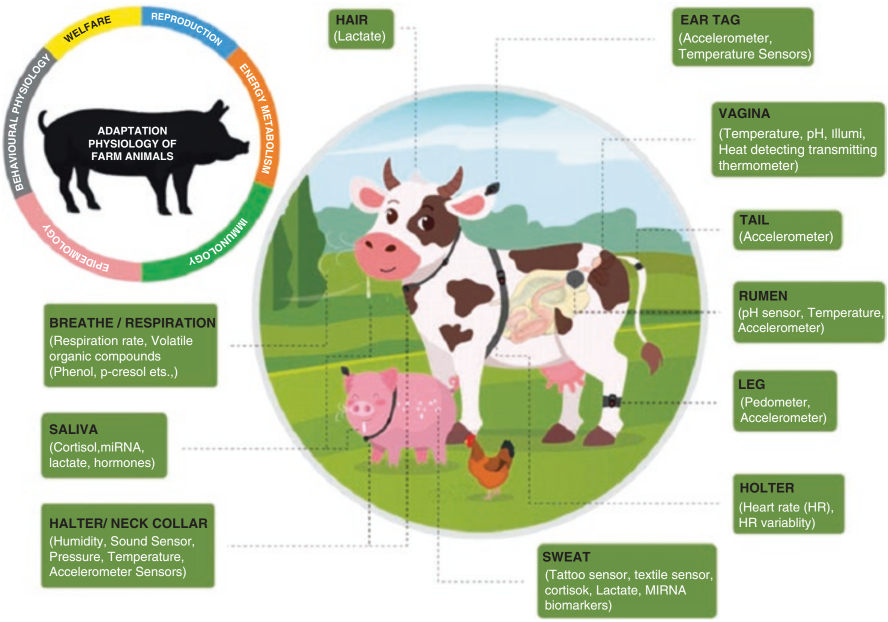


Fig. 11.15 Real-time monitoring of animal welfare based on physiological signals using wearable sensors and novel biomarkers. (Source: Neethirajan 2020b)

'3V', which stands for volume, variety, and velocity (Laney 2001). Recently, data science has emerged as a separate branch of study which integrates statistical analysis and computer algorithms for data analytics (Wimmer and Powell 2015). Managing, processing, and effective use of big data in the area of remote sensing is a great challenge (Chi et al. 2016), which advances big data analytics (Wolfert et al. 2017). The application of data analytics allows efficiently solidifying the farm management with optimum resource utilization, predicting future outcomes, and improving the decision-making process (Wolfert et al. 2017; Koltes et al. 2019).

Big data play a very important role in storing a large set of data on a remote server, and using highly developed technologies, it furnishes a scalable solution to livestock farming practices. Big data analytics allow monitoring disease transmission (VanderWaal et al. 2017) and identifying and predicting diseases (Gulyaeva et al. 2020). Digital farming service systems depend on big data analytics and modeling in the decision-making process for nutrition, production, reproduction, health, and welfare issues. For example, da Rosa Righi et al. (2020) developed the MooCare predictive model in managing dairy farms and predicting milk production.

6 Artificial Intelligence

Turing Test first floated the idea in the philosophy of artificial intelligence. In 1950, Alan Turing, a young British mathematician, published a landmark article "Computing Machinery and Intelligence", in which the question "Can machines think?" was substituted with the question "Can machines do what we can do?' and he delineated how to design intelligent machines and how to examine their intelligence (Harnad 2008). Thus, he proposed a test to examine the machine's capability for exhibiting intelligence equivalent to human intelligence, called the Turing test (Turing 1950). However, the term 'artificial intelligence' was coined in 1956 at a conference at Dartmouth College, in Hanover, New Hampshire.

Artificial intelligence or AI is a set of algorithms concerned with the machine's intelligence. AI is thought to be far better at predicting the situation than the human mind. AI integrates computer science and huge datasets in solving problems and making decisions. It encompasses subfields of machine learning and deep learning. AI truly has created a paradigm shift in every sector of today's life. AI technologies are now being used in refrigerators, smoke detectors, heating systems, air conditioners, digital TVs, and others to make homes smart. In recent times, AI has transformed livestock management, maintaining biosecurity, forecasting and tackling diseases, trading, and marketing in value chain a lot in recent years.

6.1 Automated and Intelligent Field Scout (AIFS)

Low power and low maintenance AI-enabled edge devices and sensor technology are more in practice with mobile application mapping in veterinary services. In contemporary times, cameras and AI are being used to develop a "smart" farm (https://keymakr.com/livestock.phpa). As an integral part of livestock welfare, AI models can promote with the help of image annotation and the peripheral observations of possible sickness features. Algorithms can label images of animals in a variety of states of health, allowing machine learning models to accurately assess the condition of any animal. This technology, in addition to other livestock data, can give livestock managers early warning of sickness in the herd allowing them to intervene. Polygon annotation and semantic segmentation techniques can be applied to images to allow AI models to track animal movement and chart activity levels like feeding and intake rates, etc. as shown in Fig. 11.16. AI-powered drone technology is allowing farmers to count herds automatically and identify missing animals. Machine observation can provide the training datasets that enable AI models to track feeding rates, ensuring that animals are eating and growing properly.

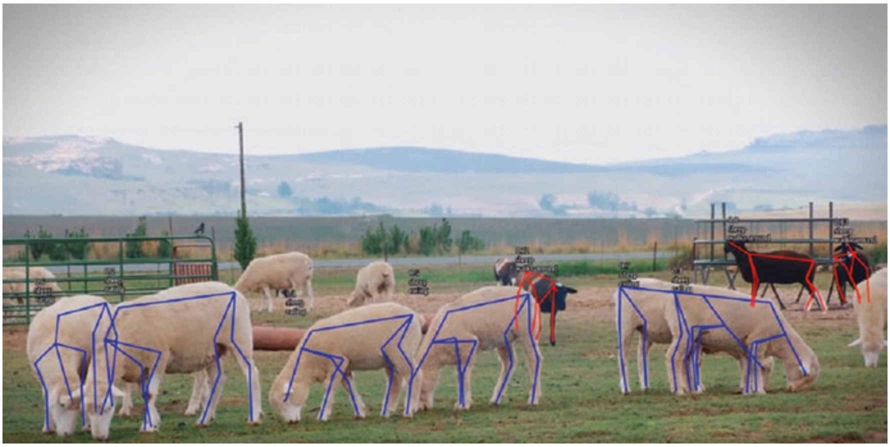


Fig. 11.16 Activity monitoring of livestock during field grazing. (Source: https://keymakr.com/livestock.phpa)

6.2 *Machine Learning*

Machine learning (ML) is a branch of artificial intelligence of computer science, which allows algorithms for statistical analysis and inference (Morota et al. 2018). Machine learning history was started in 1943, when neurophysiologist Warren McCulloch and mathematician Walter Pitts first presented a mathematical model of neural networks in an article entitled 'A logical calculus of the ideas immanent in nervous activity'. In 1959, Arthur Samuel, an American IBMer and pioneer in the area of computer gaming and artificial intelligence, coined the term machine learning (Samuel 1959). ML is an emerging field of interest in precision livestock farming to utilize livestock farming data (captured as text, audio, videos, and images) and generate information for taking need-based activities for the improvement of livestock farm management and thus eliminate the need for a human data analyst (Benjamin and Yik 2019). The application of advanced technologies like AI and ML algorithms to use big data for analysis, classification, prediction, identification of deviations from standard patterns, and notification is presented in Fig. 11.17.

Around the world, automation in livestock support is highly deployed by incorporating soft logic-based predictive decision. These decisions depend on classified ML technique and annotation systems. The accurate classification depends on prior data set to enable the machine for near-perfect output. ML is a branch of AI algorithms that construct a model based on sample data, known as "training data". Supervised and unsupervised learning are two major classifications of ML tasks. Supervised learning is a machine learning technique in which models are constructed using labeled data under the supervision of training data. It means some data already tagged/ labeled with the correct answer (training data) are provided to the machines as the supervisor that teaches the machines to forecast the output

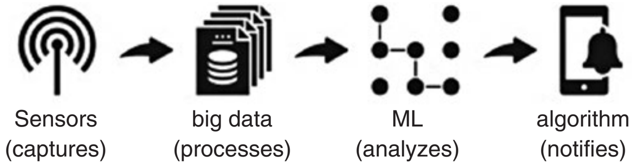


Fig. 11.17 The collection of advanced technologies to use big data and generate better outcomes. (Source: Neethirajan 2020a)

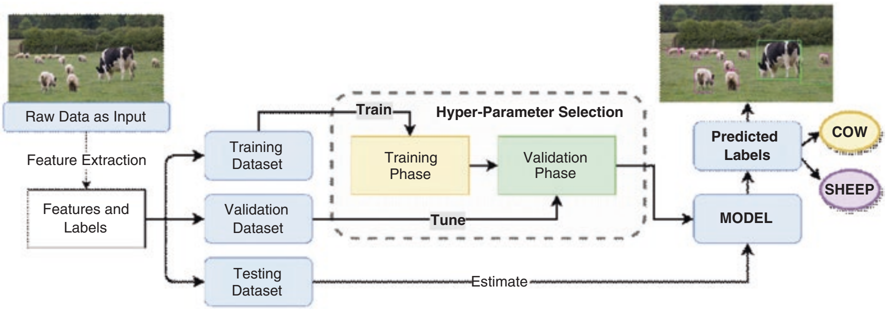


Fig. 11.18 Generalized ML procedure for the outputs in livestock system

correctly. Unsupervised learning is a machine learning technique in which models are not supervised using training dataset; however, it discovers hidden patterns from unlabeled data. A generalized ML procedure for the outputs in the livestock system is presented in Fig. 11.18.

6.2.1 Machine Learning Models for Feature Extraction

Machine learning applications in agricultural technologies pave many different ways of applications to get anticipated results. The most popular models in agriculture are Artificial Neural Networks (ANNs), Deep Neural Networks (DNNs), Convolutional Neural Networks (CNNs), and Support Vector Machines (SVMs). Like the function of the human brain, ANNs construct a simplified model of the structure of the biological neural network performing complex functions such as pattern generation, decision making, etc. DNN is a subfield of ANN. DNN is much more complicated than ANN. In DNN, learning is deeper and it works for prediction, creative thinking, etc. CNNs are mostly used for image and video recognition that is specifically designed to process pixel data, and rarely for audio recognition. SVMs analyze data for classification, regression analysis, and clustering.

6.2.2 Regression Analysis in Machine Learning

Regression is the appropriate algorithm to find the relation between variables for which the primary features data can be identified. For example, the primary features data for the best condition in milk production in any regulated farm condition can be identified using regression analysis.

The regression line may be like:

$$Y = b_0 + b_1X_1 + b_2X_2 + \ldots\ldots\ldots b_nX_n$$

Here Y = Amount of milk produced

X_1, X_2.. = Variables that are provided in the data (amount of foods, age, temperature, etc.)

b_0, b_1… = Coefficients obtained on regression

6.2.3 K Nearest Neighbor Algorithm to Predict Production

In dairy farming, the pertinent questions arise from the measuring of milk yield that is expected from a cow with the use of various food and nutrients. For a new batch of cow, it is difficult to know an estimate of milk production. K Nearest neighbor (KNN) algorithm may be applied to solve this problem. Norouzzadeh et al. (2018) reported various image annotation groupings for AI and ML and application of deep learning for classifying different action attributes in livestock management system as shown in Fig. 11.19. Image resources Cogito training datasets for AI are shown in Fig. 11.20. Intelligent computer vision for identifying each cow in the herd and monitoring its daily habits is presented in Fig. 11.21.

6.2.4 Applications of Machine Learning in Artificial Intelligence-Based Livestock Farming System

ML application is very much usable for the exact estimation of economics of livestock farm based on production line as well as monitoring animal behavior for the early detection of diseases. Liakos et al. (2018) have reviewed application of ML in different aspects of livestock farming as depicted in Table 11.2.

A representation of how machine learning algorithms may predict production potential and generate decision-making strategies in dairy farming as shown in Fig. 11.22.

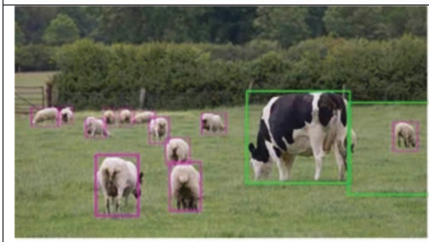
Input Image	Identification and count	Additional Attributes
	COW: 26 Confidence Score: 8.3/10	Standing : 100% Not Resting: 98% Not Moving: 5% Eating : 97% Not Interacting: 0%
	COW: 1 Confidence Score: 9/10 ---------------------- -- Sheep: 12 Confidence Score: 6/10	Standing: 100% Not Resting: 100% Not Moving: 0% Eating: 100% Not Interacting: % Standing: 78% Not Resting: 97% Not Moving: 14% Eating:77% Not Interacting:23%
	COW: 5 Confidence Score: 5/10 ---------------------- -- Sheep: 3 Confidence Score: 7/10	Standing: 100% Not Resting: 100 % Not Moving: 0% Eating: 100% Not Interacting:0% Standing: 100% Not Resting: 30 % Not Moving: 0% Eating: 33% Not Interacting: 0%
	COW: 4 Confidence Score: 8/10	Standing Not Resting Not Moving Eating Not Interacting

Fig. 11.19 Application of Deep Neural Networks (DNNs) for identifying, counting, and describing livestock grazing behavior in farm environment. (Source: Norouzzadeh et al. 2018)

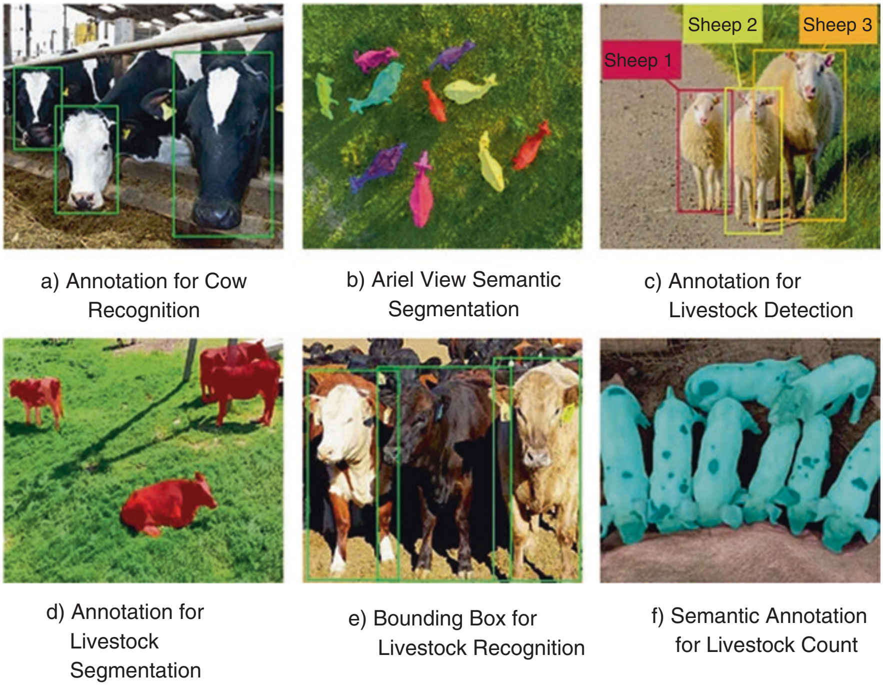


Fig. 11.20 Image resources Cogito training datasets for AI. (Source: https://www.cogito-tech.com/)

Fig. 11.21 Intelligent computer vision for identifying each cow in the herd and monitoring its daily habits. (Source: https://www.cainthus.com/)

Table 11.2 Applications of ML in livestock farming and animal welfare

Author	Animal species	Observed features	Functionality	Models/ algorithms	Results
Dutta et al. (2015)	Cattle	Features like grazing, ruminating, resting, and walking were recorded using collar sensors with three-axis accelerometer and magnetometer.	Classification of cattle behavior	EL/bagging with tree learner	96% accuracy
Pegorini et al. (2015)	Calf	Chewing signals from dietary supplements, such as tifton hay, ryegrass with rumination, and idleness which were recorded using optical FBG sensors	Classification of chewing patterns in calves	DT/C4.5	94% accuracy
Matthews et al. (2017)	Pigs	3D motion data on standing, moving, feeding, drinking, etc. were collected using depth video cameras	Tracking of animal behavior and various activities of pigs	BM: Gaussian Mixture Models (GMMs)	Animal tracking: Mean multi-object tracking precision (MOTP) = 0.89 Accuracy behavior annotation: Standing: Control R2 = 0.94, Treatment R2 = 0.97 Feeding: Control R2 = 0.86, Treatment R2 = 0.49
Craninx et al. (2008)	Cattle	Milk volatile fatty acids (acetate, propionate, and butyrate)	Prediction of rumen fermentation pattern from milk fatty acids to determine molar proportions of volatile fatty acids	ANN/BPN	Acetate: RMSE = 2.65% Propionate: RMSE = 7.67% Butyrate: RMSE = 7.61%

(continued)

Table 11.2 (continued)

Author	Animal species	Observed features	Functionality	Models/ algorithms	Results
Morales et al. (2016)	Hens	Data on the farm's egg production line were collected over a period of seven years	Early detection and warning of problems in commercial production of eggs	SVM	98% accuracy
Alonso et al. (2015)	Cattle	Geometrical relationships of the trajectories of weights along the time	Estimation of cattle weight trajectories for future evolution with only one or a few weights	SVM	Angus bulls from Indiana Beef Evaluation Program: weights 1, MAPE = 3.9 ± 3.0% Bulls from Association of Breeder of Asturiana de los Valles: weights 1, MAPE = 5.3 ± 4.4% Cow from Wokalup Selection Experiment in Western Australia: weights 1, MAPE = 9.3 ± 6.7%
Alonso et al. (2013)	Beef cattle	Zoometric measurements of the animals 2 to 222 days before the slaughter	Prediction of carcass weight of beef cattle 150 days prior to the slaughter day	SVM/SVR	Average MAPE = 4.27%
Hansen et al. (2018)	Pigs	1553 color images with pig face using RFID tag	Pig face recognition	DNNs: Convolutional Neural Networks (CNNs)	96.7% Accuracy

Source: Liakos et al. (2018)

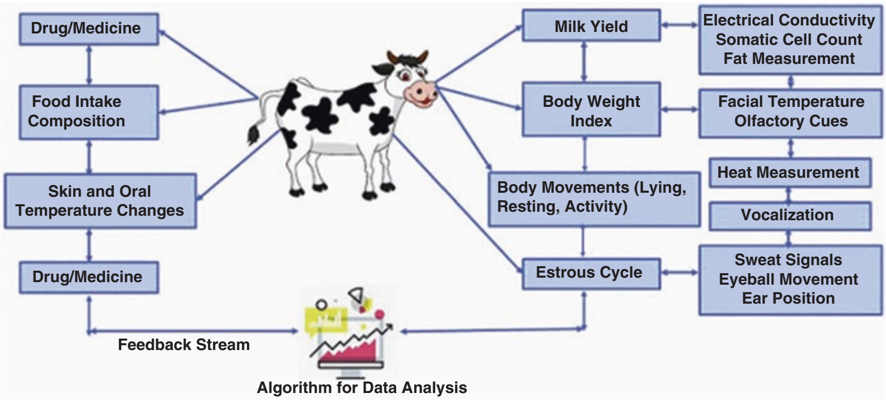


Fig. 11.22 How machine learning algorithms may predict production potential and generate decision-making strategies in dairy farming. (Source: Neethirajan 2020a)

Fig. 11.23 Use of drone for monitoring behaviors of sheep and smart sensors to help in the early detection of any deviation from normal behaviors or any other issues. (Source:https://www.design-indaba.com/articles/creative-work/drone-design-reaches-new-heights)

7 Drones or Unmanned Air Vehicle

Over the last few years, unmanned aerial vehicles (UAVs) or drones have come up as one of the world's most talked technologies which are used in a wide range of fields, such as defense, the entertainment world, social functions, agriculture, livestock farming, and many others. Drones support many tasks in vigilance, surveying, social functions, disaster risk management, agriculture, livestock monitoring, etc. (Ayamga et al. 2020).

Drone technology has opened a whole new perspective in animal husbandry and agriculture at large. In agricultural operations, drones can collect and provide real-time data from the farm fields (Malveaux et al. 2014). GPS-enabled drones with better-operating cameras and sensors and customizable applications for smart phones and tablets with user-friendliness can provide quality data and information in agriculture, livestock farming, and natural resources (Hogan et al. 2017). There is a huge opportunity of using drones in air surveillance of poaching, precision farming, animal herding to providing healthcare, etc. (FAO 2018). Drone application in livestock farming for the collection of real-time data and monitoring of animals on the farm is shown in Fig. 11.23.

8 Robots

The use of robots in various agricultural activities, such as environmental monitoring, soil analysis, planting seeds, fertilizer application, weed control, and harvesting has already been popular. The emerging application of robots in livestock farming support and management is also growing. The use of robots has made everyday activities easier in livestock farming, such as animal traceability, automatic heat detection, and automatic milking system (Edwards et al. 2015; Gargiulo et al. 2018). Since the 1980s, the development of milking robots has made farm activities easy for automated milking, cleaning, feeding of cows, automatic recording of data on animals, and labor engagement (Ordolff 2001). Barkema et al. (2015) summarized that milking robots were adopted by more than 20% of dairy farmers in Denmark and Sweden, between 15% and 20% of the farmers in Iceland and the Netherlands, between 10% and 15% in Norway and less than 10% in Finland, Germany, and Canada, and 6% of the farmers in Switzerland. Faromatics' ChickenBoy (https://faromatics.com/) is a significant intervention of robotics equipped with a series of sensors that are directly used in the chicken barn. These robotics devices can measure temperature, humidity, and air quality, including levels of ammonia, an indicator for litter conditions whether wet or not. Through technology advances, the spread of technology is still restricted due to limited access to technologies, initial cost involvement, and lack of knowledge on technologies with cost-benefit ratio. Gargiulo et al. (2018) observed that the adoption of precision dairy technologies by the larger farms was more than small farms in Australia. Groher et al. (2020) found that the adoption of digital technologies was also positively correlated with the number of livestock animals (Fig. 11.24).

Fig. 11.24 The robotic rotary milking parlor. (Source: https://www.agupdate.com/farmandranch-guide/news/dairy/new-robotic-milking-parlor-features-the-latest-in-technology/article_eb6e9530-9826-11e8-ad4a-8329f5374a69.html)

9 Conclusions

We are already in the era of digital technologies such as high-speed internet, smartphones, and cheap computing programs. Currently, more than half of the world's population uses the internet either through computers or smartphones. The real-time alert on different farm issues has already been implemented through smartphones in many countries across the globe. The advanced digital technologies are going to set in agriculture and livestock farming for improving efficiencies and gaining greater outputs in a bigger way in the days to come. The application of digital technologies in livestock production systems has come to play a more decisive role in monitoring the farm thoroughly, understanding the dynamics and impact of climate change, mitigation, animal disease surveillance, prevention of outbreak of livestock diseases, and preparedness for pandemic crises. However, most of the studies have been done in the large and organized livestock farms of North America, Europe, and Australia continents. Farm data of North American, European, and Australian farms cannot be compared with data of smallholder farms in developing countries, since the socioeconomic conditions of such smallholder farms are different and thus the issues and challenges of smallholder farms are unique. Thus, there is a demand for country-wise regional or local studies under varied socioeconomic conditions.

There is a range of technology options that have high potential, but require further testing and refinement at the farmers' field before they can be considered technically feasible and economically viable and culturally fit.

The present information is an important first step toward understanding the potential of technologies for application in livestock farm management. These technologies are still in the budding stage in livestock farming, particularly smallholder farming systems. The lack of awareness on the effectiveness and economic benefits of using digital technologies in livestock production systems is the key challenge in the adoption of these smart technologies. Constant education and sensitization are essential in order to make aware and make the farmers ready to adapt any of these smart technologies. Nonetheless, infrastructure facilities, internet connectivity, economic capacity of the farmers, high start-up cost, etc. are still important challenges before we expect widespread adoption of digital technologies in livestock production systems. In order to make digital technologies usable and economically viable, there is a need for computer science and engineering research for discovering low-cost hardware devices, context-specific technologies for long-term operation, efficient collection and storing of large amounts of data, user-friendly computer programs, advances in networking, common infrastructure, sharing facilities of information, and delivery of best practices in real time.

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Chapter 12
Mobilizing Pig Resources for Capacity Development and Livelihood Security

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Abstract Livestock farming forms an important economic activity throughout the globe. In particular, they play a crucial role in the socio-economic prosperity of the developing and least developed countries by providing major support to rural livelihood. Pig farming is a viable and profitable enterprise that can be easily adopted and adapted by smallholder farming systems. Pigs can be easily integrated into small- and marginal-scale farming systems and can be fed with by-products from crops that cannot be consumed or used more efficiently by small-scale farmers. In the developing nations, the piggery sector directly empowers the rural poor, precisely the women and tribal population. Besides providing nutrition, pig farming acts as insurance to the weaker section of the society against agricultural failures and loss of labour through sale of pig and pig products. Nevertheless, this sector is still in its developing stage in India and agripreneurs have started taking interest in pig rearing. There are many bottlenecks in its advancement to full capacity, which need to be addressed. Scientific interventions and extension activities aimed to mobilize pig resources towards the empowerment of weaker sections of society can lead to their better livelihood and provide nutritional security as well.

