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SDG: 2
Zero Hunger

A photograph of a red tractor with a yellow tank and a long red spray boom, moving across a green field and spraying a fine mist. The background shows a hazy horizon with some distant buildings.

Jagadish Timsina · Tek N. Maraseni ·
Devendra Gauchan · Jagannath Adhikari ·
Hemant Ohja *Editors*

Agriculture, Natural Resources and Food Security

Lessons from Nepal

 Springer

Sustainable Development Goals Series

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Agriculture, Natural Resources and Food Security

Lessons from Nepal

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Foreword by John Dixon

Nepal is a land-locked country of immense diversity, ecologically and ethnographically. The hills and mountains of the Himalayas dominate the landscape, so that average altitude exceeds all countries in the world except nearby Bhutan. A narrow east-west strip of lowland Terai divides the Nepalese Hills from the Ganges floodplains of India. The dissected landscape and limited infrastructure are major constraints to, but simultaneously opportunities for, sustainable development. The remoteness, diversity, dynamics, and integration of many of the farming and food systems of Nepal have been a severe challenge to researchers and policy makers for many decades. The livelihoods of Nepalese farm families are in transition and depend on four evolving pillars: available natural resources; the management of interdependent crops, livestock, and forests; linkages to value chains; and off-farm income from local, regional, or international work. Cereals, especially rice, wheat, maize, millet, and barley, underpin dietary energy consumption for farmers and city-dwellers alike, increasingly supplemented by vegetables, milk products, eggs, and meat. Today, livestock—cattle, sheep, goats, and yaks—plays important roles in human nutrition and cash income. Their traditional functions as sources of manure for plant nutrition and draft power for ground preparation, threshing, and transportation are being replaced by mechanization. Forests provide fuelwood, timber, fodder, leaf litter, and ecosystem services. The use of external inputs such as seed, fertilizer, feed, and seedlings is low by Asian standards, yet growing as infrastructure and market systems develop. Farming system productivity is also lower than many Asian countries, and slow growth is a challenge for household and national food security. In fact, the national food system has increasing dependence on cereal imports.

Planners often distinguish three broad farming and food systems in Nepal—the lowland Terai, the mid-Hills, and the high Mountain systems. Typically, the lowland Terai systems have larger average farm sizes (although still small), more irrigation, and better access to input and produce markets, including the mega-markets of neighboring India—and good potential for crop intensification and diversification. The Hill farming and food system features strong crop–livestock–forest linkages and strong social capital which are both weakening as population pressure grows and market access improves, especially in districts close to cities or with well-organized value chains for milk or horticultural produce, e.g., orange. Off-farm income has grown in importance for rural livelihoods and farm investment. The

mountain farming system features even stronger population pressure on limited cultivated land and features a variety of minor food crops, potatoes, and grazing yaks, cattle, and their crosses. Tourism is an important source of local income. Both the hill and mountain systems have experienced strong temporary out-migration in search of remittance income as well as permanent relocation to urban centers and the Terai—and growing evidence of abandonment of marginal cropland.

Due to the confluence of ecological and economic characteristics, Nepal has a unique rural development experience from which lessons can be drawn for other small land-locked and mountainous countries around the world. This book, *Agriculture, Natural Resources and Food Security: Lessons from Nepal* is a valuable compendium of rural development knowledge for South Asia and other developing regions of the world. Each of the 24 chapters takes a deep dive on one or another component of the farming and food systems of Nepal. Related to crops, the well-experienced authors document urban agriculture, agro-biodiversity, soil health, pest and disease management, food safety, food production, fruits and vegetables, post-harvest management, citrus production, seed systems, and emerging approaches of conservation agriculture and regenerative agriculture. In relation to animal production, the book analyses livestock development, livestock (and land) ownership, fisheries, and the emerging one-health approach. The role of forestry is examined through the drivers–pressures–states–impacts–responses (DPSIR) framework and the success of community forestry (for which Nepal is famous) leading to emerging thinking on ecosystem services and selective logging policies. The pillars of crops, animals, and forests are tied together through the crosscutting themes of the water–energy–food nexus (as a planning framework), climate-related crop simulation modeling (as a decision support system tool), and a final chapter on gender and adaptation to climate variability. Many of these chapters present analyses of relevant sector and sub-sector trends which point to a mixture of challenges and successes. As in other countries, these agricultural dynamics arise from seven drivers and trends associated with demography, natural resources and climate, knowledge systems and gender, science and technology, markets and infrastructure, and institutions and policies. Overall, the book signals an optimistic view of farming and food systems development in Nepal. In fact, with a recently updated constitution and governance institutions, Nepal looks forward to a vision of achieving the sustainable development goals by 2030 and graduating from the least developed country status to a middle-income developing country soon to create a prosperous and happy Nepal.