Keywords Piggery · Pork · Artificial insemination · Disease control · Productivity

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1 Introduction

Pig farming contributes to the livelihood of smallholder farmers, both directly and indirectly. It provides income through sale of pigs and their products and also provides household protein nutrition (Lemke and Valle 2008). The quick return is ensured by certain inherent traits of pigs like high fecundity, better-feed conversion efficiency, early maturity, and short generation interval (Bharati et al. 2021). Along with it, the investment on buildings and equipment is also very less in pig farming. Pigs are reared under a variety of production systems, ranging from extensive backyard to highly specialized intensive indoor systems (Pietrosemoli and Tang 2020); however, the global pig production system is dominated by smallholder pig farming (Oosting et al. 2014), which constitutes about 56% of the world's pig population, producing 2–5 heads per year (Riedel et al. 2012). The smallholder pig farmers mostly follow a mixed crop-livestock system in many countries like China, India, Vietnam, Thailand, Singapore, Malaysia, Indonesia, Philippines, Cambodia, etc. Integrated pig farming gives them an additional source of income and serves as an insurance against agricultural failures. Globally, China is the leading producer of pigs with 316 million population (FAO 2020). Figure 12.1 indicates the distribution of pig population in the top seven pig producing countries of the world. In most of the Western countries, highly developed intensive system of pig rearing is practised. In fact, China's small-scale pig keepers are the largest community of pork producers worldwide. About 50–80% of all pigs produced in China originate from smallholder farms (Neo and Chen 2009). Similarly, in India, smallholder pig farming forms an important livelihood resource for small and marginal farmers with less than 1 hectare of land and especially rural tribal people and women farmers (Naskar and Das 2007). They mostly rear pigs in small-scale unorganized farms as an integral part of diversified agriculture, similar to smallholder farms in other developing pig rearing

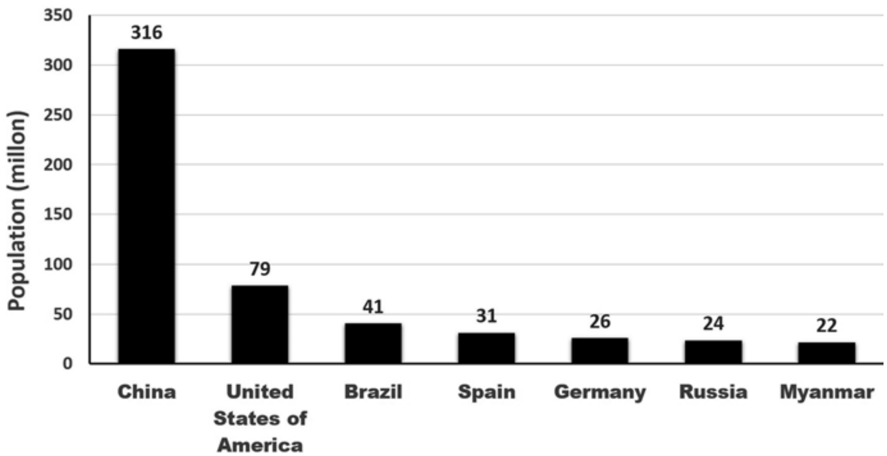

Fig. 12.1 Distribution of pig population in the world (top 7 countries). (Data source FAO Stat 2019)

nations. India occupies seventh position in Asia with 9.06 million pig population (Fig. 12.2). Out of these, 8.17 million pigs are reared in rural India, which forms about 90.12% of total pig population (20th Livestock Census, 2019, DAHD). It constitutes about 1.69% of total livestock population in India (Livestock census 2019). It contributes to 2% of Asia's pig population and 1% of global pig population (FAO 2020). It is mainly the socially and economically backward poor strata of rural poor, women, and tribal, which are closely associated with pig rearing (Kumar et al. 2020). This clearly depicts the significance of the piggery sector in socio-economic development of smallholder systems of rural India.

In India, especially in the North-East (NE) states, pig is the most important livestock and pork is the most favoured meat. The high proportion of the tribal population in states of NE, Jharkhand, and Chhattisgarh support pork consumption and pig rearing is an integral part of their way of life from ancient times (Payeng et al. 2013). Hence, the demand for pork and pork products exists at the farmgate in NE (Kumaresan et al. 2007). Moreover, pig farming is gaining popularity as an enterprise in other states, which cater to the domestic demand in NE states. Due to a significant share of vegetarians and Muslims in India, the demand for pork is usually limited to the hotel, restaurant, and institutional sectors (HRI). With the increase in urbanization and change in food habits, the taboo associated with consumption of pork is waning, and its demand is felt in cities, which is projected to increase in near future.

The piggery sector in India is gaining slow but with steady momentum. The total pig population has improved consistently with small growth over the past 50 years. India shares only 5.23% of total pork production in the world. Pig contributes 4.98% of total meat produced in India (Fig. 12.3) (BAHS 2019). Interestingly, about 50% of the country's pork is consumed in NE India, which they get from their own production as well as procurement of live pigs from other parts of the country (Das and Bujarbaruah 2005). Pork production in India is limited, representing only 9% of the

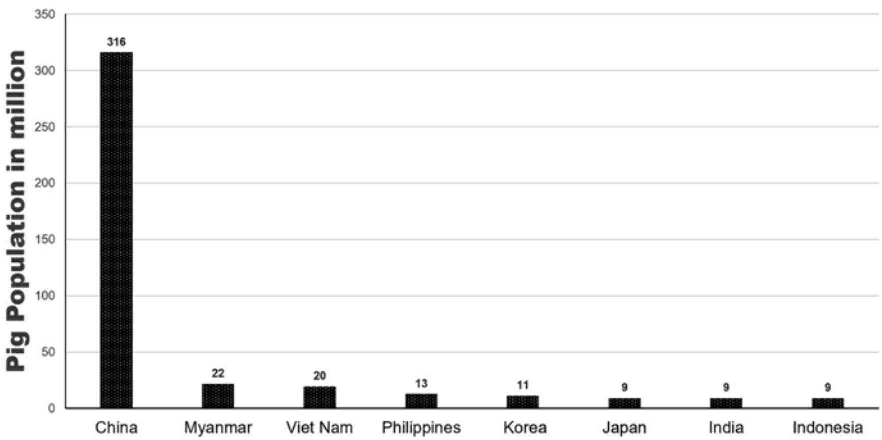

Fig. 12.2 Distribution of pig population in Asia (top 8 countries). (Data source FAO Stat 2019)

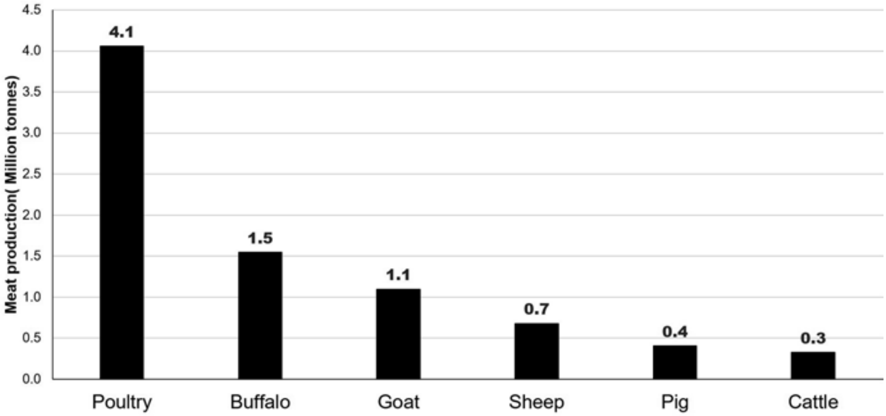

Fig. 12.3 Contribution of different species in meat production in India. (Data source BAHS 2019)

country's animal protein sources. India is a net importer of pork. Most pork imports are in the form of processed meat. In 2018, India imported over 500 metric tons of this meat. On the other hand, the pork exports for the same year were around 270 metric tons.

2 Scope of Piggery Sector

The world population may increase 50% in the next 30–50 years, but that will increase meat consumption by twice. Moreover, by 2050, it is expected that the population in India would increase by 34%, which meant in the current level of production the meat demand will be three times. The developed countries consume a significantly higher amount of meat as compared to developing countries. Furthermore, as developing countries become more developed, meat consumption will concurrently increase. In order to secure food as well as nutritional security for a fast-growing population, there is a need for an integrated approach to livestock farming. Among the various livestock species, piggery offers the most potential source for meat production due to certain inherent traits like high feed conversion efficiency, litter size, and low generation interval. Pigs have the highest feed conversion ratio among livestock. In fact, pigs are the most efficient feed converter meat animal after the broiler chicken. Apart from providing meat, it is also a source of bristles which are used for making brushes and manure for organic farming. Pig farming provides employment opportunities to seasonally unemployed rural farmers and women folks, thus generating supplementary income to improve their living standards. Pigs can consume a wide variety of feeds and can be reared on backyard scavenging system, kitchen waste and agri-industrial by-products including several types of meat that humans don't consume. Breeding pigs is easier and faster than other common livestock. A sow reaches reproductive maturity at about 7 months of age and thus can be bred early and can farrow up to 12–15 piglets at once, twice a year. Starting pig farming requires small initial investments for building sheds with low-cost equipment for maintenance, cleaning, feeding, and watering. The dressing percentage of pig is 65–80%, which directly determines the pork yield. This is quite higher in comparison to other livestock reared for meat purpose like poultry, goat, and sheep or buffalo whose dressing percentage is around 60%. Another significant benefit of pig farming is the production of pig manure which can be used as organic manure in agriculture, fish ponds, and pond fertilization. Fat deposition is faster in pigs than most other animals. Animal fat has huge application in soap and chemical processing industries.

Globally, pig meat has high demand as it is used for making value-added products like ham, sausages, bacon, frankfurter, pickles, curry, etc. Although the Indian market for processed and value-added pork products is small, the demand in the majority of this market is catered through imports. There exist fragmented local companies which manufacture value-added and traditional Indian processed pork products, but their presence is scanty and the industry is still in nascent stage. Due to changing trends in the lifestyle and food habits of people, pork is gaining popularity and has felt demand. With the decrease in social taboos associated with pork production, the demand for pork is going to be three times higher in the near future. In the places where high demand for pork is felt, live pigs are transported from other parts of the country through various routes to meet up their requirement (NAP 2017). The opening of NE corridor of India to southeast Asian countries will give a global market opportunity for pork and pork products. Hence, pig production in a developing country like India requires an immediate transformation from backyard subsidiary enterprise to a commercial venture. Therefore, looking into the prospects of the piggery sector to alleviate poverty, provide nutritional needs, uplift socio-economic status of rural masses, and meet the demand of animal protein, mobilization of pig resources for capacity development and livelihood security is for sure going to yield convincing results.

3 Bottlenecks in Piggery Sector

Although pig rearing plays a pivotal role in uplifting the socio-economic status of the weaker section of the society and a significant percentage of the tribal population depend a greater extent on pig rearing for their livelihood, the majority of such population don’t have means to undertake scientific pig farming with improved foundation stock, proper housing, feeding, and farm management practices. In majority of the rural areas, free-range scavenging system predominates (Mohakud et al. 2020). The local pigs scavenge for the bulk of their food around homesteads, farms, and adjacent areas. Pigs are fed some form of supplementary feed later in the day, which consists of locally available feed resources like cassava, cracked cereal grains, or household scraps. Productivity of these village pigs is generally low with suboptimal growth rates and litter sizes of three to five piglets. There exists a low productivity index among Indian pig breeds with respect to potential growth rates and mature body weight and this gap needs to be filled to develop the pork and pork-based industries. There are few bottlenecks in the present pig production system in India and other developing nations alike, which is a major hurdle in the development of the piggery sector as an enterprise.

3.1 Insufficiency of Quality Germplasm

Good quality sows and boars are indispensable for high-performing farms. It is thus important to improve the genetics, rather than increasing the number of low-quality animals. The availability of a fewer number of breeder farmers throughout the country leads to a shortage of quality germplasm for pig farmers. Thus, the implementation of breed improvement programme might be a better strategy to address the required demand for good quality founder stock for pig farms. New and quality germplasm has been introduced by state and central governments for enhancing the production of pork as well as the adoption of breeding technology for the production of lean meat using exotic and upgraded indigenous pigs. They maintain swine breeds of superior germplasm, which aims at upgrading local animals to enhance productivity and production at farmers' field level; nevertheless, they are insufficient in fulfilling the needs of pig farmers, either due to their remote location or a big gap between demand and supply. With the advent of use of liquid-extended boar semen, which can be stored for 7–10 days under refrigerated conditions, artificial insemination has gained popularity among pig farmers. In India, the unorganized as well as organized pig farms suffer due to lack of quality semen for artificial insemination in pigs. Large-scale availability of high-grade location-specific exotic, crossbreed, and indigenous boars, sows, and piglets needs to be maintained through establishment of pig breeding and multiplying units at farmers field level so that the availability of quality germplasm is ensured to the pig farmers in every corner of the country. Moreover, establishment of infrastructure and upgrading of technology required for preserving and distributing boar semen needs to be upscaled.

3.2 Shortage of Feed Resources

Feed, being the major input factor in all livestock production systems, is critical for productivity of the pig farming. The growth and development of an animal are conditioned by the adequate availability of nutrient-balanced feed (Niemi et al. 2010). Feed costs account for most of the production costs in almost any animal production system, but in the pig industry, feed alone constitutes as high as 65–75 % of the pig production (Board 2008). Any drastic increase in feed cost can reduce the profit margins of pig rearing (Schmit et al. 2009). India is facing an extreme animal feed shortage, which is a major factor behind the recent rise in pig-rearing cost. As per the estimates of the Standing Committee on Agriculture (2016–17), India, the deficit in the requirement and the availability of dry fodder, green fodder, and concentrates will be likely 21 per cent, 40 per cent, and 38 per cent, respectively, by 2025 in India. The growing gaps between demand and supply are a matter of concern. Reduction in forest and pasture land is the reason behind the reduction in green fodder availability. Commercial concentrates feed comprising maize, wheat, and soybean meal and other protein sources is expensive and directly competes with humans and other milk animal's diet. In fact, the high cost and shortage of quality feed are one of the major reasons for lower productivity of Indian pig than the global average. In smallholder system, pigs are fed with rice polish, kitchen waste, vegetable, and fruit waste along with locally available feed resources like wheat bran, dry fishes, fresh squash, tapioca, tree leaves, etc. However, the farmers lack knowledge on the bioavailability of nutrients in these feedstuffs and feed their animals based on their traditional knowledge and practices. Therefore, a need arises for cost-effective alternative feeding strategy incorporating locally available non-conventional feed resources to lessen the cost of pig production and maximize profit.

3.3 Diseases

The advent of new diseases and occurrence of different infectious diseases is one of the important factors which affects the development of the pig industry and hampers the profit of the pig farmers and entrepreneurs. The presence of disease adversely affects feed intakes and efficient utilization of feed. There are many important diseases which severely hamper the pig industry like Classical swine fever disease, Porcine Respiratory and Reproductive Syndrome, Foot and Mouth Disease, swine influenza disease, porcine circovirus disease, mastitis, porcine parvovirus disease, coccidiosis and respiratory diseases, *Streptococcus suis* infection, etc. The most significant ectoparasite which has serious economic impact on growing pig is Sarcoptic Mange. Besides ectoparasites, intestinal parasite *Ascaris suum*, the pig nematode, significantly hampers the economics of pig farming. The growth rate and feed efficiency may be depressed by up to 10% due to ascaris infestation. As the eggs of ascaris are highly resistant in nature, the infection with this parasite remains highly significant for the foreseeable future. Recently, the outbreak of PRRS and African swine fever disease has severely affected the pig industry. African swine fever (ASF) is a highly contagious viral disease of swine, causing 100% mortality in domestic pigs. This disease caused mortality of 17000 pigs in Assam state only till June 2020 after its 1st report in February 2020. As the mass culling of the whole farm is the only way to control these diseases, a major proportion of pigs have been culled and a great loss to farmers occurred and forced the small pig farmers to change their profession. To control the disease, the best way is to maintain proper biosecurity measures at the farm and effective management of the farm to reduce disease incidence. It could be done through thorough cleansing and disinfection, disease diagnosis and reporting, timely vaccination against major economic diseases, etc.

3.4 Veterinary Services

Most of the pigs in smallholder farming system are reared in a rural area. Rural tribal folks and women farmers often lack professional knowledge on health management of pigs (Balogh et al. 2009). In those pockets, the veterinary services have not reached sufficiently; also, along with that there is a lack of awareness programmes for pig health, routine health management practices, and biosecurity measures. In addition to lack of capital investment, they try to decrease their input costs by minimizing the cost of veterinary inputs, and in most cases, they do not recognize the role of veterinary services in improving performance in pig breeding enterprises. Veterinarians, by virtue of their proficiency and their knowledge of meat inspection, play a broader role in facilitating the transfer of science-informed animal care recommendations and requirements to the farmers (De et al. 2021). Government and industry documents on animal care and transport also include statements recommending that pig farmers seek veterinary advice before loading and unloading pigs. Even if the veterinary hospitals and services are available; the cold chain of different available vaccines is sometimes collapsed due to electricity failure in the rural interior area. These factors hamper the performance of pig farms located in rural interiors, which needs interventions at the level of local government and veterinary departments.

3.5 Safe Pork Production and Facility of Hygienic Slaughterhouse

Small-scaled pig farming, which dominates India's pig production and rural farmers, is less likely to adopt safe pork production practices due to the low capital resources with them as compared with large-scale or commercial farmers (Zhou et al. 2015). Investments on production and slaughter infrastructure are not feasible with rural women folks practicing pig farming in the backyard system. Large-scale pig producers can easily purchase quality inputs because of the return of scale they achieve, which ultimately reduces their production cost. Studies have revealed that production economics is an important factor influencing farmer's safe pork production behaviour (Wang and Wang 2012). Farmers' education level is another major factor that may influence farmers' safe production behaviour. Hence, awareness programmes and extension activities on safe pork production practices should be conducted to increase its adoption level. A major portion of the pig production in India as well as in South-East Asia is in the form of unorganized small-scale household rural production. In those areas, the facility for the hygienic slaughterhouse for pigs is almost nil and pigs are slaughtered on the floor according to the traditional method. The selling of pork is also widely distributed in the unorganized retail sector. Most of the people purchase pork from open outlets in form of wet meat, since consumption of fresh local meat is more preferred which may be because of cultural or consumer perceptions. Pork processing and storage unit are not developed in the production pockets; however, traditional practices of increasing the shelf life of pork are followed to prevent spoilage of leftover pork either by preserving them or preparing pork products. Training programs on safe pork production practices and hygienic slaughterhouse culture need to be imparted to augment quality pork production in rural small-scale piggery sector.

3.6 Lack of Skilled Labour

Farm labour plays an important role in the success of the farm, especially in the developing and under-developed nations, where mechanization in farming is yet to be established. The piggery sector has experienced many changes in the management of pig production facilities. Initially, with small-scale pig farms, it can be managed with the family labour, but with the increase in capacity of farm and introduction of exotic breeds, the labour need also grows. Large-scale commercial farm and pork production unit require skilled and semi-skilled labour to manage farms and routine activities. Skilled labour contributes to another major production cost after feed on these farms. With the increase in specialization of farm units like pork preservation and production of value-added products, the need for a skilled labour force increases. Mechanization is required in case of high output on the rail slaughter house system. Mechanization demands huge input at a time as an installation cost, but all those works can be done cheaply in India with skilled labour. An abundance of labour is a great advantage in these countries, still the deficit of skilled labour and reluctance of the people to get involved in the piggery-related work is another constrain in the pig industry. Another pressure is urbanization, which attracts the migration of rural young people to the cities which ultimately leads to labour scarcity for the piggery sector. Skill development programmes aimed at imparting training in specialized pig production channel are critical for fulfilling the labour demand of the pig industry.

3.7 Climate Change

With the change in environmental conditions, global warming, urbanization, and population explosion cause the shrinking of land availability and water. Furthermore, the increase of rainy days in some parts of India increases susceptibility to different diseases, and hence, piglet mortality. The changing environment sometimes provides a favourable situation for the emergence of new diseases. It is expected that the disease pattern will change with the climate change as the life cycle of vector and the gastrointestinal parasite will change. Nonetheless, the chance of feed resource availability will face acute shortage due to destruction of cultivation area in flood or shortage of water. The storage life of feed is simultaneously getting hampered due to humidity change supporting different detrimental fungal contaminations in feed. Investments in shelter management to combat seasonal stress, mainly heat and cold stress, will be critical to successful outcome of pig production system. With these challenges, strategies need to be formulated so that the piggery sector can be least affected by extremes of climate change and drive a growth among the smallholder farmers.

4 Strategies to Tap the Potential of Piggery Sector

Meeting the future demand and secure the livelihood of the rural pig farmers is the prime objective. A highly motivated and productive work plan needs to be generated with proper incentives for smallholder system to boost the overall production capacity. A consistent goal of farmers and government to reach the realized target is critical to uplift the rural economy through the piggery sector. In this regard, National Action Plan recommended some important strategies for overall growth and improvement of the sector.

4.1 Production Cost Reduction

Although most of the pig production in the present condition is backyard type with scavenging and semi-scavenging system in the rural sector, to fetch better return and meet the future huge demand, the farmers need to be mobilized into much more organized in their own small-scale production system. The major production cost in organized farms is feed cost. The feed expenditure takes the major chunk of production cost in the pig industry. The farmers have to address the production cost through precision in feeding management, identifying unconventional feed resources and agricultural by-products and following a scientific pig rearing system, effective health management, and proper use of available resources. Each pig has individual nutrient requirements. The farmer has to fulfil the individual requirements. Excess feeding will cause excretion of the valuable nutrient and when the nutrient goes into the field through the slurry, it saturates the soil and leads to a bad environment. Therefore, it states the requirements of precision feeding according to their age and body weight. Furthermore, farmers have to consider the nutrient and micronutrient balance as per their physiological stages.

4.1.1 Non-Conventional Feed Resources (NCFR)

Pigs are monogastric animals or animals that have a simple stomach. Their digestive system is relatively simple and they don't have the ability to digest and utilize large amounts of fibrous material in their diet like ruminants do. However, these animals have the ability to feed resources of varying types. Pigs are omnivores and can utilize both animal and plant material to aid in maintenance, growth, and production. Hence, non-conventional feeds can be of both plant and animal origin. The plant NCFR supply the energy which takes the place of maize and the animal NCFR supplement protein to the diet. Animal NCFR used in pig diet include meat, bone, fish and blood meals, feather meal, and hatchery by-products such as dead birds and eggs. Silkworm pupa can also be included in this list. Plant NCFR include rice polish, bananas, cassava tubers, sugarcane, potatoes, bananas, wheat millings, maize gluten and sorghum gluten, cotton, soybean and sunflower, molasses and sugar beet pulp, citrus and pineapple pulps as well as fresh fruits that were not consumed by humans. These non-conventional feeds can be good sources of energy, amino acids, and minerals in pig nutrition and can be used to promote the growth of pigs at different physiological states.

However, their dietary inclusion might be restricted by the presence of anti-nutritional factors (ANF) like tannins, trypsin inhibitors, lectins or glucosinolates, and high fibres, which interfere with nutrient digestibility in pigs (Woyengo and Nyachoti 2011). Nutrient digestibility of these feeds can be increased by interventions like chaffing, heat treatment, dehulling, and enzyme digestion. Chaffing causes reduction of particle size for feeds, because it increases the surface area of particles for action of digestive enzymes (Liu et al. 2013). ANFs like trypsin inhibitors that are present in non-conventional feeds for pigs are heat labile, and therefore, heat treatments can reduce them (Jezierny et al. 2010). Seed hulls are rich in tannins and fiber, which reduce their nutrient utilization. Dehulling of seeds reduces the content of these ANFs and may increase their nutrient utilization in pigs. It was observed that replacement of 30% hulled faba bean with dehulled faba bean improved starch digestibility from 95 to 98% in diets fed to grower pigs (Van der Poel et al. 1992). Scarification of cereals decreases hull fiber content and also removes mold and mycotoxins that remain on the hulls of grains (House et al. 2003). Plant-based non-conventional feeds have a high proportion of phosphorus in phytate that is weakly digested by pigs (Woyengo and Nyachoti 2011). Moreover, phytate decreases absorption of other dietary nutrients by binding to them or digestive enzymes. High fibre in conjugation with phytate decreases nutrient digestibility in pigs (Woyengo and Nyachoti 2013). Therefore, adding supplemental fiber and phytate degrading enzymes like carbohydrases and phytases to diets can amplify the nutritive value of alternative feeds (Zijlstra et al. 2010). It has also been proposed that predigestion of fibrous feeds with exogenous enzymes before feeding to pigs may increase nutrient availability of non-conventional feeds, and hence, optimize their addition in pig diets (Columbus et al. 2010). If these resources are used judiciously in a pork value chain, it will produce added advantages like lowering feed costs for commercial producers and provide the small-scale farmers to earn a living by feed formulation from NCFR. It is environmentally safe, since there is minimal wastage of industrial by-products. The increase in carcass quality causes high demand. Use of minimal chemical treatments allows pigs to be reared on a more organic diet and manure produced can be utilized for agriculture production. However, further research is required on genetic variation and growth prospective of pigs fed with NCFR.

When using alternative feed resources, the cost of inclusion of alternative feed resources needs to be critically considered before their inclusion in pig diets. Even if the product is cheaper, factors such as transportation, special processing needs, and storage must be taken into account (Board 2008). Moreover, for its implementation in pig diets, research on its nutritive value and the effects of including such alternative feedstuffs on their growth, productivity, and quality of pork is mandatory. Also, farmers need to be trained on how to utilize locally available non-conventional feed resources and optimizing their use in pig diets. Standardization of the level of inclusion of NCFR is critical for providing balanced feed for optimum growth and performance. The inclusion rate of ingredients is dependent on palatability, nutrient availability, protein quality, nutrient interrelationship, and the method of processing as well as feeding techniques. Characterization of alternative feedstuffs can reduce their risk for dietary exclusion and also increases the flexibility of feed formulation. The increased awareness about the nutritional quality and impact on growth performance and carcass quality of alternative feedstuffs (Muthui et al. 2018) has increased the reliability on using these non-conventional feed in pig diet. However, finding low-cost and reasonably economic pig feed for different locations is mandatory to harness the potential of NCFR.

4.1.2 Precision Feeding

Farm animal production is frequently associated with problems of limited arable land and the environmental issues, and hence, improving nutrient efficiency becomes an essential concern because with the expected increase in the human population, these problems are going to get aggravated (Niemann et al. 2011). Thus, maximizing feed efficiency, with minimizing production costs, and environmental impacts are the main challenges for pig farming practices. Precision feeding, a major breakthrough in pig nutrition, brings one of the most promising avenues to promote nutrient efficiency and yield superior quality and safe pork with the lowest environmental impact and high animal welfare standards. It is the application of feeding techniques that requires animals to be fed with diets customized according to the production objective and individual requirements along with due consideration of environmental impact and welfare issues. It involves feeding individual animals with routine changes in nutrient requirements which is actually required in real time. Development of precision feeding systems requires correct knowledge of available nutrients in feed ingredients, precise diet formulation, and determination of the nutrient requirements of individual pigs or group of similar pigs (Pomar et al. 2009). Application of precision feeding systems in commercial farms can be implemented with ease (Banhazi et al. 2012a) compared to the smallholder pig rearing systems. However, precision feeding at the individual level can yield success where measurements, data processing, and control actions can be implemented on individual animal (Wathes et al. 2008). Hence, to further develop precision feeding systems, it is essential to advance our understanding of numerous animal physiological and metabolic processes. Another area of concern is that precision feeding is based on mathematical models and nutritional concepts which are mainly developed for average population responses. If this principle is applied in feeding individual pigs with daily customized diets, it may result in inaccurate results (Remus 2018); hence, it is mandatory to distinguish the dietary requirements of a population from those of an individual pig. Besides this, the new understanding of individual metabolism and nutrition, rather than a group of animals, will allow pig rearing sector to flourish, since it will cut down the cost of feed (Pomar and Remus 2019). Precision feeding will yield immediate and substantial benefits to the pig farmers. But, in order to realize this gain for smallholder farming systems, advanced scientific knowledge in pig farming should be integrated with information and communication technologies customized for use by farmers who are literate or semi-literate. They need to be demonstrated and on-farm hands on training need to be provided to pig farmers, so that farmers can implement precision farming in practicality.

4.2 Pig Productivity Improvement

However good the feed might be, the performance of an animal cannot go beyond the genetics. Another avenue to increase the pig productivity can be improved through utilizing improved breed of a pig by breed improvement and identifying superior germplasm suitable to the particular agro-climatic needs. Superior genetics attain higher growth rate and higher feed efficiency with balanced feeding. Knowledge on pig breeds and their performance is requisite to attain high production benefits.

4.2.1 Exotic Breeds

The farmers and entrepreneur having high input facility and investing power can adopt exotic breeds of pig for commercial pig farming. The exotic breeds have been recommended region wise in the country like for Northern part of India Large White Yorkshire (LWY) and Landrace (LR), for North-eastern India Hampshire and LWY, for Eastern India Hampshire and Tamworth, for Central India LR and LWY, for Southern India LWY, and for Western India LWY. Exotic animals have some adaptability issue and disease incidence, but they have excellent growth and reproductive performances which attract the entrepreneurs who are interested in high return in short span of time.

4.2.2 Indigenous Breeds

The farmers in the breeding tract of indigenous breeds should be encouraged to rear the indigenous breeds of their region. This will not only conserve the local germplasm which is well-adapted to the particular regions of the country, but also maintain the uniqueness and purity of the indigenous breeds and thus variability in the pig genetic resources will be maintained. The farmers having low input for pig farming and not much support can do backyard farming with indigenous breeds and they can use these indigenous pigs for upgrading nondescript pig population. There are 10 indigenous breeds, like Doom breed in Assam state having superior pork quality, Ghoongroo breed in Bengal region is very prolific breed, Nicobari pig in Andaman and Nicobar islands, Niang Megha breed in Meghalaya state, Agonda Goan breed in coastal state Goa, Ghurrah breed in Uttar Pradesh, Tenyi Vo breed in Nagaland, Zovawk breed in Mizoram, Purnea breed in Bihar, and Mali breed in Tripura state. These breeds have been adapted to diverse climatic conditions in the country.

4.2.3 Crossbred Varieties

The beneficial characters of both indigenous breeds and exotic breeds can be introgressed into a single animal by cross-breeding programmes. There are many crossbred varieties developed by cross-breeding and selection and continuous *inter se* mating to stabilize the breed characteristics after 7–8 generations of inter se mating and selection. These crossbreds developed have much better growth and reproductive performances than indigenous breeds and better meat quality, disease resistance, and adaptability to local conditions than exotic breeds. Moreover, these crossbreds can be reared in medium input system; they need less input than exotic breeds, but more than the indigenous breeds. Thus, the farmers who have moderate input facilities can use the crossbreds for starting their pig farming and can gain better economic return.

4.3 Household Return Hike

The household income of the pig and pork producers can be enhanced through the processing of different value-added products for that processing plants and cold chain setup is essential which will facilitate diversified animal produce (Organic & hygienic). Nonetheless, proper waste management also can be an indirect source of income if they learn to organize the whole process that further generates employment. The value addition of the pork can give the farmer maximum return and income. Along with the value addition, the technology for improving the shelf life of the product through different packaging and addition of healthy functional foods like fruits, antioxidants, bioactive compounds, and vitamin addition has to be promoted to attract consumers. Nowadays, different value-added products are available which fulfil the taste of the consumer, improve quality, and optimize convenience. Therefore, it is time to promote the production of value-added products at utmost importance. Other than farm excreta, a huge amount of waste is produced during slaughter. Slaughterhouse waste consists of bones, tendons, skin, and the contents of the gastrointestinal tract, blood, and internal organs, which neither be sold as meat nor be used in meat by-products in India. In the present condition, our slaughterhouse waste management system is very poor which demands serious thinking for effective utilization.

4.4 Strengthening of Marketing Chain

Unfortunately, pork production and mostly the supply of pork are the most ignored part in our country. Mostly, the pork is sold in the open market and may be contaminated with dust and dirt without any packaging for local consumption. This long-established conventional selling system is mostly unhygienic and disintegrates the image of the Indian pork industry. Furthermore, the unorganized sector also determines marginal profits for the producers. However, to sustain the global market and modernization of the other field, the pork industry also has to develop in the contemporary integration for the development of the farmer, processors, and well-being of the consumers. For this adequate market, infrastructure has to be developed with the fulfilment of the marketing facilities. Presently, there is an acute shortage of pork slaughterhouses and processing plants throughout the country. Therefore, it is essential to set up a modern slaughterhouse with a pork processing plant as the State of Art. Not only the slaughterhouse and processing plant, there needs to be the installation of cold storage for maintaining the cold chain as pork is a highly perishable product. Besides, proper transportation with cold chain facility also has to be established to distribute the pork product as per the demand in different cities and pocket. At least, a rural slaughterhouse is very much essential for producing hygienic meat for the local consumers.

4.5 Control of Emerging Disease and Prevention

Animal health always plays a key part in the production system. Incidence of disease and emergence of new diseases take a huge toll on pork production. Close monitoring and surveillance for the diseases are of utmost importance for controlling the outbreak and progress of the piggery industry. The spread of infection and disease not only impedes the production of pigs, but also certainly hinders the quality of the pork product. Animal health is closely related to day-to-day management practices and nutritional abundance. Therefore, for ensuring the optimum health of the pork, the management practices and feeding of the animals have to be as per their requirements. Through strategic control, eradication of economically important diseases will definitely boost the total pig production in the country. A proper health improvement scheme is essential to implement safeguarding the pig from diseases. The health improvement scheme also incorporates periodic health check-ups, monitoring, awareness programmes, disease diagnosis, and treatment programs along with the supply of quality feed and supplements. The producer must follow the vaccination schedule and deworming schedule. The farmers and animal handlers have to be trained for first aid and emergency management. The morbidity and mortality should always remain under control through focused veterinary health programmes.

The above strategies and steps are very much essential for the betterment of the existing farmer and pork production system. However, it is necessary to encourage the farmers for entrepreneurship development of the pig farming to meet the huge demand of the pork in the country and NE region and further export. For entrepreneurship development, the farmer needs bank credit and insurance cover, farmer cooperative, subsidy on livestock rearing input, and distribution of the quality germplasm unit.

4.6 Development of Local Cooperatives for Pig Farming

Farmers' cooperatives have proven to be a grand success in the development of livestock industry. They have increasingly played an important role in agricultural food industries, supply chain, and marketing as they connect and coordinate farmers, intermediaries, and companies. The success of milk cooperatives in India is a shining example of a miracle they can perform in transforming the life of farmers and the face of milk-based industry. In a similar analogy, development of regional pig farmers' cooperatives through a central system can provide pig farmers access to technical expertise, veterinary services, and financial resources, which would otherwise be inaccessible to rural smallholder farmers. Pig farmers' cooperative would provide greater direction, leadership, and motivation to uneducated rural women folks from their local progressive farmer. The farmer-owned cooperatives can provide production supplies and marketing services, which are usually difficult for small and marginal farmers, due to the lack of transportation facility and knowledge on market linkage and supply. Cooperatives must help farmers collectively purchase high-quality superior breeds and encourage them to use breeds reproduced by known farms of repute, instead of purchasing from unknown farms or companies. This would ensure that the breeds purchased are safe, prolific, and resistant to epidemic diseases. Cooperatives should engage veterinarian services because they are the professionals who can provide suggestions and treatments on health management and services for better farm performance. Process to streamline frequent visit of veterinarian should be in place, which can be arranged solely by cooperatives or jointly by the cooperatives and their collaborative companies/state/central governments. Cooperatives can help change farmers' behaviour on safe pork production substantially by increasing awareness on how to use vaccinations, health calendar, how to address waste, and which feeds to purchase (Chen et al. 2018).

Also, the significance of services related to collective selling of pig and pig by-products by cooperatives cannot be ruled out. Cooperatives could collaborate directly with downstream stakeholders or connect with pork processing industries to help farmers sell pigs. Thus, in this way, pig cooperatives are a promising way to provide critical help to improve farmers' livelihood by providing pig selling services and contributing to stabilization of farmers' income from rearing pigs.

4.7 Institutional Support

In this regard, capital subsidy is provided by the Department of Animal Husbandry, Dairying, and Fisheries, Ministry of Agriculture, Govt. of India, for ensuring the viability of the pig breeding, rearing, and related activities. The goal of the scheme is to encourage commercial pig rearing by farmers/labourers to improve production performances of native breed through cross-breeding by using selected animals of high-performing breeds. Producer companies, partnership firms, corporations, NGOs, SHGs, JLGs, cooperatives, and individual entrepreneurs are eligible for scheme (Table 12.1).

4.8 Science and Technology-Driven Intervention

4.8.1 Introduction of Area-Specific Need-Based improved breeds

India is home to ten registered breeds and many local nondescript pig breeds, which are distributed in their home tract throughout the country. These indigenous pig breeds are adapted to the local climatic conditions and are reported to have better heat tolerance, meat quality, good quality bristles (Mohan et al. 2014), and early sexual maturity (Karunakaran et al. 2009) when compared with exotic/ crossbreds. However, exotic pigs introduced in India, viz. Large White Yorkshire, Hampshire,

Table 12.1 The institutional support provided for pig farming (Source DADF, GoI)

Components	Subsidy
Pig breeding farms	25% of the outlay (33 1/3 %) in NE states (including Sikkim and hilly areas) subject to a ceiling of Rs. 1.50 lac (Rs. 2.00 lac in NE states including Sikkim and hilly areas)
Pig rearing and fattening units	25% of the outlay (33 1/3 %) in NE states (including Sikkim and hilly areas) subject to a ceiling of Rs.19000/- (Rs. 25300/- for NE states including Sikkim and hilly areas)
Retail outlets	25% of the outlay (33 1/3 %) in NE states (including Sikkim and hilly areas) subject to a ceiling of Rs. 2.50 lac (Rs. 3.33 lac in NE states including Sikkim and hilly areas)
Facilities for live markets	50% of the outlay subject to a ceiling of Rs. 2.50 la

Duroc, Landrace, etc., have higher growth and production performance. Exotic pigs and their crossbreds have gained popularity over indigenous breeds and are preferred for rearing by pig farmers. But they require higher inputs in terms of feed and farm management compared to indigenous pigs. Hence, the choice of pig breeds for rearing should be based on local climatic conditions and input cost available so that the farmer is not burdened and can gain considerable profits to expand the capacity of his farm. The indigenous breeds can be promoted for breeding purpose under low input production system (Patra et al. 2016) and exotic and their crossbreds under high input systems. The indigenous, crossbred, and exotic pig population dynamic has also changed in India. Although the crossbred and exotic pigs increased by 12.7% from the year 2003 to 2012, the majority of the pig population in India is of indigenous breeds (76%). However, the increase of crossbred pigs showed a sharp increase in total population contribution shares from 14% in 1992 to 23.86% in 2012. In India, on the basis of the demand from different classes of farmers and availability of input, different types of pigs were developed which could be utilized by farmers for their social and economic upliftment. In this direction, breeding units of pure indigenous registered breeds can be set up at the multiplier farms in their domestic tract so that crossbred pigs or pure indigenous breeds can be made available to farmers/entrepreneurs/ SHGs/Cooperative societies/Farmers Producer Organisations, etc. The list of crossbred varieties developed under All India co-ordinated Research Project (AICRP) centre and at ICAR-NRC on Pig is given in Table 12.2.

4.8.2 Adoption of Artificial Insemination in Pig Breeding

It ensures accelerated propagation and amplification of genetic merit, economic savings, delineated reproductive management, and disease control (Althouse and Rossow 2011). Hence, the availability of quality tested semen for AI in pigs through semen banks can help in bringing superior genetics and reduce the cost of keeping breeding boars at farm.

Table 12.2 Crossbred varieties developed under All India co-ordinated Research Project (AICRP) centre and at ICAR-NRC on Pig

Crossbred varieties	Developed at state	Breeds used for cross-breeding
Rani	Assam	50:50 Hampshire X Ghoongroo
Asha	Assam	50:50 Rani X Duroc
Mannuthy white	Kerala	75:25 % for LWY and Desi of Kerala
TANUVAS KPM Gold	Tamil Nadu	75:25 LWY X Desi of TN.
Lumsniang	Meghalaya	75:25 LWY X Niang Megha
HDK-75	Assam	75:25 Hampshire X Doom
Landly	UP	75:25 LR X Ghurrah
SVVUT 17	Telengana and Andhra Pradesh.	75:25 LWY X Desi of Andhra Pradesh.
Jharsuk	Jharkhand	50:50 Tamworth X Desi of Jharkhand

4.8.3 Training on Scientific Pig Practices

Proper training of pig farmers for timed AI, housing, breeding, feeding, reproductive management, and slaughter in pigs under different rearing systems is crucial to attain success in pig farming. Feeding of balanced concentrate feed according to age requirement to pigs is practiced in commercial-type pig rearing system, but the smallholder, backyard system of pig rearing hardly follows this practice. The traditional pig feeds provide inadequate nutrition to support optimal growth rates and to maintain good health. Even if the concentrates are readily available in the market, lack of knowledge and cost constraints do not allow them to follow concentrate feeding. Few farmers follow feed formulation by mixing feed ingredients like maize, wheat bran, or rice polish, or the locally available feed materials and fed it to pigs in addition to farm and kitchen waste. However, protein-rich feed ingredients or mineral and vitamin mixture are hardly added to the pig diet. This is possibly because pig producers lack knowledge of pig nutrition together with financial constraints. The productivity of pig farming is strongly linked to the feed resource availability and the cost of commercial feed, hence adoption of alternative feed resources can compensate for feed cost. Hands-on training on the development of area-specific alternate feed resources and silage making for profitable farming should be encouraged. With the advent of new emerging zoonotic diseases in pig, training on biosecurity measures and health management is another key area, which should be imparted to pig farmers. Moreover, farmers can be trained on pork processing techniques and production of pork products by value addition for additional income. The development flowchart is depicted in Fig. 12.3, wherein farmer's capacity building on scientific pig farming can significantly increase their income from pig rearing and help in changing their outlook towards this sector. This will change the adoption behaviour and motivate more farmers towards choosing scientific pig practices over traditional methods, which will in turn result in livelihood upgradation of rural community as a whole.

4.8.4 Entrepreneurship Development

Development of a strategy for location-specific entrepreneurship development, with readymade plan for 100/200/500/1000 animal, can attract educated, unemployed youths from small and marginal families towards pig rearing. This plan should include guidance on capital investment, credits suppliers, animal procurement, feed formulation, and marketing strategies with complete information on value chain in piggery sector. For undertaking pig farming on scientific lines, mentorship should be provided with matters relating to policy, planning, and operations for obtaining agriculture credit. The window of operation should be streamlined with ground-level credit institutions and banks providing investment and production credit for various activities under piggery sectors for ensuring integrated rural development. Coordination of the development activities through a well-organized channel between technical services department and technical centres at the credit institutions should be ensured. For construction of pig farms with very large outlays, detailed project reports need to be prepared which should include information on land development, construction of sheds, and purchase of the founder stock, equipment, feed cost, and probable income generation. Hence, training on project report preparation which is a prerequisite for sanction of the loan should be imparted.

4.8.5 Subsidized Supply of Inputs

Scientific pig production and hygienic slaughter require sophisticated instruments and setup, which are largely unaffordable for small and marginal pig farmers. In order to popularize pig rearing as an enterprise for rural development, incentives and subsidies on inputs for setting up modern slaughter house, pork processing units, and pig farms can boost the interest of younger agripreneurs and small and marginal farmers towards scientific pig production.

4.8.6 Trainings on Farm Management

Application of automatic monitoring of animals and farm resources will provide continuous data on health and performance of animals, which will be beneficial for the timely detection of estrous, farrowing, and diseases in individual animals. This will in turn support production decisions, decrease the use of antibiotics, and avoid the spread of infectious diseases (Banhazi et al. 2012b). Managing farm records and feeding schedule by means of advanced scientific technologies will make it possible to identify diseases early and apply individual treatments precisely to improve herd performance, reduce antibiotic use, and contribute to improved public safety. Adoption of scientific pig farming practices by smallholder farmers will ultimately augment profitability, efficiency, and sustainability of the overall pig production system.

5 Conclusion

Livestock rearing is a key livelihood and risk mitigation strategy, especially for small and marginal farmers in the developing countries. Pig has always remained associated with the socio-economically weaker sections of the society, compared to any other livestock species and this signifies greater potentiality to contribute to a faster economic return to the farmers. Pig production system has changed dramatically in the developed economies and wave of change has also affected all levels of the pig production system including slaughter, processing, and retailing in developing and underdeveloped economies as well. The traditional medium-sized independent pig farming is projected to be gradually replaced by commercial-type, scientifically managed farms. However, looking into the vast percentage of population thriving on subsistence level pig farming, a major population may still continue with smallholder pig farming system. Various levels of interventions required for mobilizing pig resources and their effects are represented in Fig. 12.4. It cannot be doubted that science and technology-led intervention can address the future challenges for growth and development in pig husbandry sector; however, empowerment of the economically poor rural tribal households, especially women, is critical for adoption of new technologies for pig rearing.

Pig rearing is yet an unorganized venture, which deserves science and technology-driven support to make it a full-fledged enterprise like the poultry industry. The various stakeholders require promotion at various levels such as technology, entrepreneurship development, and financial support to bring Indian pig farming to a global level. The competitive forces of changing technology, economies of farm size, and consumer preferences for organic pork are sure to transform the face of the piggery sector and cooperatives will have a major role to play. They can provide new incentives and induce change in the adoption behaviour of pig farmers for scientific farm management, which have significant effects on the methods of production, economic outcome, and social well-being of the pig farmers. Moreover, the collective and coordinated efforts of veterinarians, scientists, cooperatives, progressive farmers, and the entire pork value chain are required to create pig as a profitable venture. Dedicated field workers for bridging the gaps in knowledge of farmers on scientific practices of pig farming are critical for mobilizing the pig resources for advancement of this sector. Furthermore, the demand for pork products is expected to increase in the future, which may be strongly influenced by local socio-cultural values; hence, pigs reared in conventional smallholder systems may gain preference

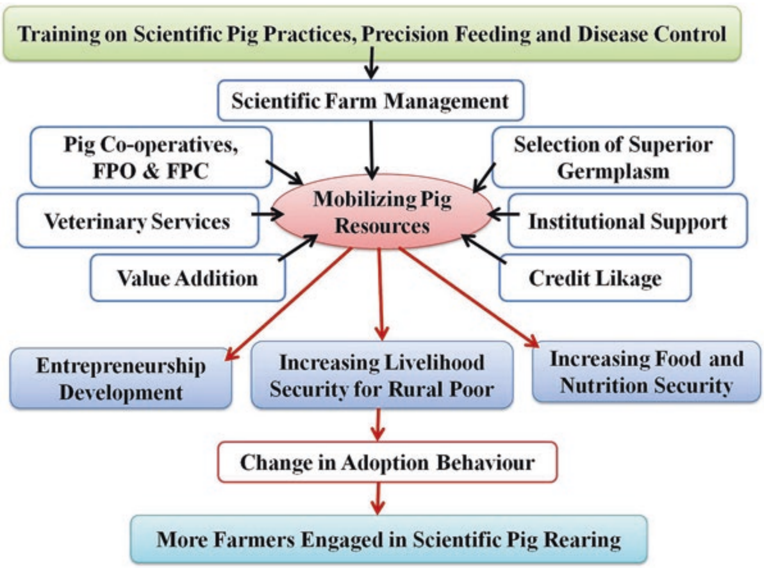

Fig. 12.4 Various levels of interventions required for mobilizing pig resources

due to their closeness to natural system in comparison to highly stocked intensive system. For developing and least developed countries, where meat industry has not yet been fully explored, piggery sector has great promises to offer; however, its domestic and export potential needs to be fully explored. Therefore, it has immense potential to ensure nutritional and economic security for the weaker sections of society, especially for smallholder systems.

Conflict of Interest The authors declare no conflict of interest.

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Chapter 13
Agricultural Value Chains: A Cardinal Pillar for Future Development and Management of Farming

S. K. Dubey, Reshma Gills, Atar Singh, Uma Sah, and R. R. Burman

Abstract Agricultural research organizations worldwide consider that value chains are essential for the efficient and effective management of food production systems. More than a concept, it acts as an operational model for sustainable development through the economic advantages which it could make in the global competitive marketing economy. This chapter tries to give a detailed and structural description of the value chain development process as a tool for Future Development and Management of agriculture. This chapter starts with a discussion about the value chain concept as an operational model and why it is needed in agriculture. The chapter also contains a detailed description of the history, structure, stakeholders, and players in agricultural value chains. Further, the chapter deals with the process of value addition, different models of value chain development (Farm to fork model/ Farm to Foreign model/Local value chain development), frameworks for value chain development intervention like “Will-Skill” framework and Adopt-Adapt-Expand-Respond (AAER) Framework, and Business perspectives and Business development services (BDS) in agriculture value chain development. The chapter also gives a detailed description of different quantitative and qualitative methods for the value chain analysis and the role of market systems in the value chain development process. The chapter illustrated the process of value chain development and the probable constraints in each stage through real-time field examples quoted from Indian agriculture.

Keywords Agricultural value chains · Management of farming · BDS · AAER · Stakeholders

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1 Value Chain: An Operational Model

The term value chain has gained worldwide attention among researchers, policy-makers, marketing agents during the last four decades (WTO 2013) due to globalization, and liberalization-assisted changes in the global trade economy. The term has integrated with developmental activities of almost all the areas, including agriculture (Donovan et al. 2015), knowledge creation (Chyi Lee and Yang 2000; Ermine 2018), education (Dorri et al. 2012; Pathak and Pathak 2010; O'Brien and Deans 1996), marketing (Zahay and Handfield 2003), health (Walters and Jones 2001; Sharan et al. 2015), hospitality (Odoom 2012; Sharma and Christie 2010), emotional, and attitude (Lopez-Mosquera and Sanchez 2012) dimensions. A value chain is not a tangible object that everyone can see. Instead, a value chain is a way of indulgence in producing, marketing, buying, and selling different things by providing and integrating capital, access to various networks, markets, innovations, knowledge, and technologies. It describes the full array of activities that are prerequisites to bring a product or service from idea conception through the transitional stages of production, processing, marketing, and delivery to ultimate users, after-sale customer services, and final discarding after use (Kaplinsky 2004; Nadja and Merten 2015). More precisely, the term value chain can be called the value-adding activities of any firm for its products, based on their understanding of their capabilities and customer needs and wants (Kumar and Rajeev 2016; Kaplinsky and Morris 2020).