Each chapter and the whole book contain development insights in relation to highly constrained smallholder agriculture which are of immense value to researchers and policy makers in Nepal and in other countries with similar situations and farming systems. For example, the successes and challenges of the Nepalese Hill diversified farming system (termed the South Asian Highland Farming System by FAO and the World Bank) are directly relevant to 65 million ha across the South Asian Himalayas from Afghanistan to Myanmar, as well as similar farming systems in east and southeast Asia, Africa, and Latin America. The great potential for integrated farming systems

with effective market access, such as agroforestry systems incorporating trees, crop, and livestock, is emphasized. In a similar fashion, the insights from interlinked agricultural and tourism development in the Nepalese Mountain farming system (termed the South Asian Sparse Farming System) are valuable for 34 million ha across the South Asia region, as well as the high mountains of Africa and Latin America. Of course, these highland and mountain farming systems constitute the water towers which underpin energy and food production for hundreds of millions of lowland populations in South Asia and the rest of the world. In conclusion, the analyses of the rural development experiences in Nepal will be valuable reading for many researchers and policy makers in emerging economies around the world.

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Foreword by Bimala Rai Paudyal

Nepal is one of the richest countries in the world in terms of its incredibly diverse ecology, ecosystems, and biological resources. Human diversity further makes the country rich in knowledge, skills, and capacities. The country is strategically located between two large and rapidly growing economies, namely China and India. However, despite its richness in geographic, environmental, and socio-cultural diversity, the country remains economically poor where poverty, food insecurity, and malnutrition have persisted through time. Agriculture, engaging two-third of labor force, is virtually stagnated with growth rate remaining less than 3% for the past three decades. Its share to the economy is constantly decreasing from 66% in 1970 to 33% in 2010 and 23% in 2020. While food security in Nepal has improved in recent years, the improvement is linked, not to the agriculture production but, to the rapidly growing remittances from overseas migration. About 4.6 million people are still food-insecure, and nearly, half of all children below the age of five are malnourished in the country. Why is there such a wide gap between the potentials and realities?

With the growing realization that food security is intrinsically linked to human and national security, especially in the context of climate crises and geo-political dimensions, recent years have witnessed increasing interest and investment in Nepal from all corners, especially toward innovations, modernization, and expansion of domestic markets in agriculture. The rising demand for homegrown staple food and high-value commodities in domestic and international markets already provides tremendous opportunities for an increased and diversified agricultural production and income. This is an opportune moment to assess and compile good practices, challenges, and opportunities in terms of policies, technologies, extension, and service modalities in such a way that this momentum is capitalized sustainably and equitably.

Although there has been some research and learning documentation on macro- as well as micro-level initiatives to address the policy and knowledge gaps in the sector, the initiatives are scattered and very few come to the notice of dominant policy makers, practitioners, and academics to make an impact. A systematic and comprehensive documentation with professional scrutiny would provide a solid basis for policy makers and practitioners for much-needed improvement needed in the sector. This book, *Agriculture, Natural Resources, and Food Security: Lessons from Nepal* is a product of an enquiry from experts, scientists, academic, researchers, and practitioners that

are multidisciplinary in nature and are interrelated in many ways. The book not only explains the current gaps and explores the potentials in the sectors within the rapidly changing sociopolitical and environmental contexts in Nepal but also showcases practices that can be scaled up throughout the country and beyond. It also provides a useful reference to many other countries in the world that are rich in natural and human resources yet challenged in achieving food security.

Divided into four major parts of interrelated themes, the book provides 24 chapters, and each chapter is rich in content and methodological rigor. Part I—“Agriculture, Horticulture, and Post-harvest management”—highlights a wide range of issues and good practices related to agricultural production and services. Authors outline the potentials of urban agriculture as a model of well-being; advocate for conservation and the use of agro-biodiversity and for improving soil health and security for food security; introduce the concept of plant clinics for better access to crop health services; assess the food production and productivity gap; highlight the need for increased investment for production and post-harvest management of fruits and vegetables; importance of strengthening national seed system and the conservation of agriculture technology. Furthermore, they caution the readers on the growing risks of toxins, contaminants, and adulterants in food and recommend the solution.

In Part II—“Livestock and Fisheries”—authors highlight the contribution of livestock and importance of land and livestock ownership for food security in Nepal and point out constraints, gaps, and opportunities for livestock development; explore the contribution of fishery in the economy; emphasize the interconnectedness of animal–human–environmental health in the context of the COVID-19 pandemic and introduce the “One Health” approach for more collaborative, multidisciplinary, and multi-sectoral solution. Furthermore, the authors introduce a comprehensive framework (DPSIR) to analyze the socio-ecological impacts of transhumance system. Part III—“Forestry, Community Forestry, and Agroforestry”—provides insightful reflections on the potentials of agroforestry becoming an alternative to crop-focused farming and assesses the implications of logging policies and practices on livelihoods. Drawing on lessons from community forestry management, they further assess the potential of an ecosystem-centered approach for local livelihoods and suggest a way forward for a wide and sustainable impact.

In the final part—“Cross Cutting Topics”—authors introduce the W-E-F nexus approach to policy planning and development for sustainable and equitable water, energy, and food security. The potential of crop simulation models to increase food security is explored in the context of changing climate. The final chapter acknowledges the importance of gender roles and relations and examines the interplay between gender equity and adaptation in the Nepalese Himalayas. Increasing feminization of agricultural works on the one hand and widening gender disparities in access to and control over information, technologies, and services on the other requires more dedicated investigation on gender barriers, opportunities, and implications. More importantly, because of direct exposure to nature and greater dependency to perform gender roles, women hold vast knowledge, skills, and capacity for

conservation and sustainable management of natural resources. Such assets need to be valued, protected, enhanced, and promoted for replication/adoption at a wider scale. I believe that the next volume of the book or similar work would shed more light on this often neglected, yet critically important aspect.

I am truly honored to have been one of the first-round readers of such a rich book and for having an opportunity to introduce the book to other readers. I congratulate the authors and the editors for this successful endeavor. I believe the book meets the thirst and hunger of those looking for knowledge, evidence, and sectoral analysis to improve agriculture production and food security in Nepal and beyond.

Thank you.

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Preface

We, in this editorial team, have spent 20–40 years researching on Nepal's agriculture, natural resources, and environment, which form the backbone of Nepalese economy, local livelihoods, and sustainable development. While people and environment have lived together over the millennia in this Himalayan nation, every time we plan our new research, we notice issues of concerns in these sectors. The past decade has been particularly unprecedented, leaving us intrigued and perplexed, as we see the country become a net food importer from a food exporter. The country remains food-insecure, with more than 15% (4.6 million) people experiencing food access problem. Immediate causes are obvious: limited agricultural productivity, low-value addition, and increasing conversion of fertile agricultural land into settlements and other non-agricultural uses, and so on, but there are also deeper level dynamics which are behind these issues. Productive agricultural lands are being abandoned, while food demand is growing. Land, forest, and natural resources are underutilized while a large proportion of youths migrate to other countries for menial jobs to send money back home so families can buy imported food. Forest area has increased while harvests are restricted, despite known sustainable harvesting technologies. Some technological advances in agriculture are emerging, but social and environmental costs of modernization have been ignored. Research and development work is highly fragmented across sectors ignoring the system-wide dynamics.