A value chain in agriculture or "Agricultural value chain" recognizes the set of action activities and actors involved in bringing a natural or primary agricultural product from the "farm to fork" for final consumption. The value is added to the product at each stage of its transformation (FAO 2005a; FAO 2010a). The product transformation might have happened in various stages through various activities like cleaning, grading, processing, packaging, transporting, storing, marketing, and distribution (Kidoido and Child 2014). Vertical and horizontal action networks interlink the transitive movement of produce in each stage. Similarly, each activity node of the value chain has backward and forward action networks or linkages. In the economic concepts, it can be termed as a miniature of an economic system in which upstream agents (producers/ farmers) are connected to downstream cohorts (consumers at various stages) by technical, financial, territorial, organizational, and social relationships (Joshua et al. 2021; Yanti et al. 2021). Since agriculture plays a substantial role in the socio-economic and cultural development of many of the developing countries by its significant contribution to the total gross domestic product (Junankar 2016), continuous monitoring, and development of agricultural value chains in terms of valuable resources like infrastructure, knowledge, technology, human, financial, and policy are needed (Donovan et al. 2015). Since the value chain acts as an operational model for sustainable development, evolving value chains for economic advantages and identifying and upgrading the existing ones for the functional headways are beneficial for the agriculture-dependent countries to make their face in the global competitive marketing economy. Understanding the different commodity value chains and their functioning makes improved infrastructure and technologies; instead, it will help make better planning and research for increased performance, efficiency, and cost reduction in different linking activities. While integrating with the value chain concept, the standardized production process enables the firms to manage the resources efficiently.

2 Are the Agricultural Value Chains Needed?

More than a fascinating word, the agricultural value chains are the need of the hour. Since the food on the plate is not a miracle but a product of a series of processes, the government needs to take a rational stand to assure a better price realization for the producer and a fair price for the consumer. To ensure national food security without wounding the producers' emotions, value chains with systematic, robust, dynamic, and efficient building blocks are essential. We always talk about the profits at both ends while considering a business. If agriculture is considered a business activity, we can say the producers and the consumers are both ends. When the agricultural produce is traveling from one end to another, it was estimated that about 30% of the consumable food produce is wasted (Maryam and Bin 2017) in either quality or quantity (Ghamrawy 2019), which is equal to feeding the starving population all over the world. What do you consider about the relationship between the price of the foodstuff and the quantity of food wasted along the value chain? Yes, it is definitely in a linear relationship in the early phase and can be altered to the exponential relation status when the wastage is very severe and uncontrollable. How can we ensure a fair price for the consumer and price realization for the producer in such a situation? It is a challenging task. It can be attainable by creating and developing well-equipped value chains which can optimize the use of natural and financial resources at the same time to reduce the post-harvest losses. The agricultural value chain development further added to one of the fundamental objectives of SDG 12, *Responsible Consumption and Production* (UNEP 2015).

3 History of Value Chain Development

Though Micher Porter was credited with coining the "value chain" terminology during the 1980s to analyze various activities of a firm in his work on comparative advantages (Porter 1985a, 1985b), the concept originated two decades before. While observing the developmental stages of the value chain as an operational methodology, two distinct traditions are coming to the picture. One is the French concept of "filiere," and another is Wallerstein's concept (Faber et al. 2009; Bair 2005; Lancon et al. 2017). The French "filière concept" has its origin in techno-empirical commodity-specific agricultural research to influence the needs and requirements of commodity-centered colonial and post-colonial French states. This concept was

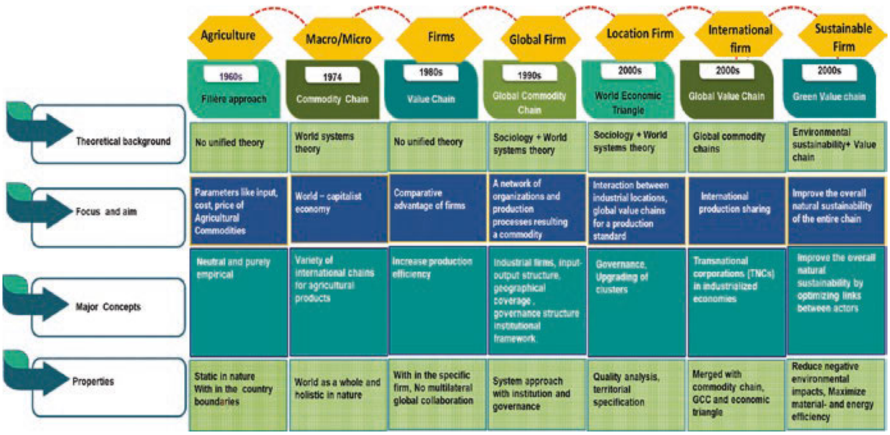

Fig. 13.1 Comparison of various value chain concepts. (Modified and adapted from Bair 2005; Fabe et al. 2009; Ernst and Young 2013)

applied prodigiously to agricultural commodities without any specific time framework since its inception (the 1960s) to the globalization era (Philip et al. 2000). Wallerstein's concept of the commodity value chain was based on world-systems theory (Hopkins and Wallerstein 1986), elaborating the dependency theory (Daniel and Thomas 1982) and trying to see different nations as economic units. Later decades the concept has made additions on different dimensions and appeared with different terminologies; *global commodity chain during the 1990s* (Gereffi et al. 1994; Philip et al. 2000), world economic triangles (Messner 2002), global value chains 2000s (Humphrey and Schmitz 2002; Gereffi et al. 2005), and green value chain (Martinez and Mathiyazhagan 2020). A detailed description of the various value chain concepts is given in Fig. 13.1.

4 Structure of Value Chain

Even though different schools of thought originated in the value chain concept, the Portal's *Generic Value Chain* concept is most widely used in the agriculture and allied sectors. Knowledge and understanding of the critical elements and structures of value chains are essential to make them robust to enhance efficiency (Alhassan and Abunga 2020). The agricultural value chain concept translates the movement of farm products from the farm to the plate (final consumer) through a series of activities done by many actors. The structure of any agricultural value chain consists of the network of activities that are interconnected in either forward and backward directions or vertical or horizontal directions along with the players responsible for the product transition to meet the needs of chain actors for commodity. Through this, relationships are being managed in terms of quantity, quality, time, and price between the agents responsible for the input supply for production (input dealers), persons accountable for efficient and quality production (producers), and agents responsible for the collection and supply of the produced products to the ultimate consumers (marketing channels). The generic model of the value chain given by Porter (1985a, b) in his book "Competitive Advantage: Creating and Sustaining Superior Performance" comprises primary and secondary activities. Primary activities in the value chain are directly linked to the creation or production of products, goods, or services. The secondary activities play a booster role in enhancing each actor's effectiveness and efficiency in the product transition process of a particular value chain to obtain comparative or competitive advantages over the others (Pila et al. 2010: Lowitt et al. 2015). The primary activity in the classic value chain concept consists of five generic categories, and each class is divided into several specific actions. In the context of agricultural value chains, the primary activities can be categorized as (a) *Inbound Logistics*: Collection of activities associated with pre-production process and the production supplementary process like arranging and receiving inputs like seeds, fertilizers, types of machinery, labor, etc. and the specific and time-bounded production-related activities done in the field to produce the quality products. It is the stage of making an inventory control of the raw materials and managing the producer supplier relationship. (b) *Operations*: It encompasses activities involved in transforming the inputs and services into outputs with an added value. In this stage, the raw resources are transformed into a product ready for marketing or sale. Activities involved in the operations are intended to add value or utility to the produces in terms of time, space, or form. The functions like matching, sorting, branding, processing, etc. may create a form utility, and the operations like storing and warehousing may add time utility to the produces. At the same time, transportation and related logistics may add to the space value. (c) *Outbound Logistics*: It is generally comprised of the output delivery activities like collecting the finished product, sorting the same with quality and need parameters, scheduling the orders placed, and finally distributing (physically) the products to the end-users or consumers. (d) *Marketing and Sales*: It is the activities that may lead to the actual reach of the product to the final consumers—this aims to provide a means by which consumers can procure the products for their end-use. This primary activity is the exact tailored integration link between the producer and the consumers like a conductor in each subgroup of a symphony orchestra (Singh 2013). It coordinates the customers' expectations with the product production activities through proper monitoring, advertisements, and feedback mechanisms. The activity of marketing and sale supports flexibility in the value chain and provides an essential platform that impacts both the supply and demand side through a collaborative relationship. (e) *Service*: Just reaching the consumer is not an end to the value chain of any product. It needs many transformations for the final consumption of end-use. In the case of non-agricultural goods, it needs installation, after-sale services, repair, etc. Similarly, agricultural commodities need to be garnished for the final consumption or end-use through various activities and services. For the competitive advantage of the value chain, each primary activity is vital.

The secondary or supporting activities have four generic components: (a) *Procurement*: It is the action of purchasing or acquiring inputs and services used in the agricultural value chain. It can also like employing particular technologies like direct seeding, selecting a specific variety of vegetable seeds, etc. (b) *Technology Development*: Technologies are the principal components of any process, including agriculture. Technological inputs are needed in every point and stage-like production of inputs like fertilizers, chemicals, improved crop seed development, land preparation, sowing, intercultural operations, harvesting, primary and secondary processing, marketing, transportation, final consumable product preparation, and customer service procedures. Scientific skills back some technology development processes, but others through artistic skills (cooking a food item). An array of technologies for a range of activities to improve the product and the process optimization for the increased margin and consumer satisfaction are invented and refined through research and development activities. (c) *Human Resource Management*: It consists of activities referring to the selection, recruitment, hiring, personnel development, rewarding, and training done for the value chain of either a commodity or firm. It supports all the stages and occurs at different levels in the value chain. (d) *Infrastructure*: It can either be a tangible property like road, vehicle, cold storage, machinery, etc., or intangible things like management policies and strategies, government support activities, quality management, financing, planning for future development and expansion, information management, account keeping, legal formalities, etc.

5 Stakeholders and Players in the Value Chain

A stakeholder is a person or group involved in any defined process or impacted by the activities or inertias of others in that process. Hence in the agricultural value chain where the farm product is produced and transformed, and transferred to the consumers, many stakeholders are involved (Fig. 13.2). Networks of activities directly or indirectly connect them.

Dubey et al. (2020a) in their study conducted in Champawat district, Uttarakhand, pointed that for the tomato crops different value chains were observed and various stakeholders were identified. They include the liquid cash providers, research institutions, and KrishiVigyan Kendra (KVK) for knowledge transmission and advisories, private-hybrid seed suppliers, infrastructure dealers to give the greenhouse and poly house technique, primary processors to do farm level value addition, and the governing agencies like government institutions and state horticultural department. Similar groups of stakeholders were also observed for the value chain of capsicum (Dubey et al. 2020b) and cocoa Claudia et al. 2020).

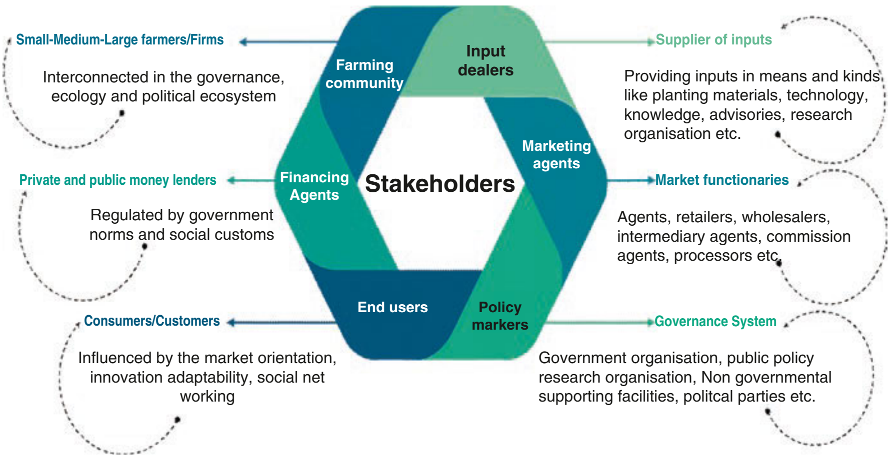

Fig. 13.2 Stakeholders in the agricultural value chain

6 Differentiating Supply Chain vs Value Chain and Horizontal vs Vertical Value Chain

While understanding the value chain structure, we might come across two different notions of value chain classification, i.e., supply chain vs value chain and horizontal vs vertical value chain. Do they differ in conceptual understanding, or difference is only in terminology? Let us have an account. While considering the supply chain and value chain, these concepts may be pronounced the same in many cases. But in the conceptual definition, function, and origin, these are different (Gattorna and Walters 1996: Walters 2002). In simple words, the supply chain is the function or activities that help reach the product from the producer to the consumer. At the same time, the value chain is the activities that add value to the raw product till it reaches the final consumer. Similarly, both the supply chain and value chain concepts have different thoughts of origin. The supply chain is based on operational management principles and mainly for conveyance and consumer satisfaction. The value chain concept originated from the business management principles intended to create value to the products and make a comparative advantage. The sequence of operation for both the supply chain and value chain also shows differences. In the supply chain, the activities start with a product request, and through various actions in the chain, it reaches the consumers, whereas in the value chain, the activities begin with a customer request. Based on the customer's needs, value is added or created through a series of actions before it reaches the customer.

The concept of the horizontal and vertical value chain in agricultural commodities can be more palatable when looking at the value chain as a whole in a global marketing scenario. The horizontal value chain is the network of activities done at the same level of a value chain as different farmer organizations as a whole, input dealers, etc. The interconnected chains of activities may help them to widen the same value chain in a different location or territorial dimension. It may help them have better bargaining power, better access to the markets and finance, etc. Simultaneously, the vertical integration or value chain indicates the networks of activities with different functions, but that is at the same value chain. It integrates various tasks in a commodity value chain (like sorting, grading, packing, processing, storage, selling, etc.) to make a value chain stronger by reducing the cost of attaining a controlling position in the given market (McKague and Siddiquee 2014a, b: Saenz et al. 2015: Shrestha et al. 2015: Kletti and Deisenroth 2018).

7 Virtual Value Chain and Its Importance

Every value chain, even for an agricultural commodity or an industrial product, has two central parts: one is the physical value chain part through which the product moves or transforms for the end-user, and the other one is the virtual value chain (Rayport and Sviokla 1995), of information and knowledge transmission. It is essential to know about the virtual value chain in the current information world to develop the value chain development strategies properly. Think about an agricultural commodity, like *French fries.* The physical value chain of the same indicates potato production, grading, packing, transportation, processing, etc. Here the actors and activities are physically visible. It starts from the production process, which leads to the potato produced at the field to prepare the *French fries* for the final consumption as per the consumer demand. In each activity, different types of infrastructure and machinery are involved, and that is tangible. At the same time, another invisible network supports the physical value chain, which everyone can sense. It integrates the thought process of the producer to produce a particular crop, knowledge regarding various varieties, information of inputs needed for the production, learning about the different field operations and management practices, government policy, information on different methods of primary and secondary processing, the knowledge about the recipes for the preparation of *French fries*, etc. These invisible linkages are present in every value chain, without which the proper functioning of the physical value chain may not be possible (Czerniawska and Potter 1998: Schliffenbacher et al. 1999).

8 Understanding the Value Addition Process

We used to wonder how the price of a product changes with slight modification in its color, shape, packing, etc. Sometimes the same product has different prices at different places or at another time? What may be the reason? Is it simply because the seller is deciding some price and imposing the same on the consumer, or it might be due to some defined process and actions that happened. Leave aside the unscrupulous activities followed in the value chain, which may lead to the highly volatile

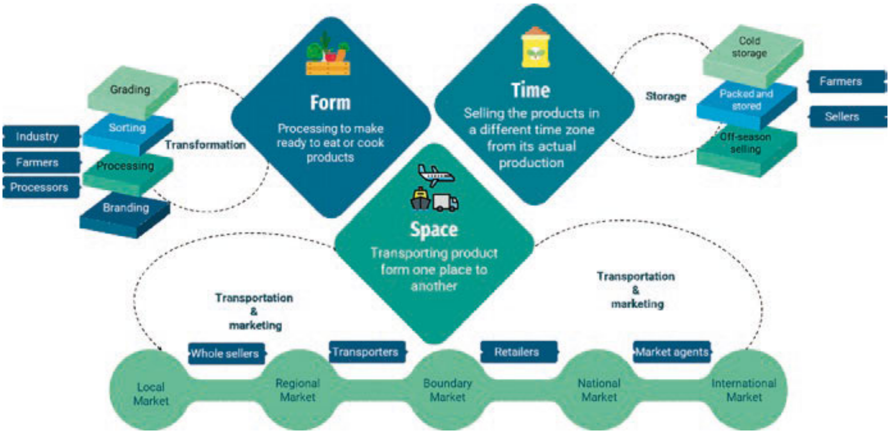

Fig. 13.3 Utility enhancement activities in the agricultural value chain

price for the commodity, and we can look into the objective value addition process. Before going to the value addition process in detail, let us understand the term *value-added.* According to FAO (2014), value-added is the difference between consumers' willingness to pay for a particular food product or crop produce and the non-labor cost of producing the same. It is the total wages, margins (profits for the value chain stakeholders), taxes, positive or negative externalities associated with the product development, and the consumer surplus. In general terms, value addition is a worthwhile process as it generates high value and returns to the producer and greater consumer satisfaction. This process includes changing the physical state or form of the product, like making flour from grains, ketchup from tomato, etc., as in the traditional norms. Also, it includes any activity that enhances the utility of the product either in its time, space, or form dimensions (Lu and Dudensing 2015). Networks of activities are associated with each type of utility enhancement (Fig. 13.3).

9 Farm to Fork Model

This model is alternatively known as the "farm to table model," in which the different value-added activities from the production to till consumption stages are integrated. The principal purpose is to reduce post-harvest losses through efficient value chain activities and to ensure the food safety of the population (FAO 2010b). The model also aims to balance the producer cost and consumer price, preserving the quality and freshness of the produce in the entire value chain and improving the economic status of the farmers. The efficiency of the value chain activities is enhanced by reducing the marketing chain length, improved technologies, farm gate collection and procurement, infrastructure creation, and mobilizing the farmers for better bargaining power, so that the consumer can get direct access to the products, and simultaneously substantial increases of the producers share in consumers price. The farm to fork model also adds to the traceability of the product along the value chain, which is of great concern today.

10 Farm to Foreign Model

Value addition activities that enable the agricultural product to cross national borders and regions are qualified under this Farm to Foreign model of value addition. The process of value addition is done through multilateral trade agreements and multinational collaboration. This model can be treated as an output of globalization and liberalization policies. It can be equated with the "flying geese" pattern of value addition (Akamatsu 1962) by integrating the resources and value addition activities at different niches. This model may help procure the comparative advantages in a single value chain in various stages of the value addition process. It will help widen the reach of a commodity in different territorial and time zones, increase the profit for the product, and help the developing countries realize economic growth (Swinnen 2016).

11 Local Value Chain Development Process

The value chain development process is an intervention to create and strengthen the mutually advantageous linkages and networks among the different players of the value chain from producer to consumer to work in a synergetic mode to use the available market opportunities for profitability enhancement (Donovan et al. 2015, 2016; Hainzer et al. 2019). The essential idea of the value chain development is the country's economic development through strengthening the market functioning. Hence, value chain development interventions are wested on learning, trusting, and benefit-sharing principles to create a win-win situation for the players or participants (Webber and Labaste 2010; UNIDO 2011). The value chain development process is categorized into two, i.e., global and local, based on the macro and micro perspective. Since Indian agriculture is predominated with small and marginal farms, which lack regional comparative advantages, we concentrate more on the local value chain (LVC) development process. The local value chains aim to integrate the local sector to produce an efficient value chain and develop value chain levels. While analyzing with a marketing lens, each value chain competes against each other within the market space. In the local value chain, the competition to win the consumers' preference is with the global value chains, which are importing identical products in the market where the local value chain (LVC) operates (Nadja and Merten 2015). According to Springer-Heinze (2018), the value chain development process is based on the triple bottom line approaches of sustainable development goals, i.e., giving importance to the nation's economic growth, protecting ecological sustainability, and allowing social inclusion in all means. While undertaking a value chain development (Global or Local), some basic things need to be considered (IFDA 2014). The first and foremost thing is the consideration of market and market potentials as it is the primary driver for all value chains. Suppose any product that has an added utility by the value addition does not find any demand in the market. In that case, the farmers/producers and chain actors will not get any additional income. Hence the market and consumer demand is the essential thing that needs to be considered for the value chain development. Similarly, it is also important to note that each value chain serves a different and specific market. Another significant dimension is the dynamism of the value chain, which often changes with technology, input availability, consumer preference, marketing strategies, government regulation, etc., at the micro, meso, and macro levels.

12 The Value Chain Development Cycle

The value chain development activities are in cyclic nature, as the market for which the value addition of the product is being done is very dynamic due to various factors associated with it. As in any program planning and implementation strategy, the value chain development process consists of five different stages (Fig. 13.4). The first stage is *Identification of the sector*: in the case of agricultural value chain development, this stage involves the selection of the commodity or crop for which the value chains need to be developed. Before selecting a particular commodity or sector, one should need to answer the questions like, *What is the objective of this action? Whether the contribution from the sector is enough to make the investment and interventions worthy? What will the sector achieve after the value chain development?* etc. Based on the target set and the answers obtained from the primary investigation, one needs to finalize some criteria for selecting a particular value chain for the development interventions. Because in the local condition, for a specific commodity or crop or produce, more than one chain of actions is available, and selecting the most suitable one will give the most efficient results.

The criteria for the selection of a particular sector should be developed based on the prospects, relevancy, capacity of the sector, feasibility of interventions, the quantum of profit and positive externalities, etc. The second step in the value chain development process is *analyzing the existing marketing system and market chain analysis*. It is the part where the value chain analysis, research, and value chain mapping are integrated. The interconnectedness and linkages (Springer-Heinze 2007: Humphrey and Navas-Alemán 2010) are the core component in any value chain. Hence, mapping the linkages of the actors and activities is necessary to understand the interdependencies of various components (Stein and Barron 2017).

This visual tool and illustrative methodology will help the development partners to understand the key nodes in the value chain (actors or market players in quantity and quality dimensions), the interlinking actions (value-creating activities in size, intensity of competition, and the relationship terms), and the supporting

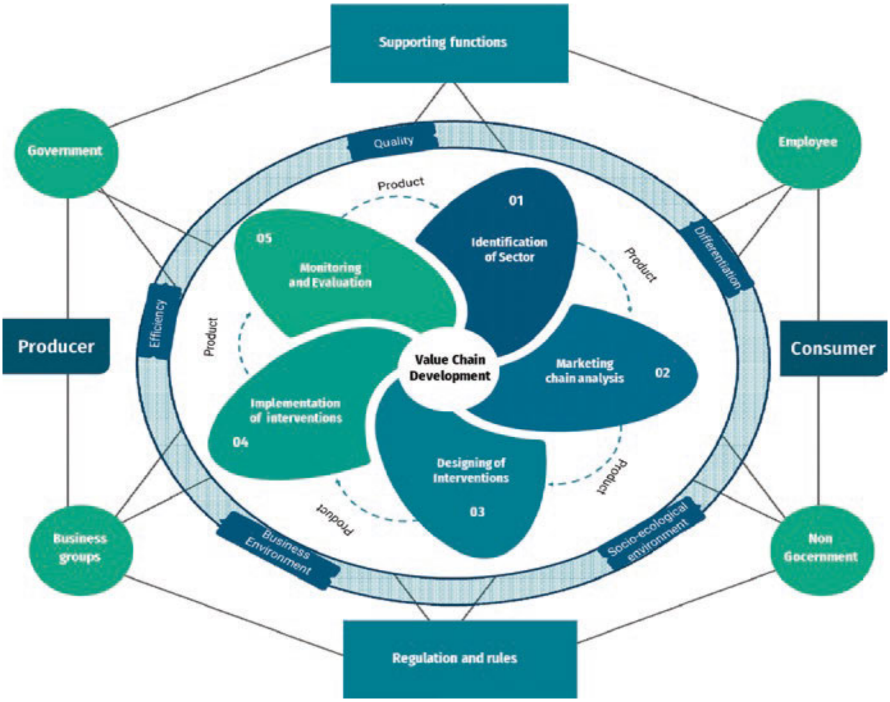

Fig. 13.4 The value chain development cycle

functionaries like government, not-for-profit organizations, financing institutions, input supplying industries, framer and processor associations, etc. (in terms of rules, laws, regulations, and non-legalized procedural formalities) (McCormick and Schmitz 2001; McKague and Siddiquee 2014a, b). An example is given in Fig. 13.5. It will also help to comprehend the opportunities, constraints, and weaknesses that need the intervention points (Ran et al. 2013). The value chain research and analysis quantifies the players' capacity and incentives in the value chain, through which the market demand of the particular sector or commodity is being analyzed. It will indicate future development direction, consumer preference, and motivations or drivers for the actors in the value chain in a quantified form (a detailed explanation is given in Sect. 7 of this chapter).

The third step in the value chain development process is designing interventions for the development activities, which help provide sustainable solutions for the problems identified in the value chain analysis. The intervention can be of various forms. Creating a new linkage, adopting a business model, accessing more information and technological support, competing more rigorously with the other players, making cooperating agreements, taking an exit from the current market, or launching the product in a new and different market, etc. are some among of the market up-take strategies (Nadja and Merten 2015; Jochem and Trude 2015; ILO 2019a). After the designing of interventions, the timely and efficient implementation of the

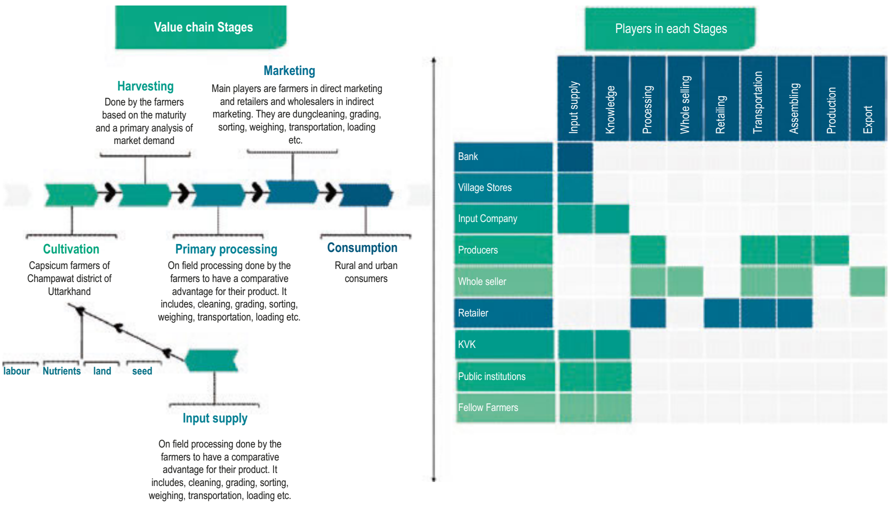

Fig. 13.5 Value chain mapping of capsicum in Champawat district of Uttarakhand, India. (Adopted from Dubey et al. 2020b)

same is essential. It is the stage in which the actual development of value chains in the selected sector happens. The strategic performance is not giving or developing choices for the actors; instead, it is about empowering them to choose a particular action from different alternatives (Herr 2007; Nadja and Merten 2015). The final stage is the monitoring and evaluation of the implemented strategies and their level of achievement. It is an essential activity for upscaling and out-scaling the developed value chain development models and correcting the inefficiencies in the adopted methods. Different triggers are there for the value chain development process. If a selected value chain lacks efficiency in terms of cost, resources, time, and the functional mode, it needs a developmental intervention for reducing inefficiencies. Similarly, the social and environmental dimensions, needs and opportunities of product diversification and differentiation, business development environment and related factors, etc. act as triggers for the value chain development in agriculture (Nadja and Merten 2015; Stein and Barron 2017; ILO 2019b).

13 Frameworks for Value Chain Development Intervention

As mentioned in Sect. 4.2, successful value chain development activities depend on the strategies which one has planned and implemented. Though many types of interventions can be designed based on the market value chain analysis and mapping, the intervention which matches the available resources and situation will be the one that might give expected results. Different frameworks are developed to place the strategies for the most efficient execution. Here we are discussing two such frameworks in detail.

13.1 The "Will-Skill" Framework

The Springfield Centre has developed the framework with a matrix (2 × 2) form. It has the skill (capacity) and will (motivation or incentives) to represent two dimensions of the value chain actors' categories (The Springfield Centre 2015; ILO 2015. 2021). The framework has four different players based on the high-low combination of motivation and capacity (Fig. 13.6). The intervention strategies may vary based on the extent of capacity and motivation a value chain player has. (1) *High will-Low skill (Contributors)*: The value chain player has the high motivation or incentive level to adopt a particular value chain strategy as designed but has low skill or capacity to execute the same. The capacity enhancement activities or skill development may be helpful for the players to make an efficient move. The primary form of support is training, mentoring, advisories, etc. Similarly, the access to information regarding the skill development and agencies providing such supports may help them acquire the skills for the particular value chain development. (2) *Low will-High skill (Potential detractors)*: The value chain player or agent who is highly skilled enough to expand the current work, i.e., launching the business in any other region. But the incentives by doing so may be significantly less to pursue the same due to the high risk associated. Here development agencies need to adopt the strategy to peruse the action designed is by giving support to reduce the risk associated. The horizontal integration of the different chains to share the cost to reduce the risk and contract farming can be helpful for them. (3) *Low will-Low skill (Low performers)*: It is the situation in which the value chain player may lack both capacity and

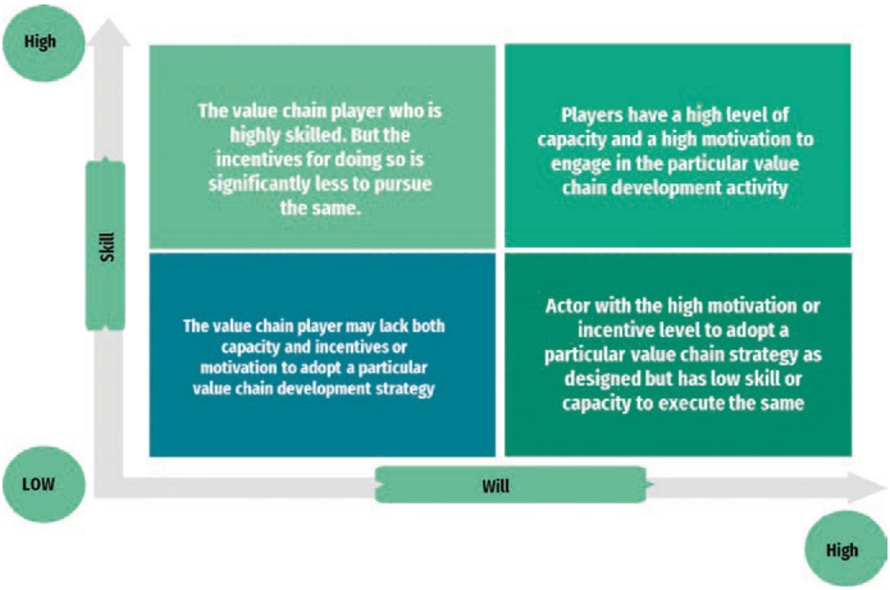

Fig. 13.6 Will-skill framework for value chain development

incentives or motivation to adopt a particular value chain development strategy. Actors may be reluctant to adopt a particular strategy by asking questions (like *What will I get from it? Am I capable of doing so?)* with probably the same answer of impossibility. Here, the value chain development actor or agency needs plans to impart skill and provide motivators to make the actors part of the development process. (4) *High will-High skill (Challengers)*: These players have a high level of capacity and a high motivation to engage in the particular value chain development activity. To implement the value chain development strategies, they need an enabling environment and supporting regulatory measures. Hence, the major work of the value chain development agency is to find out the external factor, which promotes or blocks the action.

13.2 Adopt-Adapt-Expand-Respond (AAER) Framework

It is a 2 × 2 matrix framework that enables monitoring and assessing the systematic changes in the value chain development interventions and their implementation. Value chain development programs also aim to change behavior or working habitat of different players through different interventions for system efficiency. Like the Will-Skill framework, this framework also categorizes the value chain players based on their behavior towards the interventions. The two dimensions of the categories are pilot and crowding in. The adopt and adapt classes are coming under the piloting dimension, and the expand and respond types are in crowding in dimension. The framework (Fig. 13.7) will help the value chain development agency to plan what should be done next? (ILO 2021; Jake 2020). The pilot dimension is for engaging

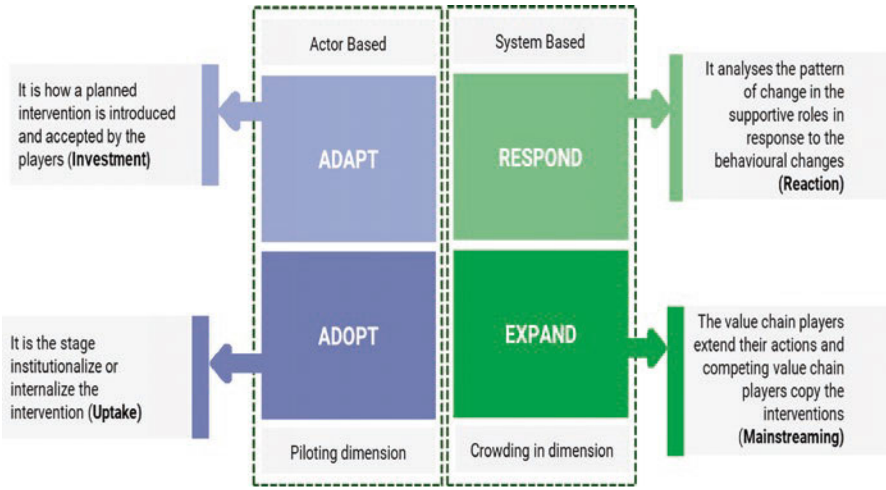

Fig. 13.7 Adopt-Adapt-Expand-Respond (AAER) framework

different market players appropriately on various interventions designed to value chain development. At the same time, crowding in is enhancing the responsiveness of the players towards the interventions planned and implemented in a sustainable way through improving the support function like rules, regulations, and creation of a suitable environment. The *adopt* is how a planned intervention is introduced and gradually transferring its ownership to the value chain players. In this stage, the ultimate behavioral change need not happen. The player is motivated to adopt any particular intervention by giving some examples or showing its benefit. When the value chain actor is convinced with the incentives they gain, they gradually try to institutionalize or internalize the intervention. Here the ownership is transferred to the players, and changes occur in the behavior of the players. The process is termed *adapt.* In the *expand* process, the value chain players extend their actions, and more people benefit. Similarly, competing value chain players copy the intervention adopted and adapted by the other players, increasing visibility, reach, and diversity. The *respond* component is that examines the supporting function of the existing value chain. It analyses the pattern of change that happens in the supportive roles in response to the behavioral changes of the value chain players through the adoption and adaption of the interventions. Thus through AAER framework, the proper designing, placing, monitoring, and evaluation of value chain development activities and interventions are possible.

14 Business Perspectives in Agricultural Value Chain Development

Agriculture is no longer a farm activity alone; instead, it is a sustainable livelihood supporting activity. Considering a farmer as an investor or operator of an enterprise is time relevant. Rural development programs in developing and underdeveloped nations are more oriented to make farmers as a businessman or farming as agribusiness (Tohidyan Far and Rezaei-Moghaddam 2019; Beuchelt and Zeller 2012). If a farmer is considered a simple producer, then the farmer or producer's activity ends with the production process. But in the actual situation, it is extended to primary processing, value addition, marketing, etc., which are termed as business activity. For efficiency enhancement and profitability, each farmer should be engaged in capital formation, investment, and risk-taking at each stage, which are the fundamental characteristics of a business. In the value chain development context, farming is integrated with all value creation activities and decision-making processes. Hence it is better to term agriculture as agribusiness (Lans et al. 2020).

15 Business Development Services (BDS) in Agriculture

Business development services (BDS) are the non-financial assistance or services offered to meet the demand of players to develop a value chain (agribusiness) with an efficient and functioning marketing system. It includes entry support activities, growth and expansion supports, productivity enhancement support, technological support and advice, training for business development, infrastructure support, sustainability support regulation, marketing assistance, etc. (Springer-Heinze 2008; Alexandra 2001). These BDS are very important, especially for the smallholder and marginal farmers, as those may help them have more access to financial services. A general classification of BDS done by the Small Enterprise Education and Promotion (SEEP) Network and International Labour Organization (ILO) suggest seven classes of BDS: (1) Input supply: the process of linking the input dealers with the farmers, facilitating enhanced access to the input market, etc. (2) Product development and technological backstopping: training on different forms of product development, training to use advanced technologies for product formation, etc. (3) Marketing facilitation and enhanced access to the market: giving accurate market information and market intelligence services, linkages between different market functionaries, advertisement and propaganda, online trading support, etc. (4) Infrastructure facilities: road and transportation facilities, marketing infrastructure creation, cold storage and warehousing, drinking water and electricity, etc. (5) Training and technical support: for production, processing, marketing, warehousing, etc. (6) Policy support: compliance training, advocacy over different policies, etc. (7) Alternative financial support (Alfons 2005).

16 Farmer Producer Organizations (FPOs) and Value Chain Management

While considering the value chain development activities, farmer producer organizations (FPOs) are the significant ones to be discussed. The most crucial element needed in a value chain development function is enabling the producers to have better bargaining power. In a country like India, where the majority of the framers are coming under the category of marginal and small, it is essential to organize them for efficient and improved value chain activities. The definition states that *A Producer Organisation (PO) is a legal entity formed by primary producers, viz. farmers, milk producers, fishermen, weavers, rural artisans, craftsmen* (NABARD 2015). A conceptual framework is given in Fig. 13.8. "Amul" can be cited as the most successful example from India under this. The main aim of the FPOs is to make sure better earnings for the farmers by incorporating the economics of the scale while marketing the product and better bargaining position while purchasing the inputs (Markelova et al. 2009).

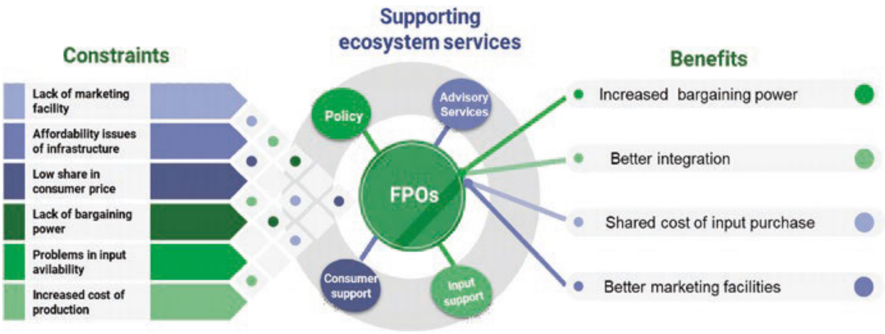

Fig. 13.8 Farmer producer organizations (FPOs) and value chain management

FPOs provide an enabling environment for better input availability (the wholesale price of the inputs are always lower), market facilities (through collective marketing and sharing the marketing cost), and togetherness while arguing for government support for the farmers or producers (Latynskiy and Berger 2016; Bijman and Wijers 2019; Ravi Kumar and Babu 2021). Though the FPOs are identified as a tool to make farming a business through the integration of the farmers, its development needs support ecosystem services. It includes supportive policy for risk mitigation, licensing, and other related activities; extension and advisory services for market selection and processing; consumer support and linkages; and support to procuring quality inputs like capital labor and other production and post-production inputs (NABARD 2020). Even if the establishment of an FPO is necessary for the value chain development activities, the process is constrained by many factors in different stages. The significant constraints are less involvement of youth or young leaders to take responsibility (Verma et al. 2020), lack of proper coordination among the member for different group activities (Kathiravan et al. 2017), lack of professional management, and access to credit facilities (NABARD 2020).

17 Value Chain Analysis (Quantitative) Methodologies

As discussed in Sect. 4, the quantification of the cost involved, the price gained, value-added, services provided, etc. are essential for the development of value chains in any commodity sector. The process starts with selecting a particular crop/commodity/product for which the value chain analysis needs to be done. It is followed by mapping of different chains of activities (primary and support activities) and players in it. The quantification of the cost involved, the value created, and the profit obtained at the micro and macro levels are the next steps. In other words, the value chains are analyzed based on the activities which lead to a reduction in cost or increase in the differentiation for comparative advantages. Since the value chain is an input-output flow (McCormick and Schmitz 2001; Wood 2001) the analysis (accounting) can be conducted in two different forms: (1) physical analysis (quantum of product transferred from one actor to another actor) and (2) financial and economic analysis (financial analysis is based on the market price; hence any market distortion will have a direct reflection on the same, and economic analysis is more concentrated on the shadow price (Fabe et al. 2009). With a micro perspective of value chain development in mind, we concentrate more on the financial analysis aspect of the value chain analysis in this chapter. A standard procedure of the financial analysis of value chains is cost–benefit analysis. Here the monetizing the cost and benefits of a value chain and expresses the same over time or quantity of the product produced. According to FAO (2005b), the most critical term in the value chain analysis is the value-added. How will we calculate the value added to any product through a value chain activity? To answer this question, one needs to understand how a product gains value. The value is created through series of actions that use several inputs in the form of materials (row inputs and product, primary processed product, etc.) and kinds (the services in terms of labor, human power, advisories, financial services, marketing support, policy support, etc.). In a market system, the consumer gets a value-added product with a price, which included the value-added in it and the cost of production of the product in the final consumption form. Similarly, the gross profit in the value chain is the difference between the value-added and the total cost of production. Hence, the value-added in the particular product can be calculated as the sum of the gross profit and the product's cost of production.

$$Gross\ Profit_i = VA_i - (X_{1i} + X_{2i} + X_{3i} + X_{4i} + \ldots\ldots\ldots\ldots\ldots\cdots + X_{ni} \quad (13.1)$$

where,

VA_i = value-added for the ith product/ commodity
X_{ni} = Cost of nth input for the production of ith product

In the financial value chain analysis, three essential items are generally there: (1) The gross product (calculated as the market price of the total quantity of the product produced). It includes the final product marketed, product kept for the own consumption, and the product kept as intermediate inputs for making any other value-added product. (2) Cost of production. It indicates the cost accrued for any intermediate good (seeds, fertilizer, plant protection inputs, primary processed materials, etc.) and services (labor cost for family and the hired labor, marketing cost, cost of primary processing, cost incurred for the support, and advisories, etc.) (3) The depreciation cost of fixed assets (farm implements, buildings, vehicles, warehousing facilities, marketing infrastructures, etc.) used in the value chain. The viability of the value chain developed is measured based on the extent of the benefits over the cost incurred in the value chain with the help of profitability indicators. The significant indicators used for the value chain analysis are given in Table 13.1 (Dizyee et al. 2017; Mango et al. 2018; Gebre et al. 2020).

Table 13.1 Financial analysis indicators in value chain development

S. no	Indicators	Explanation	Calculation
A.	**Farm-level analysis**		
1	Yield (kg/ha) (Y)	The total quantity of main products and the by-products produced at the farm level.	$Y = \overset{i=1}{\underset{n}{?}} y_i + \overset{j=1}{\underset{k}{?}} y_j$
2	Farm-gate price (Rs) (R)	The farmer selling price (either to consumers or to the marketing agents).	R = Rupees/Kg
3	Gross revenue (GR)	It the total revenue obtained for the producer by selling the main products and by-products.	$GR = Y \times R$
4	Cost of production (C)	The total cost incurred for the inputs in the production process (fixed cost + variable cost).	$C = VC + FC$
5	Variable costs (VC)	Cost of seeds + fertilizers + plant protection + services + other inputs.	$VC = \overset{i=1}{\underset{n}{?}} vc_i$
6	Fixed cost (FC)	The cost incurred for the fixed assets used in the production. process (implements + processing equipment + buildings + machinery + taxes, etc.).	$FC = \overset{i=1}{\underset{n}{?}} fc_i$
7	Net farm income (NR)	It is the profit obtained for the producer after reducing the cost incurred in the production and processing.	$NR = GR - C$
8	B:C ratio (BCR)	It is the ratio of the present value of all benefits to the total cost of the process.	$BCR = \frac{GR}{C}$
9	Operating expense ratio (OER)	It is the ratio of operating cost for the production of the product to the gross revenue obtained from that product.	$OER = \frac{VC}{GR}$
10	Breakeven point (BEP)	It is the situation in which no loss and no benefit to the process or activity. BEP is the status when the cost of production is equal to the profit obtained.	$BEP = \frac{FC}{GR ? VC}$
B	**Marketing analysis**		
1	Marketing cost (MC)	The total expenses incurred for a marketing agent (producer in direct marketing, retailer, and wholesaler). It includes title changing charge (purchasing cost), handling costs like primary processing and marketing.	$MC = \overset{i=1}{\underset{n}{?}} mc_i$
2	Market margin (MM)	It is the difference between the selling price (SP) and the buying price (BP) for the market agents (retailer and wholesalers), or it is the difference between the farm gate price and cost of production if the producer is directly marketing the product (per unit).	$MM = \overset{i=1}{\underset{n}{?}} \frac{SP_i ? PP_i}{y_i}$ Or $MM = \overset{i=1}{\underset{n}{?}} \frac{R_i ? C_i}{y_i}$ Here n = number of intermediaries

(continued)

Table 13.1 (continued)

S. no	Indicators	Explanation	Calculation
3	Consumers' purchase price (PP)	The price at which the consumer is purchasing a product for the final consumption.	$PP = \overset{i=1}{\underset{n}{?}} y_i ? BP_i$
4	Producers' share in consumers price (PS)	The percentage share of the producer in consumer price for a product.	$PS = \frac{PP ? (MC + MM)}{R}$
5	Marketing efficiency (ME)	Measures how efficient a value chain in the operating situation.	$ME = \frac{PP}{MC + MM}$

18 Value Chain and the Market System

In the traditional value chain development practices integrated approach was missing. Value chains were developed based on the marketing chain analysis instead of considering the value chain as a system (market system) (ILO 2016). But in the recent development in the value chain analysis methodologies, the value chain analysis integrates different marketing subsystems. The production, marketing, and consumption of one or more inputs and services between these subsystems (product-market system, labor market system, advertising and supporting market system, etc.) are general phenomena. The output of the market system analysis gives a comprehensive view of the value chain with its integrated marketing system (Fig. 13.9).

19 Constraints in the Value Chain Development Process: An Indian Scenario

The agricultural value chain development process is not devoid of challenges and constraints. The nature of activities, multiplicities of the actions, different sub-marketing systems, etc. create many challenges during the integration process. The limitations on value chain development in the Indian context can be grouped as vertical and horizontal integration challenges, technological and infrastructural constraints, financing challenges, policy and governance issues, and, most importantly, socio-cultural issues (Devaux et al. 2018; Gills et al. 2016, 2017). According to Naik and Suresh (2018), the major challenge in the value chain development process is how to guarantee the involvement of small and marginal farmers with fragmented landholding in sourcing the linkages or networks. The challenges faced at the farm level marketing, lack of integration among the different players in the value chain, and inefficiency in compliance with the quality parameters required for the value chain entry are significant challenges associated with the horticultural value

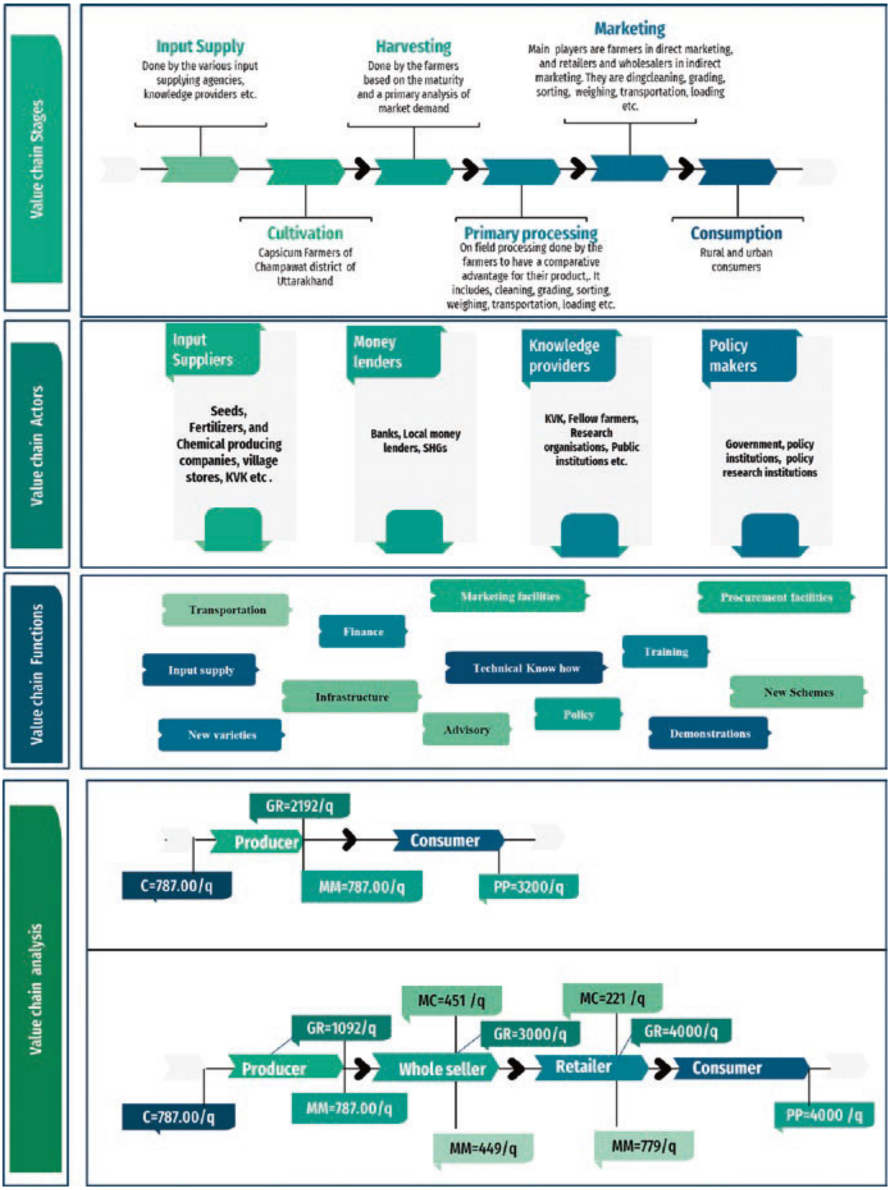

Fig. 13.9 Market system approach for the value chain analysis (Authors creation: source, Dubey et al. 2020b)

chain development (Musa et al. 2014). Other than the techno-economic challenges, some other important social, cultural, and political factors also affect agricultural value chain development. According to FAO (2010c), the agricultural value chains are not gender-neutral, and poor and less literate women were severely affected by

	Production	Processing	Marketing	Governance
Technical Constraints	• Non availability of improved varieties • Inadequate technical capacity	• Non availability of machineries • Inability to keep the quality standards	• Lack of cold market information and intelligence • Large number of middle men	• Non linkage between the policy making body and the stakeholders
Infrastructure Constraints	• Lack of improved farm implements • Lack of electricity for irrigation	• Lack facility for storage, packing, transportation and processing	• Lack market place or yards • Lack of e-trading facilities	• Poor investment in creation of cold storage, roads and other public amenities
Financial Constraints	• Lack of finance • High rate of credit • Non-legal money lenders • Distress sale of produce	• High cost of suitable machineries • High payback period in investment	• Distress sale of produce • Difficulties of contract enforcement • Price uncertainty	• Lack of price policy by the government • Low awareness about government support policies
Human Resource related Constraints	• Lack of labour • High labour cost	• Lack of skilled labour • Low adhesion in groups	• Lack of marketing skills	• Poor investment in human resource development (training, capacity building etc.)