These concerns have been the seedbed for the germination of this book. While these concerns animated our collective work, our rich experience and research network provided the confidence to embark on this project. We have had the opportunity to analyze various facets of Nepal's problems and opportunities from various disciplinary angles, from Nepal as well as from Australia, where four of us have been living and working for years. We have worked from within Nepal as well as from outside and have active research projects during the production of this book. Over 60 researchers and experts who joined us as contributors to this volume bring unparalleled insights into why Nepal is facing such challenges and how these can be tackled. All this experience put us in the unique position to explain Nepal's agriculture and environment sector and identify emerging and potential solutions to make Nepal food secure and environmentally sustainable.

This book emerged out of our collaborative work at the Nepalese Association of Agriculture, Forestry and Environment in Australia (NEPAFE), which was set up in early 2019 with a goal to advance scientific cooperation between Nepal and Australia in the agriculture and environmental sectors. NEPAFE provided an excellent platform for us to come together and share our concerns and visions. As members of NEPAFE, we decided that compiling cutting-edge research in the form of an edited volume could be an important contribution to policy and practice. The idea was endorsed and supported by the NEPAFE community, and the editorial group was formed to take the project forward. We then approached Springer with a proposal and book outline which was accepted.

The book takes an integrated and cross-sectoral approach to diagnose problems and identify opportunities. It takes an interdisciplinary approach in presenting the research and practice-based knowledge. We focus on presenting the realities of Nepal while also connecting to wider literature on the diverse topics. This way, our aim has been to identify lessons for Nepal as well as similar developing and mountainous countries in South Asia and the Global South. We believe this book is particularly unique on two counts. First, it covers multiple sectors. Second, it taps into the knowledge of those researchers who have good understanding of the local practical contexts.

Overall, this book showcases recent studies and experimental insights of authors who are actively engaged in Nepal's agriculture and natural resources management policy and practice. Chapters in the book demonstrate how various components of the food systems based on agriculture, livestock, and forestry systems have been researched and managed providing foundations for food systems innovations and how they contribute to achieving various United Nations Sustainable Development Goals (SDGs). Some crosscutting chapters explore gender and climate adaptation, nexus approach to research, development and policy, and application of crop simulation models in research and policy practices and decisions. The book features some of the internationally acclaimed practices with a potential to make significant contributions to food, nutrition, and livelihood security. Overall, the book has investigated why Nepal is facing an increasing level of food insecurity, despite having rich natural resources and explored opportunities for improvement.

The whole work of writing and editing of this book happened at a challenging time. Like with many other things, the COVID-19 pandemic made it difficult to have face-to-face interactions, but also enabled us to see the effects of such crises in Nepal's food system. The cooperation of the chapter authors has been extraordinary, making it possible for us to deliver the manuscript on time to Springer. We thank authors for their willingness to contribute and commitment to revise the paper multiple times in response to the reviewer feedbacks. We have been greatly benefitted by the work of over 40 reviewers who provided critical and constructive comments on the drafts, in some cases needing reviews of multiple versions. We are equally grateful to the publisher

for a timely publication and providing useful feedback on the initial proposal. We hope this book will contribute to scientific and policy debate around effectively managing agriculture, natural resources, and environment in Nepal as well as similar countries around the world.