Fig. 13.10 Constraints of agricultural value chain development in the Indian context

gender stereotypes. They were entitled to lower payment and forced to work in more insecure conditions. Based on the regional studies on different agricultural commodities, the challenges of value chain development can be different and combined in varying degrees of intensity. The general classification of the constraints of value chain development is given in Fig. 13.10.

20 Food Waste in the Value Chain

The value chains are pronounced as a tool to prevent (reduce) food losses. But in many of the developed nations, a huge quantity of food is being wasted in the value chain. Food wastage encompasses two terminologies, i.e., food losses and food waste. Food loss is the amount of the product being wasted till retailing in the value chain, and the term food waste is the product which is ready to eat form (fit for consumption) is being wasted. In the whole chapter, we have discussed different strategies for value chain development (physical), which can be treated as a silver bullet for food losses. But food wastage is a behavioral problem created and cultivated through custom, culture, habit, and tradition. More than 30% of the food is wasted at the plate, which is sufficient to feed the hungry people of the world (Gills et al. 2015). Hence to reduce food wastage in general, it is essential to have value chain development strategies in combination with the efforts to change the behavior of the people.

21 Conclusion

We discussed the process, methodologies, and challenges in agricultural value chain development in general and particularly emphasizing cases from the Indian context. Value chain development in agriculture is vital as it is still the primary employment generating sector (43%) in the Indian economy (World Bank 2021). Similarly, agriculture is no longer a farming activity alone; instead, it is a business activity with all the essence (investment and risk-taking) and structure (different stages of product development and title transfer till consumption). As indicated in the chapter, the value chain is a holistic process that includes farming, aggregation, transportation, primary value addition, logistics, and after-sales services. While closely understanding, the value chain structure has existed in the agricultural sector from historical periods. The crop and product are produced at the farm, and consumers consume the product in differentially accessed forms through several players, channels, and agents. The changes that happened in the developed world have triggered the systematized value chain development concept in agriculture through the structured organization and governance system. The ever-dynamic consumer choices, pertinent system challenges, and technological progression always demand comprehensive and adaptive value chain development strategies. Hence, in this chapter, we tried to emphasize the different stages of value chain development and how we can build a sustainable value chain through skill, will, and adoption behaviors. The challenges and the constraints like lack of last-mile connectivity, deficiencies, and inefficiencies in the marketing system, existence of a large number of intermediaries, and unscrupulous players, information access difficulties, insufficient infrastructure facilities like cold storage, roads, electricity, building, and storage structure, financial unsustainability, risk and increased transaction cost, etc. are hurdles in the rural value chain development process in India. In recent times structural changes had happened in the policy outlook in India, and now the economic development is more concentrated on Atmanirbhar ("self-reliant India") principles. It has a particular focus on the production of improved technologies for production processing and quality control, creation of marketing facilities and infrastructure, encouraging aggregation among the players to have more profit and efficiency, etc. Though the fragmented and small landholding is a challenge, the diversity of the crop produced and its market potentials are strengths to be harnessed in agricultural value chain development in India. Building the confidence among the farmers for aggregation, moving from subsistence farming to market-oriented farming, subsistence farming to market-based and business-oriented agriculture, and enhancing the accessibility, availability, and affordability of the inputs, information and policy support, etc. are relevant for the creation of an enabling environment for the value chain development.

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Part V
Fisheries and Aquaculture in Food Security and Nutrition

Chapter 14
Climate Smart Eco-management of Water and Soil Quality as a Tool for Fish Productivity Enhancement

Puja Chakraborty and K. K. Krishnani

Abstract Climate smart eco-management is an approach for reorienting and transforming the aquaculture system under changing climatic conditions to ensure food security for the increasing global population. Widespread alterations in temperature, rainfall pattern, and extreme weather events threaten the aquaculture production system and amplify the risk of economic loss. These potential threats can be minimized by increasing the resilience capacity of the production system through various climate smart strategic approaches. The strategic adaptation approaches include species diversification, integration of agri-aquaculture such as integrated multitrophic aquaculture (IMTA), aquaponics, various advanced techniques like biofloc, recirculatory aquaculture system (RAS), culture of stress-tolerant species, inland saline aquaculture, implementation of BMPs in disease and environment management, etc. Climate smart adaptation strategies are likely to help in achieving 'sustainable fisheries development goal' and create a 'triple win' situation for the practitioners and stakeholders by enhancing fish production, making the production system climate-resilient, and reducing the greenhouse gas emission. Moreover, execution of climate smart aquaculture approach is quite flexible, context-specific, and can be supported by various financial schemes and innovative policies.

Keywords Water quality · Soil quality · Climate smart eco-management · IMTA · RAS

1 Introduction

The menaces of climate change to natural ecosystems and human society have been upraised to a top priority. It is now broadly accepted that climate change is not only a potential threat, but has become a new reality of twenty-first century. The ongoing

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climate change has drawn attention in the global corridor related to various developmental policies and worldwide governance (Ahmed and Solomon 2016). The accumulation of Greenhouse Gases (GHGs) in the atmosphere is associated with global warming and leads to the emergence of distinctive climate patterns in different agro-climatic zones. Change in climatic conditions is believed to modify weather patterns on regional scale, resulting in extreme weather events. Climate change has serious repercussions causing floods, landslides, drought, tropical cyclones, hurricanes, cold waves, heat waves, and alterations in various climatic parameters including rising sea levels, gradual change in water temperature, upsetting seasonal cycles, ocean acidification, and variations in oceanic currents. Weather extremes are certainly more traumatic and acute in nature, triggering injuries and transmission of communicable diseases and deaths (Hashim and Hashim 2016). These changes in the physical parameters can affect the ecological functions of the aquatic ecosystem and would also pose a challenge to the fisheries and aquaculture sector due to their adverse impact on reproductive ability, conception rate, sperm count, feed intake, and untimely mortality of the cultured species (Cochrane et al. 2009; Ahmed and Solomon 2016 ; Bhattacharyya et al. 2020).

Moreover, glacier melting, rising sea level, changes in precipitation rate, ocean acidification, and reduced groundwater level will have a significant effect on coral reefs, estuaries, rivers, lakes, and wetlands. Therefore, mitigative measures to accomplish adaptability and optimum production are required, while minimizing the adverse impacts of climate change on fisheries and aquaculture systems. In this context, it has been observed that fisheries and aquaculture practices also make a modest but still remarkable contribution to greenhouse gas (GHG) emissions during culture operations, transportation, processing, and storage of fish and fishery products. Although greenhouse gas emissions from fisheries and aquaculture sector are minimal when compared with other food production sectors, the situation can be improved further, with various identifiable measures and technical interventions (De Silva and Soto 2009).

To safeguard fish production under changing climatic scenarios, the aquaculture sector has to be governed efficiently. The most appropriate adaptation approach for the sector under changing climatic conditions could be the diversification of the production systems. A diversified production system is more resilient to water scarcity, temperature change, pest attack, and disease outbreak. The adaptation methods are widely classified as resource relocation, use of information and communication technology, diet-based adaptation, and genetic management. Henceforth, the vulnerability of the aquaculture sector can be reduced and the resilience capacity of fisher communities involved in smart aquaculture practices should be strengthened. In the era of global climate change and higher requirements for animal protein, the expansion of climate smart aquaculture can potentially provide sustainable management strategies to the fisheries and aquaculture industry (Bhattacharyya et al. 2020; De Silva and Soto 2009).

2 Potential Impact of Climate Change on Fisheries and Aquaculture

Climate change can directly affect the performance of individual aquatic organisms at their various life stages through modifications in morphology, physiology, and behaviour. Combination of climate change along with edaphic stresses will lead to extreme ecological responses which include microevolutionary processes, alteration in species distribution, and reduced productivity and biodiversity (Harley et al. 2006).

Aquaculture practice, like other agricultural activities, will suffer from the consequences of deep-rooted global climate change. Among the inevitable challenges of global temperature rise, substantial water scarcity and ocean acidification will adversely impact the inland and coastal aquaculture operations (Yadav et al. 2021). It is evident that various abiotic stresses of physical, organic, inorganic, and biotoxin origin and biotic stresses of viral, bacterial, fungal, and parasitic origins are the major constraints in achieving optimum aquaculture production (Krishnani et al. 1997; Krishnani and Ayyappan 2006). Besides, climate-driven changes in the spawning activity of the aquatic organisms will influence the successful recruitment, seed production, and growth of the concerned population. Also, global warming or heat increment can strengthen the process of thermal stratification in the aquatic system and cause deepening of the thermocline layer and reduced nutrient supply to the surface water and thus plays a significant role in determining the habitat distribution of various fish species (Barange and Perry 2009). Therefore, it is explicit that various biotic and abiotic stressors coupled with global warming will have synergistic effects and will further worsen the condition.

2.1 Abiotic Stresses

For sustainable aquaculture production, it is very crucial to maintain optimum soil and water quality conditions. Various parameters like dissolved oxygen, temperature, pH, salinity, turbidity, etc. are the determining factors that should be regulated throughout the culture period (Mwegoha et al. 2010). Slight deviation in these parameters will hamper the nutrient uptake, growth, and metabolism of the farmed fish (Africa et al. 2017).

Most of the aquatic animals are poikilothermic (cold-blooded), and therefore, their physiological activities are dependent on external environmental conditions, especially on temperature. Temperature tolerance in fish can be classified as directive, controlling, and lethal temperature. It indicates that fish will start showing alarming responses before it reaches the extreme thermal limits (Fry 1971). Abiotic stresses caused by increased temperature will have negative impact on food conversion, oxygen requirements, and energy expenditure of the fish (Brett 1979). Temperature rise beyond the level of physiological tolerance may also cause reduced feeding, increased hypoxia, and mortality (Ørnholt-Johansson et al. 2017). Ecological adversity arising from climate change includes coastal acidification, reduced benthic oxygen, coastal upwellings, freshwater runoff, phytoplankton blooms, and sea level rises (Kernan 2015; Fitzer et al. 2018). Rise in sea level will result in coastal erosion, alteration of hydrodynamics and coastal geomorphology, and therefore, decrease in the availability of ideal sites for aquaculture activities. Increase in atmospheric CO_2 levels due to climate change has been suggested to cause depletion in the ozone layer and enhanced entry of ultraviolet radiation to the earth's surface with possible effects on the oceanic process (Austin et al. 1992). Ocean acidification or reduction in ocean pH will affect the process of shell formation or calcification in shellfishes. It has been reported that acidification of oceanic water can reduce the sperm motility and fertilization rate in sea urchin (*Heliocidariserythrogamma*), which implies that other marine organisms are also at similar risk (Barange and Perry 2009).

Water scarcity due to the changing climatic conditions is likely to cause conflicts among various water-dependent activities, thus affecting inland fisheries and aquaculture operations. Resuspension of sediments during extreme weather events and deposition of suspended solids from surface runoff can cause retarded growth and acute gill damage in fish while upsetting overall health conditions (Au et al. 2004). Also, extreme climatic conditions like strong waves and storms can potentially damage exposed fish cages in the coastal areas, leading to escapement of the cultured species (Jackson et al. 2015), devastation of aquaculture structures, and increased infrastructure costs (Dankers and Zuidema 1995).

2.2 Biotic Stresses

Global climate change and ocean acidification can adversely impact the immune response of the fish due to conflict between maintaining homeostasis and increased metabolic rate at higher temperature and fluctuating pH and salinity range. In the case of farmed fish, the affect can be compensated by maintaining optimum feeding regime, but in shellfishes, the immunity will be compromised as the changing climate may influence the availability of natural food sources. Additional stressors like extended photoperiod, temperature rise, depletion in dissolved oxygen content in water, and increased UV radiation can potentially act as immunosuppressive factors and make the fishes more susceptible to diseases (Markkula et al. 2007). Rise in temperature can stimulate the dynamics of pathogens by increasing the virulence factor of the pathogen and supressing immunological activity of the host. It has been observed that ocean acidification and increased sea surface temperature can promote the survival and growth of many opportunistic bacteria, including Vibrio species (Baker-Austin et al. 2017).

The decay rate of viruses and larval *Bonamia* (oyster parasite) tends to increase with rising temperature (Oidtmann et al. 2018). Temperature-induced higher metabolism of the host organism may result in increased viral replication and easy transmission of the diseases (Gubbins et al. 2013). Alteration in the environmental condition can lead to the evolution of the existing pathogenic strain with varying degrees of virulence and replication rate (Murray and Peeler 2005). Also, parasite prevalence in the areas of warm or moderate temperatures is the most common phenomenon. Increased temperature may accelerate the maturation process of fish parasites like sea lice, and therefore, increasing sea surface temperature and salinities may facilitate easy spread of the parasites and thus make them more infectious (Murray et al. 2012; Brooker et al. 2018).

Similarly, fluctuation in salinity can also affect the survival of pathogen. Pathogens have optimum salinity ranges for their growth and replication, but many viral pathogens can grow on a substantial range of salinity (Oidtmann et al. 2018). At higher salinity growth, oyster parasites, sea lice and *Paramoebaperurans,* tend to increase with potential infectivity (Collins et al. 2019; Brooker et al. 2018; Arzul et al. 2009). During the spring and winter months, decrease in salinity may lower the survival of fish parasites (Van West 2006). Climate-mediated stress will give rise to physiological responses in the host organism through which the animal tries to re-establish normal physiological functions. If the stressful condition persists for a longer period of time, it may lower the disease resistance capacity of the fishes. In this situation, the already stressed fishes will easily get infected by opportunistic pathogenic microorganisms (Raman et al. 2013).

3 Climate Smart Aquaculture

The main aim of climate smart aquaculture is to ensure food security by adapting potential mitigation strategies. Climate smart aquaculture deals with minimizing potential adverse impacts of global climate change, increasing productivity, and income generation. The adaptation strategies require efficient use of natural resources for fish production, improving the resilience capacity of the aquatic system, sustainable development, and reducing the vulnerability of fish production which is most likely affected by climate change. The transition of traditional aquaculture practices into climate smart culture technique needs to be done at each stage, including national, regional, community, and individual levels. All public and private stakeholders should get involved in the process of transition to assure that the concerned aquaculture sector is climate resilient (Ahmed and Solomon 2016).

4 Strategic Approaches Towards Climate Smart Aquaculture

Climate smart culture approaches in aquaculture have three main objectives such as achieving sustainable fish production, increasing the resilience of the sector, and reducing greenhouse gas emission. The strategic adaptation approach focuses on building resilience capacity to the consequences of climate change (Bueno and

Soto 2017), whereas mitigation is a long-term solution to global climate change and may take considerable amount of time to visualize the results (Leal Filho 2011). Therefore, adaptation and mitigation approaches should be implemented in a conjoint manner for effective results.

4.1 Mitigation of Greenhouse Gases

Strategic approach towards climate change involves reduction in greenhouse gas emission, especially carbon-di-oxide (CO_2), which can be achieved through a combination of existing and new technologies, including product substitution, bio-based feedstock, electrification, and reducing carbon footprint (Maulu et al. 2021). Aquaculture producers and stakeholders can also play a crucial role in mitigating global climate change by using environment-friendly practices such as renewable energy sources, sustainable waste management, and proper feeding practices (Barange et al. 2018). It has been observed that in aquaculture production improper utilization of feed is the major contributor to greenhouse gas emission. For instance, sinking feeds are more environmentally viable in comparison with floating feeds (Hardy 2010). Hence, application of sinking feeds will have less impact on GHG emission.

It has been estimated that approximately 93 % of global carbon is trapped in the aquatic ecosystem and approximately 30% of annual carbon emissions are generally sequestered in seaweeds, mangroves, seagrasses, coastal sediments, and floodplain forests (Nellemann and Corcoran 2009). Therefore, it is very crucial to save these habitats from destruction and enhance their sequestration ability through proper management practices. Well-managed seaweed farms and mangroves will serve as a natural breeding ground for various fish species and act as a reservoir of natural foods. Expansion and conservation of these sensitive ecosystems will lead to species richness, healthier ecosystem, and abundance of aquatic species, and thus, it can safeguard livelihoods and provide food security (Palombi and Sessa 2013).

4.2 Livelihood Diversification Through Integrated Agri-aquaculture/Advanced Culture Techniques

Another approach to climate smart aquaculture is the diversification of livelihoods, one of the successful keys to adaptation as it provides additional livelihood options to the producers and build resilience against changing climate. Diversification involves a combination of the aquaculture system with other agricultural sectors such as crops and animal husbandry either as separate or integrated systems. The process of diversification is extremely beneficial in the areas where agricultural production is predicted to increase, whereas fish production is expected to decline (Bell et al. 2013). In order to improve the resilience capacity of the culture system, it is much required to encourage the consumption of diversified fish species, usage of by-products, and reducing wastage throughout the processing chain. These initiatives can potentially stabilize the income of the fisherfolk and secure the availability of nutritious foods.

The expected surge in extreme climatic events resulted in competition for freshwater resources, while making the area prone to droughts. System-based adaptation measures such as water-saving biofloc technology and recirculatory aquaculture practices are considered a viable solution to water scarcity (Boraiah et al. 2021). Biofloc technology is a method of boosting water quality parameters in the aquaculture system through balancing optimum nitrogen and carbon ratio. This technique is scrutinized as a resourceful alternative to traditional culture practices based on the growth of beneficial microbes in the culture medium. The technology has gained recognition as a sustainable culture technique for controlling water quality, minimum or zero water exchange and producing in situ value-added proteinaceous feed (Crab et al. 2012). Likewise, to mitigate the problems of water pollution due to rapid expansion of aquafarming activities, the development of recirculating aquaculture system (RAS) has become essential. In the RAS system, the effluent pass through biological filters and can be reused for fish culture. Through wastewater reclamation, this system can effectively minimize water requirement for fish culture (Sharrer et al. 2007).

Another such promising, economically rewarding, sustainable, and environment-friendly approach is Integrated multitrophic aquaculture (IMTA) where the fish is cultured in combination with other extractive species (van Osch et al. 2019). Similarly, aquaponics is also considered a resilient system which can effectively adapt to diverse climatic conditions. This system is the integration between aquaculture and without soil cultivation of agriculture or horticulture practices. In the aquaponics system, two completely different production systems are combined together into a closed recirculating unit. The nutrient-rich effluent and organic wastes generated from the fish tank are filtered through inert substances containing plant roots. The plant tends to assimilate the nutrients from the effluent for their growth and the filtered water is then pumped back into the fish tank and can be reused for fish culture. Aquaponics system can sustainably produce additional crops along with fish, and therefore, enhance the profitability of the system, reduce the degree of water pollution and effluent discharge, and can significantly overcome the challenges of water scarcity, soil degradation, and climate change. Moreover, aquaponics is a controlled system that maintains a high degree of biosecurity and reduces the risk of disease transmission (Palombi and Sessa 2013).

4.3 Species Diversification

Aquaculture producers can also gain potential benefits from shifting the aquaculture activities in less vulnerable areas and culturing climate-resilient fish species like magur, pangasius, GIFT tilapia, etc. (Maulu et al. 2021). Selection of species for aquaculture purpose based on easy breeding and feed conversion efficiency helps to minimize the negative impacts of climate change and GHG emission (Sae-Lim et al. 2017). Fish species such as *Clariasmagur, Heteropneustesfossilis, Channastriata, Channamarulius, Channapunctata, and Anabastestudineus*can withstand hypoxic conditions, and species like *Pangasionodonhypophthalmus, Oreochromisniloticus, and* Jayantirohu can be reared under varying temperature and salinity (Boraiah et al. 2021). It is evident that stress-tolerant fish species possess improved flesh quality, increased fecundity, and enhanced post-spawning survival. In this context, a robust implementation of a selective breeding program for the development of stress-resistant species is the need of the hour. But genetic intervention for the production of improved variety of fish species greatly depends upon the diversity and availability of genetic resources. The complete information on species diversity in the natural water bodies will be advantageous for exploring the genetic resources for future studies related to the adaptation mechanism of fishes towards multiple stresses (Boraiah et al. 2021).

4.4 Inland Saline Aquaculture

Soil salinization is a global concern for both developed and developing nations. Inland saline water is unfit for traditional aquaculture activities, and therefore, culture of diversified or potential alternative fish species will ensure considerable economic growth (Pathak et al. 2019). Inland saline groundwater generally contains high concentration of calcium and lesser concentration of magnesium and potassium ion. This variation in ionic concentration adversely affects the growth and survival of fish and shrimp species as potassium concentration of inland saline water plays a significant role in osmoregulation in fishes (Evans et al. 2005). After the necessary amendment, inland saline water can be effectively used to culture a range of finfishes, crustaceans, and algal species. Euryhaline finfish species like sea bream, tilapia, eels, pangasius, milk fish, pearl spot, silver perch, red drum, barramundi, and pampanoo, and crustacean species such as *Litopenaeusvannamei and Penaeusmonodon* can be commercially cultured in inland saline water with moderate to high salinity (Singh et al. 2014).

4.5 Culture-Based Fisheries

In smaller seasonal water bodies and flooded fields, culture-based fishes can be carried out as stock enhancement process. In the case of culture-based fisheries, the only input is stocking of the seeds and it does not require any external feed resources as the selected fish species can efficiently utilize the vacant food niches. Although the fish production from culture fisheries is relatively less compared to intensive farming, it is eco-friendly, cost-effective, and involves no GHG emission related to external feeding(Palombi and Sessa 2013).

4.6 Climate Smart Eco-management as a Tool for Fish Productivity Enhancement

In aquatic system management, climate smart practices are intended to prevent negative environmental impacts including water pollution. Minimization and subsequent reduction in pollution from point sources of fish production system are in demand by various public and regulatory authorities (Boyd 2003). From the aquaculture point of view, Better Management Practices (BMPs) are considered as one of the climate smart eco-management tools for responsible and sustainable farming of aquatic organisms, while allowing the production to be carried out in a cost-effective and profitable manner. Although BMPs are not certification standards, implementation of BMP can enhance the product quality based on animal health, food safety concerns, and environmental sustainability. BMPs are voluntary, location-based, and commodity-specific management norms that have been developed to fulfill the criteria of responsible fish farming, reducing the risk associated with culture operations, and profit maximization. However, BMPs are subjected to constant improvement, evolution, and timely revision, depending on changing climatic conditions (Market 2010).

4.6.1 Environment Management of Aquaculture

Environmental management through the implementation of BMP can lead to the overall improvement of the aquaculture production system, including optimum utilization of resources, enhanced growth performance, reducing disease occurrence, and improved marketability of the produce while achieving the food quality standards. Adoption of BMP guidelines is easy without any additional input costs. Availability of quality soil and water is the basic requirement for fish culture. Different soil properties can deeply impact pond construction and influence aquaculture production. Prior to fish culture, the soil characteristics such as texture, pH, water holding capacity, organic carbon content, etc. should be studied carefully and the necessary adjustments should be done to make the soil suitable for fish culture. Similarly, water quality parameters like pH, salinity, dissolved oxygen content, hardness, alkalinity, total suspended solids, free ammonia content, etc. should be taken into consideration before selecting the aquaculture site and the species to be cultured. Adoption of BMPs provides strong evidence to the fact that environment-friendly culture activities make better business sense (Woynarovich et al. 2011). However, the areas having extreme soil and water quality parameters, where amendment is impractical, can be used to culture various stress resilience fish variety to boost the aquaculture production (Boraiah et al. 2021).

4.6.2 Fish Health management

Disease is one of the prime limitations in aquaculture production causing worldwide economic loss (Sahoo et al. 2013). Mostly, frequent disease outbreak is the result of intensified culture activities and complex interaction between pathogen, host, and environment (Bondad-Reantaso et al. 2005). Disease management in the aquatic system is a tough proposition due to the unique affairs where the opportunistic pathogens are constantly looking for the immune-compromised host (Mishra et al. 2017). In many instances, the occurrence of disease is closely associated with environmental deterioration, poor water quality, nutritional deficiency, higher stocking density, and high microbial load (Mishra et al. 2015). Therefore, the most appropriate approach to reduce the risk of disease outbreak is the implementation of Better management practices (BMPs). This can be best achieved by maintaining optimum water quality, providing adequate nutrition, preventing the entry of pathogens in the culture system, and reducing the stress by following realistic stocking densities. A better understanding of disease predominance, suitable detection and control measures, biosecurity program, usage of disease-resistant strains, and farm-level execution of BMPs can ascertain sustainable fish production (Mishra et al. 2017).

4.7 Implementation of Policies

It has been reported that extreme climatic events mostly affect the small-scale farmers due to their poor adaptive capability and lack of financial assistance. Though the concept of insurance in the field of aquaculture is relatively new, it is gaining remarkable attention throughout the world (Pongthanapanich et al. 2019). Therefore, introduction and proper implementation of insurance schemes could significantly assist the fish farmers to build resilience against changing climate (Barange et al. 2018). In this regard, the ecosystem approach to aquaculture (EAA) and fisheries will provide the tools and strategies for successful

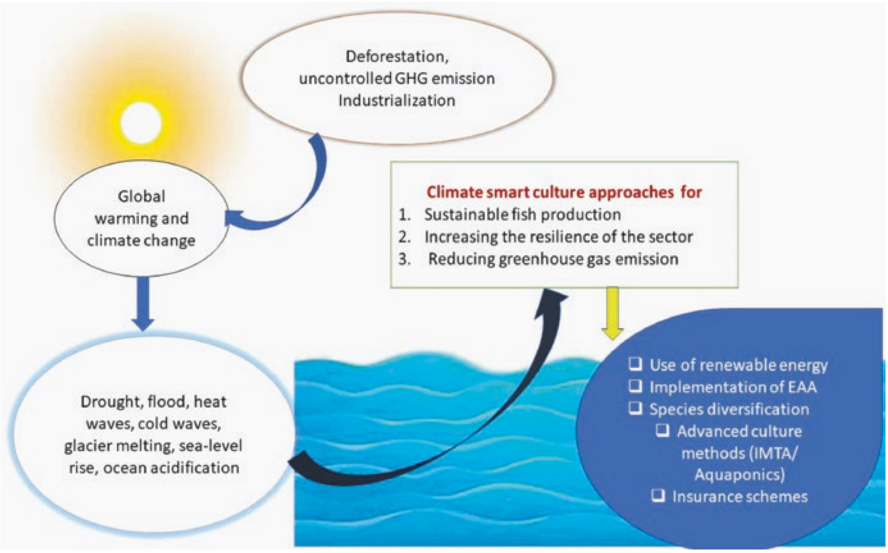

Fig. 14.1 Impact of climate change on aquaculture and their mitigation strategies

implementation of environmental guidelines, code of conduct, and policies for sustainable fish production under climate variability. Proper execution of EAA can ensure efficient use of natural resources, promoting scientific information system/ integrated monitoring services, increased adaptability of the sector, and livelihood security (Palombi and Sessa 2013) (Fig. 14.1).

5 Conclusion

The potential impact of climate change on fisheries and aquaculture activities has been highlighted in this article. Aquaculture production is continuously being exposed to the adverse effects of climate change and affects global food security. To improve the resilience capacity of the culture system, it is mandatory to make necessary amendments in the production practices. Optimization of all variables may not be always possible and hence, adaptation strategies on a priority basis should be implemented in a given production system. Developing effective and rapid responses to changing climatic conditions depends upon wider developmental goals and significant strategic planning. However, real-time adaptation methods for vulnerable regions with poorer economics will require further developmental research and execution strategies.

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Chapter 15
Advances in Nutrient Resource Management for Fisheries and Aquaculture

Gour Hari Pailan and Gouranga Biswas

Abstract Nutrient resource management is an important subject that determines the success of aquaculture. Natural fish food items such as planktons are often dependent on pond nutrient dynamics which is a complex subject. Therefore, attention is provided for proper management of nutrient resources in farming systems. During commercial farming, in addition to the inherent nutrient pool, nutrient supplementation through fertilization and feeding becomes essential to support the growing fish stock. Further, in intensive farming systems, nutrients from natural sources become inadequate to cater to the need of higher fish biomass through primary productivity. So, nutrient management of farmed animals is given utmost importance by the provision of feed. Balancing between use of fertilizers and supply of formulated feeds is required because both have some direct and/or indirect effects in influencing the nutrient status of water. Fertilization supports maintenance of conducive pond environment that favours the farmed species to efficiently utilize the feed provided. To sustain the growth of aquaculture sector towards meeting up the increasing fish demand, the availability of both nutrient resources and feed needs to escalate at the same time. In this circumstance, this chapter covers concisely various aspects of nutrients, their forms and sources in water, management of pond water nutrients through fertilization, nutrient management of cultured animals through feeding, and challenges in nutrient management.

Keywords Macronutrients · micronutrients · nutrient sources · nutrient requirement · pond fertilization · feeding management

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1 Introduction

Nutrient management is one of the key issues for successful aquaculture venture, but very often is not given importance or rather ignored. The dynamics of nutrients, natural fish food items such as planktons and fish biomass in culture environment are a complex subject, and aquaculturists do not often consider for their sound management (Kumar et al. 2005). Rather, arbitrary solution of pond nutrient management is formulated without considering field situations. Therefore, these clichéd formulations do not serve the purpose to deal the core issue of appropriate nutrient management. The inherent nutrient status of any water body could support productivity up to a certain level. When scientific farming is undertaken with a target of commercial-level production and economic benefit, natural productivity of water body along with nutrient supplementation from external sources in the forms of fertilization and feed becomes indispensable. Hence, nutrient management for culture environment as well as for the growing animals should be taken into consideration. To meet up the increasing demand for food fish with accelerating population, fish production from aquaculture needs expansion and intensification. In intensive aquaculture systems, nutrient management of farmed animals is given utmost importance through provision of feed. Because, in intensive systems, nutrients from natural sources are inadequate to contribute to fish biomass production through primary productivity. For successful semi-intensive and intensive aquaculture management, there should be proper management steps, such as high stocking density of culture animal, judicious use of fertilizers, use of nutritionally balanced formulated feeds, and water quality management, including provision of mechanical aeration (Hickling 1971; Bardach et al. 1972; Avault 1996). There should be a balance between the use of fertilizers and provision of formulated feeds, because both have some direct and/or indirect roles in influencing the nutrient status of water. However, fertilization often contributes to building up and maintenance of conducive pond environment that becomes favourable to the cultured species to efficiently utilize the feed provided (Green 2015). To maintain the current annual growth rate of 8–10% of the aquaculture sector to 2030 or beyond, the availability of nutrient resources and feeds will need to grow at a similar pace. In this context, this chapter outlines comprehensive information on nutrients, their forms and sources in water, management of pond water nutrients through fertilization, nutrient management of cultured animals through feeding, and challenges in nutrient management.

2 Nutrients, their Forms and Sources in Water

Natural primary producer of water, phytoplankton requires various elements for its growth and propagation. These elements are classified either as macronutrients (C, N, P, K, H, O, Ca, Mg, Na, S, Cl) or micronutrients (B, Cu, Co, Fe, Mn, Mo, Si, V, Zn) (Reynolds 1984; Lin et al. 1997; Boyd and Tucker 1998). Sometimes, some of the micronutrients could be macronutrients for a few species. For example, silica acts as a macronutrient for the Chrysophyta, especially diatoms (Reynolds 1984).

Concentrations of these elements in surface water often vary from location to location based on geology and climate of a particular location. However, at the same geographic location, concentrations of these elements are more variable in groundwater than in surface water. Among various macro- and micronutrients required for growth by phytoplankton, phosphorus, nitrogen, and carbon are considered as the most limiting elements for primary productivity. All three are found in various forms in pond water.

2.1 Phosphorus

Dissolved phosphorus is present in organic and inorganic forms in water. Organic forms generally originate from materials due to biological processes, such as enzymes, nucleic acids, and adenosine triphosphate. However, inorganic forms, namely orthophosphate ions ($H_2PO_4^-$, HPO_4^{-2}), originate from weathering of phosphate-containing minerals. Orthophosphate ions are the products of orthophosphoric acid (H_3PO_4) generated through ionization. In an aquaculture pond, both these orthophosphate ions are present and vary with pH. Dissolved orthophosphate serves as the main source of phosphorus for phytoplankton.

2.2 Nitrogen

Nitrogen also occurs in dissolved inorganic and organic forms in water. Organic nitrogen is a product of biogenic process and produced from free amino acids, peptides, and enzymes. Most commonly occurring inorganic nitrogen forms are ammonia-ammonium, nitrite, and nitrate ions. Dissolved ammonia (NH_3) remains in equilibrium with ammonium (NH_4^+) and the proportions of both are affected mainly by pH and temperature of water. The prime sources of ammonia in water are decomposition of organic matter by microbes and excretion by animals. Under aerobic conditions, nitrification process occurs, where ammonia is converted first to nitrite and then nitrate by oxidizing bacteria. Among the three forms of inorganic nitrogen, ammonium, nitrite, and nitrate, ammonium form is the most energetically favourable to phytoplankton for assimilation. However, nitrite and nitrate forms can also be utilized by phytoplankton after those are reduced to free nitrogen (N_2).

2.3 Carbon

Water contains both organic and inorganic carbon in dissolved forms. Numerous and variable forms of dissolved organic carbon occur in water and these include enzymes, nucleic acids, peptides, proteins, and carbohydrates (Green 2015). The main forms of inorganic carbon in water are carbon dioxide (CO_2), bicarbonate

(HCO_3), and carbonate (CO_3^{-2}) ions. Dissolved CO_2 in water comes from diffusion from atmosphere and respiration of aquatic organisms. A very meagre amount of dissolved CO_2 reacts with water to produce carbonic acid (H_2CO_3), which is a weak acid and finally dissociates into bicarbonate. There is a relationship of inorganic carbon ions with pH of water. When pH increases, bicarbonate dissociates into carbonate. Limestone is the largest source of bicarbonate released after reaction with CO_2. Phytoplankton readily uptakes CO_2 and bicarbonate ions as carbon sources.

Growth of phytoplankton is limited by nutrient concentration in water. When the water is deficient of major macronutrients, phytoplankton growth will be impaired and supplying the deficient nutrients in required concentrations will facilitate quick growth. As phytoplankton growth is influenced mostly by concentration of carbon, nitrogen, and phosphorus in aquaculture pond, proper liming and fertilization strategies are undertaken to ensure an uninterrupted surge of these nutrients. Although liming is not regarded as fertilization technically, it ensures phosphorus availability for successful application of fertilization that supplies the dissolved inorganic carbon in adequate level.

3 Fertilization for Management of Nutrients in Pond Water

The main purpose of fertilization in aquaculture pond is to make available of major nutrients essential for production of phytoplankton which serves as food for zooplankton and benthic animals (Boyd 2018). Further, these planktons and residues of plankton known as detritus and benthos are the desirable food items of fish and crustaceans (Mischke 2012). Pond fertilization enhances natural productivity by supplying essential nutrients, minerals, and vitamins required for aquatic biota production that serves either directly or indirectly as food for fish (Chakrabarty and Das 2012). Therefore, the goal of fertilization is to maximize fish production through utilization of primary, secondary, and tertiary levels of productivity. Fertilizers and manures used in pond are grouped into two categories: inorganic and organic. Inorganic fertilizers include limestone and lime-containing fertilizers, phosphate, nitrogen, potassium, magnesium, and trace element fertilizers. Organic fertilizers are better called as manures and include excreta of livestock and agricultural waste and by-products. N, P, and K are known as primary fertilizing nutrients, while secondary nutrients, such as Ca, Mg, S, and trace nutrients, namely Fe, Mn, Zn, Cu, etc. are also present in manures and chemical fertilizers. Generally, levels of primary nutrients in fertilizers are calculated as percentages of N, P_2O_5, and K_2O (Jones 1979).

3.1 Inorganic Fertilizers

The most commonly applied nutrients in aquaculture ponds are N, P, K, and Ca. Secondary and trace minerals are seldom used in aquaculture. Lime is regarded as the most common source of Ca fertilizer. Sometimes, lime is also considered as a fertilizer as it supplies the essential nutrient, Ca in water (Hickling 1971). There are various liming materials, such as limestone or calcite ($CaCO_3$), dolomite [$CaMg(CO_3)_2$], burnt or quick or unslaked lime (CaO), and hydrated or slaked lime [$Ca(OH)_2$]. Based on the pH of soil and water, lime is applied. For liming to bottom soil, both pH and soil texture are considered (Table 15.1). For newly excavated pond, lime is applied before water filling, and for other ponds, to dry bottom between crops. In general, it requires 1000–5000 kg/ha liming materials to rectify soil acidity to obtain a desirable total alkalinity (Boyd 2012). During culture, lime should be spread over the pond surface uniformly. In pond with water, lime is applied after measuring total alkalinity. One suggested approach is to apply liming material to ponds at 1000 kg/ha, and then measure total alkalinity after 14–21 days. When the desired alkalinity is not attained, liming may be repeated until it is attained (Boyd 2012).

The commonly used nitrogen fertilizers are urea, ammonium nitrate, ammonium sulphate, monoammonium phosphate (MAP), diammonium phosphate (DAP), ammonium polyphosphate, etc. Phosphorus fertilizers are single superphosphate (SSP), triple superphosphate (TSP), phosphoric acid, etc. Potassium fertilizers include potassium nitrate, potassium chloride, and potassium sulphate. MAP, DAP, and ammonium polyphosphate are used as sources of N, while potassium nitrate supplies both N and K. However, none of the chemical fertilizers contains all three primary nutrients of N, P, and K. Nutrient contents of chemical fertilizers are provided in Table 15.2. Chemical fertilizers are often mixed to prepare complete fertilizers containing desired levels of N, P_2O_5, and K_2O.

3.2 *Organic Manures*

Freshly collected manures contain considerably high levels of moisture and have bulk density ranging from 0.98–1.04 g/cm^3 (Lorimor 2004). Nutrient contents vary among organic manures based on source animals, solid or liquid states, ages, and methods of storage and livestock diets (Larney et al. 2006; Morrison 1961). Sometimes, manures are collected as aqueous slurries which contain lower levels of nutrients than that of solid manures (Table 15.3). In organic manures, N and P contents are often substantially lower compared to chemical fertilizers. Apart from N

Table 15.1 Lime requirement of pond bottom soil based on soil pH and texture (Schaeperclaus 1933)

	Lime requirement (kg/ha as $CaCO_3$)		
Soil pH	Heavy loams or clays	Sandy loam	Sand
<4.0	14320	7160	4475
4.0–4.5	10740	5370	4475
4.6–5.0	8950	4475	3580
5.1–5.5	5370	3480	1790
5.6–6.0	3580	1790	895
6.1–6.5	1790	1790	0
>6.5	0	0	0

Table 15.2 Primary nutrient contents of different chemical fertilizers (Boyd and Tucker 2014)

Fertilizer	Primary nutrients (%)		
	N	P_2O_5	K_2O
Urea	45	0	0
Calcium nitrate	15	0	0
Sodium nitrate	15	0	0
Ammonium nitrate	33–35	0	0
Ammonium sulphate	20–21	0	0
Phosphoric acid	0	54	0
Single superphosphate	0	16	0
Triple superphosphate	0	44–54	0
Monoammonium phosphate	11	48–52	0
Diammonium phosphate	18	48	0
Ammonium polyphosphate	11–13	37–38	0
Potassium nitrate	13	0	46
Potassium chloride	0	0	60
Potassium sulphate	0	0	50

Table 15.3 Dry matter (DM) and nutrient contents of different livestock manures, chicken litter, and composted manures (Brown 2013; Sharpley et al. 2009)

Manure source	Manure type	Concentration (%)			
		DM	N	P_2O_5	K_2O
Swine	Solid	30.8	0.93	1.12	0.68
	Liquid	3.6	0.39	0.27	0.23
Dairy cattle	Solid	24.1	0.72	0.46	0.73
	Liquid	8.6	0.39	0.21	0.30
Beef cattle	Solid	31.4	0.92	0.76	0.79
	Liquid	8.6	0.37	0.18	0.28
Chicken	Solid	60.6	2.71	3.02	1.74
	Liquid	10.0	0.81	0.64	0.36
Horse	Solid	37.4	0.50	0.34	0.52
Sheep	–	32.2	0.87	0.78	0.91
Composted	All types	46.4	1.09	0.78	1.00
Chicken litter	–	30.8	3.10	3.43	3.00

and P contents, organic manures contain a good amount of organic carbon (Table 15.4). This organic carbon contents promote growth of heterotrophic bacterial biomass, which ultimately helps in nutrient mineralization to enhance primary and secondary productivity (Schroeder 1978; Anderson 1987; Qin et al. 1995; Barkoh et al. 2005). However, during decomposition of organic manure in water, the bacterial population utilizes dissolved oxygen and application of manure at high doses may result in deficiency of pond-dissolved oxygen level in early morning (Qin et al. 1995). Moreover, this decomposition of organic manure and mineralization of nutrients take longer time compared to the nutrient availability obtained from chemical fertilizers.

3.3 Application of Fertilizers

There are different ways of application of manures and fertilizers. Organic manures are spread on the pond bottom during inter-crop period and broadcasted over surface water during crop (Boyd and Tucker 1998). Chemical fertilizers are broadcasted over pond water surface. For effective utilization of nutrients, granular fertilizers are mixed in water to make slurries and distributed over pond surfaces. Sometimes, mixed fertilization with organic manures and inorganic fertilizers provides better results. For example, higher tilapia production of 6000 kg/ha was achieved when pond was fertilized with chicken manure and 4 kg N and 2.1 kg P_2O_5/ha/day in comparison to 4300 kg/ha/year in pond fertilized with chicken manure alone (Diana 2012). Frequency of fertilization is also an important issue for achieving optimum pond productivity. Sometimes, fixed-rate application strategy is followed, where a defined rate of fertilizer is usually applied either at weekly or fortnightly basis. However, as the nutrients from fertilizers get quickly utilized in water, application should be repeated. For effective result, application should be done in accordance with phytoplankton abundance, but not on a fixed rate. In a situation when phytoplankton bloom is adequate, fertilization should be delayed and when phytoplankton bloom is inadequate, fertilization should be repeated (Boyd and Tucker 1998; Knud-Hansen 2006). For this purpose, measurement of Secchi disc visibility as an indicator of phytoplankton abundance is performed and a transparency of 20–30 cm is considered optimal. For carp culture with fixed fertilization rate, in case of newly excavated pond, raw cow dung is applied uniformly at 3000 kg/ha throughout the pond bottom, followed by proper mixing to increase the water retention capacity. In case of undrainable pond, basal application of cattle manure at 3000 kg/ha mixed with SSP at 30 kg/ha is done one week prior to stocking. If poultry manure is available, it is applied at 1500–2000 kg/ha instead of cattle manure. Basal application of cattle manure is not necessary when mahua oil cake at 2000–2500 kg/ha-m is used as a piscicide. During the crop, cattle manure at 1000 kg/ha, urea at 10 kg/ha, and SSP at 10 kg/ ha are mixed together with water and applied throughout the pond surface at 15-day intervals. However, the requirement of N and P fertilizers may vary as per the soil nutrient status of pond (Table 15.5).

Table 15.4 Mean and range of total carbon content (%) in livestock manures

Manure source	Mean	Range
Dairy cattle[1]	9.2	4.7–11.4
Beef cattle[2]	13.5	–
Swine[3]	12.5	11.6–13.2
Sheep[3]	10.1	6.9–12.4
Chicken[3]	19.7	13.0–23.9
Chicken litter[4]	25.8	12.2–33.0

[1]Pettygrove et al. 2009; [2]Larney et al. 2006; [3]Moral et al. 2005; [4]Sharpley et al. 2009

Table 15.5 Doses of N and P fertilizers (kg/ha/month) for carp culture pond based on soil nutrient status (Chakrabarty et al. 1975)

Soil nutrient content		
1. Available N (mg/100g soil).	Ammonium sulphate	Urea
High (51–75)	70	30
Medium (26–50)	90	40
Low (up to 25)	140	60
2. Available P (mg/100g soil).	SSP	TSP
High (7–12)	40	15
Medium (4–6)	50	20
Low (up to 3)	70	30

SSP Single superphosphate, *TSP* Triple superphosphate

Use of both organic manures and chemical fertilizers can augment the aquaculture productivity by increasing phytoplankton production in ponds. Although organic manures contain lower levels of N, P_2O_5, and K_2O than that of chemical fertilizers, due to their low cost, they can be applied in higher quantities. Thus, when applied in larger quantity, organic manures can result in greater fish production than that of commercial fertilizers, and for better effectiveness, organic manures should be applied in combination with chemical fertilizers. Therefore, fertilization will remain to be an important nutrient management practice in aquaculture for future also.

4 Feed and Feeding for Nutrient Management of Cultured Animals

In commercial aquaculture systems, the cultured species may not get proper nutrition from natural food sources because of high stocking density beyond the normal carrying capacity of the systems. Therefore, it becomes indispensable to feed the cultured animals from external sources, either completely or supplementarily. Thus, expenditure towards feeding fish in aquaculture accounts for 50–60% of the total operational cost. The feed provided to fish should be nutritionally-balanced, containing all the essential nutrients that are normally received by fish from natural food items. Nutritionally balanced diets influence the growth performance and survival of aquatic animals in a positive manner (Lovell 1989). Before development of any balanced feed, nutrient requirements of cultured animals should be known, so that the developed feed with proper energy and nutrient contents would support the growth, reproduction, and health of the animals. Moreover, nutrient requirement of fish depends on several other factors, such as feeding habit, stage of life cycle, habitat, etc.

4.1 Nutrient Requirements of Fish and Crustaceans

A complete diet provides all the nutrients (protein, carbohydrates, fats, vitamins, and minerals) required for optimal growth, survival, and health of farmed animals. Most of the commercially available formulated feeds contain the essential nutrients, including protein, lipid, carbohydrate, ash, phosphorous, moisture, minerals, and vitamins in the range of 18–50, 10–25, 15–20, <8.5, <1.5, <10, 0.5, and 0.5%, respectively (Prabu et al. 2017). In the case of indoor culture systems or enclosure systems, the cultured species may not obtain food from natural sources, so supply of nutritionally balanced supplementary feeds would only cater to the nutrient requirement of these animals (Craig and Helfrich 2013). The subcommittee on Fish Nutrition under the Committee on Animal Nutrition of the National Research Council (NRC) periodically examines the literature and current practices of feeding in aquaculture. The NRC publishes the nutritional recommendations for fishes and shrimp.

Protein is an essential component of fish diet and the most expensive one too. So, the levels more than requirement will result in higher cost of feed and increased level of nitrogenous wastes through excretion in water. Excessive level of protein in the feed is thus economically and environmentally undesirable (Lall and Tibbetts 2009). Most of the herbivorous and omnivorous fish need 25 to 35% protein in their diet, whereas carnivorous species require higher levels of protein ranging from 40 to 55% of diet (NRC 2011). Dietary protein requirement is also influenced by energy content and the ratio of energy to protein in the diet. Sometimes, when the energy to protein ratio in feed increases, the intake will decrease in fish (Cho and Kaushik 1990). Dietary protein primarily supplies the essential amino acids which are ten in numbers, including arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine for most of the fish species (Table 15.6).

Dietary lipids mainly supply the energy and essential fatty acids (EFAs) in fish (Chatzifotis et al. 2010). The EFA requirement of fish is only supplemented by the long-chain unsaturated fatty acids of linolenic (18:3, n-3) and linoleic (18:2, n-6) series (Table 15.7). Requirement of dietary lipid containing the appropriate levels of EFAs should have a range of 5–9 and 2–10% for carps and freshwater prawn, respectively. Lipid requirement for carnivorous fish has a range of 10–15% in the diet. However, salmonid and marine fish tissues contain eicosapentaenoic acid (20:5, n-3) and/or docosahexaenoic acid (22:6, n-3), which indicates a high dietary requirement for these fatty acids (Lall and Tibbetts 2009).

Generally, fish have limited ability to utilize dietary carbohydrates. However, herbivores and omnivores can utilize more amount of carbohydrate than the carnivores. In general, carbohydrate level included in the diet of carnivores is less than 20%, whereas herbivores and omnivores can utilize about 25–50% dietary carbohydrates. Carbohydrate utilization is improved when it is gelatinized. Carps and prawn have the ability to utilize complex polysaccharides like starch more efficiently than simple sugars like glucose. Crude fibre (CF) in diet should not be more than 8%,

Table 15.6 Digestible protein and amino acid requirements (% diet) of different finfish species (NRC 2011)

Nutrient	Rainbow trout	Atlantic salmon	Channel catfish	Common carp	Tilapia	European seabass	Yellowtail
Protein	38	36	29	32	29	40	38
Arginine	1.5	1.8	1.2	1.7	1.2	1.8	1.6
Histidine	0.8	0.8	0.6	0.5	1.0	–	–
Isoleucine	1.1	1.1	0.8	1.0	1.0	–	–
Leucine	1.5	1.5	1.3	1.4	1.9	–	–
Lysine	2.4	2.4	1.6	2.2	1.6	2.2	1.9
Methionine	0.7	0.7	0.6	0.7	07	–	0.8
Methionine + cysteine	1.1	1.1	0.9	1.0	1.0	1.1	1.2
Phenylalanine	0.9	0.9	0.7	1.3	1.1	–	–
Phenylalanine + tyrosine	1.8	1.8	1.6	2.0	1.6	–	–
Threonine	1.1	1.1	0.7	1.5	1.1	1.2	–
Tryptophan	0.3	0.3	0.2	0.3	0.3	0.3	–
Valine	1.2	1.2	0.8	1.4	1.5	–	–

Table 15.7 Essential fatty acid requirements (% diet) of different finfish species (NRC 2011)

Fish species	18:3, n-3	18:2, n-6	n-3 PUFA
Rainbow trout	0.7–1.0	1.0	0.4–0.5
Atlantic salmon	1.0	–	0.5–1.0
Channel catfish	1.0–2.0	–	0.5–0.75
Common carp	0.5–1.0	1.0	–
Tilapia	–	0.5–1.0	–
European seabass	–	–	1.0
Yellowtail	–	–	2.0–3.9
Japanese flounder	–	–	1.4
Grouper	–	–	1.0
Red drum	–	–	0.50–1.0

which cannot be digested when at higher level. For both fish and prawn, less than 4% CF is desirable.

Fish have the physiological ability to absorb and retain minerals from food and water (Lall 2002). Trace minerals have role in skeletal development and physiology of fish. Dietary requirement of phosphorus, magnesium, zinc, iron, copper, manganese, iodine, and selenium is important for different fish species (Table 15.8). Vitamin requirement for fish is similar to terrestrial animals. Dietary requirement of fat-soluble vitamins, namely vitamin A, D, E, and K, and water-soluble vitamins, such as thiamine, riboflavin, pyridoxine, pantothenic acid, folic acid, niacin, biotin, vitamin B12, vitamin C, and choline vitamins, has been reported for various fish and crustacean species (Table 15.9).

Table 15.8 Mineral requirements (% diet or mg/kg diet) of different finfish species (NRC 2011)

Mineral	Rainbow trout	Atlantic salmon	Channel catfish	Common carp	Tilapia	European seabass	Yellowtail
Calcium, %	–	–	0.45	0.34	–	–	–
Phosphorus, %	0.70	0.70	0.33	0.7	0.4	0.65	–
Magnesium, %	0.05	0.04	–	0.04	0.05	–	–
Sodium, %	–	–	–	0.06	0.15	–	–
Potassium, %	–	–	0.26	–	0.20–0.30	–	–
Chlorine, %	–	–	0.17	–	0.15	–	–
Manganese, mg/kg	12	10	2.4	12	7	–	–
Zinc, mg/kg	15	37	20	15	20	–	–
Iron, mg/kg	–	30–60	30	150	85	–	–
Copper, mg/kg	3	5	5	3	5	–	–
Selenium, mg/kg	0.15	–	0.25	–	–	–	–
Iodine, mg/kg	1.1	–	1.1	–	–	–	–

4.2 Common Feed Ingredients with Nutrient Contents

As per the sources, feed ingredients are broadly classified as plant and animal origins. Before formulating any feed, information about ingredients, their composition, and digestibility by target animals are important to meet the metabolic requirements and prepare good quality pellets with palatability by keeping the toxic/antinutritional components within desirable levels. Therefore, preparing an extensive list of common feed ingredients with their nutrient profiles (Table 15.10) is made beforehand based on various publications such as books (Guillaume et al. 2001; Hertrampf and Piedad-Pascual 2000; Halver and Hardy 2002; NRC 1982, 2011) and web resources (http://www.fao.org/docrep/s4314e/s4314e0j.htm; http://www.feedipedia.org/). However, the nutrient content of ingredients of animal and plant origins varies depending on the season, fertilization, cultivar or species, geographies, climate, processing of raw materials, and analytical method (Bureau et al. 1999; Cromwell et al. 1999; Dozier III et al. 2003; Glencross et al. 2007).

4.3 Feeding Management in Different Culture Systems

Use of feed type and feeding management depend on culture systems to be undertaken: extensive, semi-intensive, or intensive. Fish in the first two systems get the nutrients completely or partially from the natural food organisms in culture pond.

Table 15.9 Vitamin requirements (mg/kg diet) of different finfish species (NRC 2011)

Vitamin	Rainbow trout	Atlantic salmon	Channel catfish	Common carp	Tilapia	European seabass	Yellowtail
Vitamin A	0.75	–	0.6	1.2	1.8	31	5.6
Vitamin D	40	–	12.5	–	9	–	–
Vitamin E	50	60	50	100	60	–	119
Vitamin K	–	<10	–	–	–	–	–
Thiamin	1	–	1	0.05	–	–	11
Riboflavin	4	–	9	7	6	–	11
Vitamin B_6	3	5	3	6	15	–	12
Pantothenic acid	20	–	15	30	10	–	36
Niacin	10	–	14	28	26	–	12
Vitamin B_{12}	0.15	–	–	1	0.06	–	0.67
Folate	1	–	1.5	–	1	–	1.2
Vitamin C	20	20	15	45	20	20	43–53
Myo-inositol	300	–	–	440	400	–	420

However, in intensive systems, such as tanks, raceways, and cages, fish completely rely on nutritionally balanced diets in different forms, like dry, semi-moist, or moist. Moreover, feed and feeding management depend on species cultured and its life stages. Here, feeding management practices of the most commonly cultivated species are provided.

4.3.1 Feeding Management in Carp Culture

Nursery Phase

Though plankton is the main food for carp spawn, finely powdered mash (50–70 μm) prepared with groundnut cake or mustard cake and rice bran (1:1 ratio) can also be broadcasted at 600 g / 100,000 spawn from second day of stocking. The feed ration is increased 100 g subsequently per 100,000 spawn per day up to 13th day out of total 15 days rearing period. The larvae are starved on day 14, and on day 15, harvesting of fry is done. Daily allowance of feed in nursery pond can be fed to the fish in two equal split doses once at morning 10:00 hours and another at late afternoon at 17:00 hours (Biswas et al. 2006a). If possible, per day feeding frequency may be increased to 6–8 times, because it is more beneficial for tiny spawn in nursery ponds.

Table 15.10 Composition of common ingredients used for preparation of fish feeds

Ingredients	Moisture (%)	Crude protein (%)	Ether extract (%)	Crude fibre (%)	Total ash (%)	Nitrogen free extract (%)
Plant origin						
Rice polish	8.4–12.6	11.4–14.5	15.3–17.3	7.5–11.0	6.0–12.9	41.0–46.8
Rice bran	7.8–10.1	2.9–12.6	4.2–11.3	5.3–19.3	3.1–20.5	36.5–37.5
Deoiled rice bran	7.2–8.1	12.1–14.3	1.3–1.8	15.2–16.7	23.8–29.1	40.4–43.3
Wheat bran	9.0–13.0	8.2–15.8	2.6–6.6	4.0–13.5	0.2–4.2	34.5–37.6
Wheat flour	12.6–12.9	14.5–15.6	3.7–3.9	2.7–2.9	2.3–2.8	64.2–64.6
Groundnut cake	7.0–10.0	42.0–48.0	7.3–13.8	13.0–13.2	2.5–13.4	25.2–29.9
Sunflower cake	8.0–10.0	31.0–32.6	2.1–2.9	18.4–24.7	1.5–6.2	39.0–40.1
Coconut cake	8.9–9.1	12.2–13.7	4.9–5.1	25.6–26.5	2.6–2.8	45.8–46.4
Soybean meal	3.0–11.8	46.0–32.8	2.1–2.9	18.4–24.7	1.5–6.5	39.0–40.1
Cotton seed cake	7.0–8.2	37.0–42.7	7.0–10.0	12.6–13.0	1.0–8.2	27.3–35.3
Spirulina	8.7–10.1	50.5–51.3	1.0–1.8	2.1–2.6	11.0–11.7	26.7–27.5
Mustard cake	8.5–9.2	23.6–30.8	9.3–9.6	6.2–6.3	10.3–10.4	34.9–40.9
Gingely cake	7.9–9.0	34.0–40.0	2.0–7.8	9.6–9.7	2.9–3.1	38.2–38.4
Gingely extract	7.0–9.0	34.0–40.0	2.0–7.8	9.6–9.7	2.9–3.1	38.2–38.4
Corn or maize	10.4–10.6	4.6–5.0	7.8–8.0	3.5–4.0	1.0–2.0	72.7–75.0
Maize meal	10.4–13.5	4.6–9.5	4.0–7.8	3.5–4.0	1.0–1.5	67.5–72.7
Tapioca flour	8.0–11.5	1.8–3.1	1.3–2.3	1.8–2.0	0.2–2.3	78.8–86.9
Rice broken	10.0–10.5	12.0–12.6	4.2–4.8	5.3–5.9	3.1–3.6	65.4–69.1
Wheat broken	9.0–10.0	11.5–12.0	1.9–2.0	4.0–4.5	0.2–1.0	73.4–75.2
Rapeseed cake	11.0–11.5	35.9–36.3	0.9–1.5	13.2–13.6	6.9–7.5	32.1–33.8
Animal origin						
Fish meal	9.0–14.6	14.4–72.0	2.5–10.3	0.3–30.0	2.5–20.9	7.0–29.0
Shrimp waste	3.6–15.6	22.5–34.2	1.1–8.0	7.1–35.3	18.6–31.6	11.0–16.3
Squilla meal	14.1–14.9	46.0–47.3	2.6–3.3	13.5–15.2	18.0–20.1	5.8–6.0
Squid meal	8.0–8.5	75.0–76.9	6.5–7.1	4.0–5.3	–	–
Clam meal	7.0–8.1	50.7–52.0	8.9–11.6	3.9–5.5	6.4–6.9	22.0–23.1
Silkworm pupae	7.1–7.5	43.9–45.5	25.7–26.1	4.2–4.3	15.8–16.4	3.3–4.0
Defatted silkworm pupae	8.1–9.0	68.0–69.2	2.6–3.1	1.3–1.9	7.2–8.1	12.8–13.7
Blood meal	10.0–12.9	65.3–76.6	0.5–1.1	1.0–1.9	3.8–4.3	4.6–5.1
Meat meal	8.0–10.0	50.0–71.2	4.4–13.3	0.7–6.8	5.0–5.6	25.8–26.0
Liver meal	7.0–7.5	65.0–68.3	3.4–4.2	1.2–2.0	2.4–3.1	21.0–22.3
Earthworm	5.0–6.5	51.7–55.1	3.4–4.1	12.8–13.6	12.5–13.0	14.6–15.0

Rearing Phase

For feeding fry in a well-prepared rearing pond for 90 days period, initially, crumbles of 0.5 mm dia can be used and gradually crumble size can be increased up to 0.8–1 mm dia. Considering the plenty of live food availability, daily ration of feed in rearing pond is 10%, 8%, and 6% of body weight during first, second, and third month, respectively, and can be fed to the fish in two equal split doses once at morning 10:00 hours and another at late afternoon at 17:00 hours, if feed is broadcasted. Feeding frequency of 3–4 times per day is always beneficial (Biswas et al. 2006b). However, feeding frequency depends on feeding method. Tray (plastic or aluminium) system of feeding method is always preferable for controlling the feed loss. Total amount of daily feed amount is taken in tray, which is then hanged from bamboo pole at different places of the pond 3–4 m away from the pond side. A total of 14–16 trays are required per ha area. This method of feeding is performed once daily, and in the next day, trays are taken out, washed properly, and the feeding is continued in same way.

Grow-out Phase

During a culture period of one year or so, different types of feeds, such as dry mash, wet ball, cooked paste, cooked balls, or dry pellets, can be used for feeding fingerlings and growers in composite fish culture system. Under semi-intensive culture system, supplementary artificial feed, and under intensive culture system, complete artificial feed should be provided. Fish are fed at 5% of body weight during first 2 months, 4% of body weight during next 2 months, 3% of body weight during next 2 months, 2% of body weight during next 2 months, and 1% of body weight during final 2–4 months. Depending on the feed types, either broadcast or tray or basket (bamboo basket) or bag (used cement bag or gunny bag) system of feeding method is employed in grow-out pond (Nandeesha et al. 2013). Mixture of floating and sinking pellets at 2:1 ratio can be distributed in the pond twice daily once at morning 10:00 hours and another at late afternoon at 17:00 hours. For other kinds of feeding methods as mentioned earlier, feeding is done once daily. Either wet ball or cooked paste or cooked ball or dry sinking pellets can be offered to the carps through three-tier system of tray or basket method in which total amount of required feed per day is distributed in different trays or basket which are tied up in and hanged from bamboo poles that are placed 3–4 m away from the pond side and trays or basket are submerged in the water at 1.5-, 3.5-, and 5.5-feet depth. Mash feed and also sinking pellets can be offered to the fish through three-tier bag system of feeding method. Perforated nylon or plastic cement or fertilizer bags of 20 kg capacity are generally used for this purpose. After distributing the daily required feed inside the bag, mouth is tied and bags are hanged in the same way of tray or basket method. This sort of arrangement is required at 14–16 places per ha area. When fish nibbles near holes, certain amount of feed mixture or pellets come out through holes that are consumed by the fish, thus this system acts as the indigenous type of demand feeder (which are generally used in developed country). Tray/basket and bag system of feeding methods are useful for controlling the feed loss or waste. In composite fish culture system, for feeding of grass carp separate arrangement is required. Chopped aquatic weeds, fodder grasses (Napier etc.), lawn grass, vegetable waste, etc. can be placed on rectangular bamboo platform fixed at corner of ponds at certain depth for feeding of grass carp. The grass carp should be fed until they stop eating. Usually, they consume aquatic weeds about 50% of their body weight on a daily basis. Hence, it is advisable to feed them at least 1 hour before the application of supplementary feed to other fish. Sometimes, mixed feeding schedule such as 1–2 days feeding with low protein diet followed by 3 days feeding with high protein diet can also be practiced. Through proper feeding management, feed conversion ratio (FCR) in carp culture is possible to maintain as 2:1.

4.3.2 Feeding Management in Catfish Culture

In a pond with walking catfish, *Clarias magur*, artificial feed at 10–5% of body weight is normally dispensed or broadcasted from all sides to provide feeding opportunity to all fish. Feeding should be done twice daily once at very early morning and another at late evening as *C. magur* prefers to eat under less light (Imteazzaman et al. 2017). Water quality is very much important for feeding catfish. At low oxygen level, feeding activity of *C. magur* is reduced. Thus, pelleted feeds need to have high degree of water stability. Mash and wet balls are less preferable for catfish. Sometimes, molluscan meat and chopped chicken viscera can also be fed to catfish under pond condition. These feeds are placed at shallow zone near the side of the pond. Through proper feeding management, FCR can be maintained as 3–4:1 under pond condition.

For striped catfish, *Pangasianodon hypophthalmus,* in pond condition, a mixture of rice bran, broken rice, and small quantity of trash fish can be fed to the stocked fingerlings for first two months. From third month onward, fish are fed various formulated diets. The feed is broadcasted to fingerlings at 10% of body weight and gradually reduced to 5% for juvenile, grower, and adult stage. Through proper feeding management in ponds, fish can attain an average weight of 1–1.5 kg with FCR of 4–6:1 at the end of 8–12 month-culture period (Sayeed et al. 2008).

4.3.3 Feeding Management in Tilapia Culture

In nursery ponds for 45 days, fry is given floating feed (30% protein) at an initial rate of 10% of biomass per day, which is gradually decreased to a final rate of 5% daily. Fry should be fed 3–4 times daily. In grow-out pond, supplementary diet in the form of floating feed is provided in addition to natural food for better growth, survival, and good water quality. Low protein feed is provided at 5% of biomass per day, which is gradually decreased to a final rate of 3% daily. Feed is provided in 2–3 equal rations daily.

4.3.4 Feeding Management for Giant Freshwater Prawn, *Macrobrachium rosenbergii*

In order to enhance the growth and as a precaution against cannibalism, the prawn juveniles are provided with feed mix (rice bran: oil cake in a ratio of 1: 1) at 25% of body weight for first 2 months and gradually reducing to 3% of body weight towards the end of culture period on daily basis or at 3–5% of body weight on daily basis for the first month and then at the same rate on alternate days from the second month onwards (Mukhopadhyay et al. 2003). However, quantity of feed should be adjusted through trial and error after verifying the consumption on the following morning. To avoid cannibalism, prawn should not be hungry. Wet balls may be prepared using these ingredients and provided in plastic or aluminium tray or bamboo basket hanging from bamboo pole fixed 1–1.5 ft. away from the pond dike and submerged near the pond bottom. Ball can also be prepared with more ingredients (different oil cakes especially ground nut oil cake, fish meal, shrimp meal, silkworm pupae, beef liver meal, meat meal, squid waste, dry fish, dry *Acetes*, broken rice, rice bran, tapioca root powder, yeast, etc.) along with vitamin-mineral mixture following improved formula. Farm made or commercial sinking pelleted feed may also be used and given through same tray/basket method. Mash feed or sinking pellets can also be given through perforated bag method in which bags are arranged in the similar way to tray method. Feed can also be broadcasted around the periphery of the pond in the shallow areas. Check trays kept in different areas of the pond will help in deciding the quantum of feed per day. As prawn has nocturnal feeding habit, the feed should be given at night 20:00 hours also. Besides, special diets like boiled tilapia flesh, chopped raw meat of gastropods or trash fish, and cooked chicken entrails at 10% of the bodyweight are also administered on fortnightly basis. Sometimes, compound chicken feed mixed with trash fish and prawn meal and formulated shrimp feed may be used. In monoculture, FCR is 7–9:1 for wet feed and 2–3:1 for compound dry feed. Prawn should be sampled using cast net on monthly basis, and based on the average body weight, new feeding rate may be calculated.

4.3.5 Feeding Management for Shrimp

Shrimps are fed at a fixed daily rate based on their body weight and an estimated total shrimp biomass of the pond or tank. Daily feed ration is usually applied manually or mechanically for 4–6 times daily. In farming condition, feed intake and utilization and growth of shrimp vary depending on different biological, environmental, and other factors, such as stage of shrimp growth, water temperature, availability of natural food, feed type, feed application method, shrimp moulting stage, and health status (Tacon et al. 2013). Daily monitoring of feed intake is very crucial in feeding management for adjustment of daily ration. Feeding rate decreases with increasing body weight and reducing metabolic rate over the culture cycle (Table 15.11). With proper management of feeding, FCR in shrimp culture varies from 1.2 to 1.8:1.

Table 15.11 Feeding rate for Pacific white shrimp, *Penaeus vannamei,* fed with a feed containing 35% crude protein and 8% crude lipid at varied water temperature (Tacon et al. 2002)

Body weight (g)	Feeding rate (% of estimated biomass)		
	21–24 °C	24–28 °C	28–32 °C
1–3	8.0	6.0	7.0
3–5	7.0	5.0	6.0
5–7	6.5	4.5	5.5
7–9	6.0	4.0	5.0
9–11	5.5	3.5	4.5
11–13	5.0	3.0	4.0
13–15	4.5	2.5	3.5
15–17	4.0	2.5	3.0
17–30	3.0	2.0	2.5

5 Challenges of Nutrient Management in Aquaculture

There are several challenges for a successful management of nutrients in aquaculture. The main issue of overuse of nutrient inputs to aquaculture systems through fertilization and feeding remains evident always. Minimizing nutrient load from fertilization should be the appropriate approach according to the targeted fish production level. Very often, fertilizers are applied without knowing the N and P ratio, which causes excessive nutrient influx in most of the instances. Many times, status of inherent nutrient levels of pond environment is either not assessed or ignored prior to application of fertilizers. Another important aspect of fertilization is the method of application. Granular fertilizers quickly sink into water and then settle to the bottom before being completely dissolved. Instead, use of liquid or finely powdered fertilizers which can be applied after making a mixture with water is a more efficient alternative. This method of mixing of fertilizers with water can reduce the fertilizer rates by 50% or more (Boyd and Tucker 1998). In case of organic manures, application of raw or freshly collected matters can cause a deleterious effect upon their microbial decomposition and resultant oxygen depletion in water. Therefore, organic manures in semi- or fully decomposed condition need to be applied. The requirement of organic manure quantity is more compared to chemical fertilizers, which causes difficulty in obtaining huge amounts at a time. However, due to the low cost of organic manures which are mainly produced from household wastes, small and marginal farmers can easily afford the expense than the use of high-priced chemical fertilizers. The problem of waste accumulation from excess feeding is another biggest challenge for environmental sustainability. Moreover, manipulation of feed composition can reduce the metabolic waste output from the farmed animals. Amino acid composition of protein source can have a significant contribution towards ammonia excretion by fish. However, optimization of amino acid profile of fish feeds is a challenging task due to high variability of amino acids existing in ingredients and estimation procedures (Bureau and Hua 2010). Therefore, feed formulation should be such that there will be low nutrient output by improved FCR through the adoption of proper feeding strategy (White 2013). Development and application of species-specific feed with high digestibility and use of suitable binder for getting desired stability of diet are some of the issues that need attention. Removal of excess nutrients which cause eutrophication and pollution of the aquatic environment is another difficult task. For this purpose, low-cost methods employing biological organisms that utilize nutrients and organic wastes could be thought of and integrated.

6 Conclusion

The knowledge of nutrient management in culture environment through fertilization and feeding has been expanding steadily over a few decades. However, works on management of nutrients in aquaculture pond water have started long back compared to nutrition and feed development for cultured animals. Issues related to environmental impacts of aquaculture have floated with the supply of nutrients in the form of feed which is actually meant for cultured animals, but unutilized or waste materials from feeds cause nutrient imbalance in water and sediment. Natural food production in pond can be enhanced through provision of nutrient sources externally by means of fertilization or feeding. This natural pond productivity could be increased by fertilization for growth of phytoplankton primarily and other food items secondarily. However, natural productivity can support yields up to a certain level only, 0.5 to 4 tons/ha depending on species cultured, culture duration, and fertilization strategy adopted. Intensification of aquaculture is inevitable to efficiently produce cheap protein to feed the growing global population which will reach approximately 9.4 billion by 2050. Therefore, in aquaculture with high targeted yield, nutrients for growth of cultured animals must be met up from external source in the form of a nutritionally balanced and palatable feed. However, applying high amount of feed does not always enhance fish production as most of the feed consumed is not transformed to harvestable biomass, rather, sometimes, is wasted causing deleterious effects on culture environment. These waste nutrients (N, P_2O_5, K_2O, and other minerals) and accumulated organic matters from excretion and natural foods cause pond environmental issue of oxygen depletion due to concomitant decomposition. Therefore, holistic approaches for pond nutrient management need to be followed starting from adoption of proper fertilization and subsequent feeding strategies. Feeding management practice should be such that feed will be nutritionally complete with high digestibility to reduce waste output and inclusion of novel feed ingredients that are readily available in adequate quantity to partially or completely replace the feed components which are not sustainable economically and environmentally. However, with utmost management measures, it is perhaps impossible to avoid waste accumulation and resultant nutrient influx into aquaculture systems. Utilization of excess nutrients and organic matters is being given importance for achieving environmental sustainability of aquaculture. Various approaches aiming at pond's internal waste utilization in in situ manner rather than discharging into natural waters, such as integration of extractive species, biofloc technology, periphyton-based farming system, etc., are being evolved and should be widely used in near future.

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Conclusion

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Strategies for adapting climate uncertainties have been exercised. Many approaches could be geographically related; hence, promoting alternatives from many parts of the world would be one of the keys for mitigating climate impact. In the second volume, Kumar et al. discussed about drone technology in sustainable agriculture: the future of farming is precision agriculture and mapping, and Otieno et al. contribute to document crop production systems suitable to climate crisis. They found that aspects in soil, crop, and their management could play significant role in the adaptation. Although political aspect is believed to be important, many cases showed that its involvement was generally weak in many parts of the world.

Technology has largely been contributing in many parts of human lives and it influences further research and development in climate-related issues. Genetics is unsparingly vital to develop varieties adapted to minimal soil moisture contents. As demonstrated by Njinju et al., implementing drought-tolerant varieties in marginal lands improves the socio-economic properties of peasant farmers. Agricultural biotechnology, as argued by Abhishek Kumar et al., is also the key for adapting the climate. In addition, it helps to create a better environment if it is combined with suitable soil and crop management, as indicated in the Chap. 2 by Otieno et al.

Strategies for soil and crop management are generally complex due to the diversity of agricultural commodities and the dynamics in soil system. While fertilizer technology has been advancing, nutrient management is entirely multifaceted and

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should be done wisely to prevent further deterioration to the nature. Nitrogen, for instance, is a critical nutrient to plants; however, excessive or improper applications may lead to unfavorable situation. This book documents soil management in African countries as presented in a chapter by Gweyi-Onyango and Ntinyari for nitrogen and Hement Kumar et al. for carbon, in a hope to better understand the constraints and limitations among developing countries and records their adaptation strategies to the scarcity of soil nutrients.

Knowing point-wise soil and crop characteristics is substantial for farming. Nonetheless, with a larger extent or for agricultural planning, this kind of data is considerably insufficient. Producing maps related to any kind of agriculture-related data is fairly useful for stakeholders. As demonstrated by Trisasongko et al., Panuju et al., and Katiyar in this book, provision of spatial information will be beneficial for uncountable parties. These kinds of doable practice, alongside with the ones demonstrated in many scientific reports, should be enriched in further publications, in terms of availability of data continuation, public access to toolboxes or codes, and geographical diversity of performance. While these information are getting abundant, summary of constraints and benefits in implementing statistical models remains open to be fully developed in the future.

In a greater aspect, developing farming systems in ever-changing climate is a vivid challenge. With the diversity of native customaries and wisdom, these should be adapted locally. While adaptation would not be an issue for prosperous farmers, smallholders have lesser ability to adjust. This book provides a development scheme proposed by Haldar et al., involving the use of current technological advances with the hope that those technologies would improve the livelihood of smallholders. Certainly, future development should recapitulate any significant progress in all aspects of crop agriculture, thus allowing many parts of the world to assess possible best options in their case. The readers should note, however, that this development should not be limited to technological breakthrough, but also in post-agronomic and off-farm activities (see the Chap. 13 by SK Dubey et al.).

Similar agenda should be reworked for animal husbandry and aquaculture. Important works, such as the one reported by Bharati et al. in this book, need to be reassessed in different parts of the world to investigate the best strategies for managing the issue. Correspondingly, technological advancement while sustaining the environment like the ones presented by Chakraborty and Khrisnani or by Pailan and Biswas is imperative for further assessment in different geographies to better understand the issues related to the technology–human–environment nexus.

This volume summarizes that replicative studies in different parts of the world remain important as the issues are geographically diverse, perhaps controlled by human attitudes and local situations. These are entirely important for developing countries where smallholders dominate. With the availability of diverse cases, stakeholders may be able to learn and to adapt from the existing instance. While lacking the diversity of region, especially for Central and Latin Americas, the editors would seek to tackle the issue in detail in the future version of these edited books.

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