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Prof. Tek Maraseni (Editor) earned a double B.Sc. (Science and Forestry) in Nepal, an M.Sc. (NRM) in Thailand, where he was awarded a gold medal (GPA 4/4), and a Ph.D. (Environmental Science and Management) in Australia. He has over 26 years of research experience in identifying and adopting management practices that improve productivity, profitability and the sustainability of agriculture and forestry systems whilst reducing greenhouse gas emissions. Over the past 6 years, he has successfully completed multiple research projects in 16 countries. He has co-authored with

researchers from 31 countries and published 4 books, 32 book chapters, one submission to UNFCCC, 5 policy briefs, 25 technical reports, and 174 journal papers. He has supervised 16 Ph.D. students to completion, served as an editorial member for two international journals, and reviewed Ph.D. theses and proposals for granting bodies. His research work has been recognised through several national and international awards and fellowships: (1) US National Science Foundation (NSF) Fellowship in 2009; (2) “Queensland-China Climate Change Fellowship” in 2009; (3) US State Department “Climate Change Professional Fellows” award in 2011; (4) “Visiting Professor for Senior International Scientist” award from the Chinese Academy of Sciences in China (2013-2019); (5) First runner-up award from Elsevier Journal “Environmental Development” in 2015; and (6) University of Southern Queensland (USQ) Research Excellence Award, three times (2009, 2014 and 2021).

Dr. Devendra Gauchan (Editor) is an Agricultural Economist with expertise in agrobiodiversity, seed system and food security. He has Ph.D. degree from the University of Birmingham, United Kingdom and has worked as a consultant and expert in various national and international organizations over the past 25 years. He is currently the Honorary Research Fellow at the Alliance of Bioversity International and International Centre for Tropical Agriculture (CIAT), and serves as the Regional Officer South Asia and Research Advisor in Agricultural Economics at Platform for Agrobiodiversity Research (PAR), Rome, Italy. He is an Adjunct Professor at the Institute of Agriculture and Animal Sciences (IAAS), Tribhuvan University, Kathmandu. He was the National Project Manager of Bioversity International led projects in Nepal from 2015–2020. Previously, he was the Head of Socioeconomics and Agricultural Research Policy Division at Nepal Agricultural Research Council (NARC) Kathmandu. During his tenure at NARC, he played instrumental role in bringing social sciences dimension in agricultural research by establishing and leading Socioeconomic and Policy Research Division. He has also worked as a Post-Doctoral Fellow at the International Rice Research Institute, Philippines carrying out rice socio-economic research activities in South Asia from 2008–2011. He has published several research papers on agriculture and natural resource management in many journals and books.

Dr. Jagannath Adhikari (Editor) is a human geographer. He has over 20 years research, teaching and consultancy experiences in various areas of international development—sustainable livelihood; climate change and food security; sustainable agriculture; participatory natural resources management; land management and land reform; agrarian change and livelihoods; globalization, migration, remittances, and development. He worked as a Visiting Professor in Kyoto University (Japan) and as a Visiting Scholar and Research Fellow in Heidelberg University (Germany), The Australian National University (Canberra), University of Sussex (UK), and Worcester Poly-Technique Institute—WPI (USA). Presently, he is affiliated with Curtin University of Technology, Perth, Australia as an adjunct faculty and with

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Dr. Hemant Ojha (Editor) works partly as an Associate Professor for University of Canberra and partly as a Principal Advisor for the Institute for Study and Development Worldwide (IFSD). His work focusses on understanding and catalysing multi-scalar environmental governance in a way that supports community empowerment and climate resilience, and he pursues this goal by combining political economy and critical policy analysis with action research. From his early career work in the Himalayan South Asia, his work has expanded to Asia and the Pacific as well as parts of Africa. His critical policy analysis and action research has greatly influenced the development of Nepal's community forestry system, which is seen as one of the few global successes in community based environmental management. From Australia, his past 10 years of work in Asia and the Pacific has focussed on exploring policy and action-oriented solutions for climate resilience and inclusive environmental governance. He has also served as a lead author for several international environmental assessments, including a recent Himalayan regional assessment of environmental governance, supported by multiple OECD members. In his current action research, he is testing methodologies for fostering co-production of science, policy and practice in water and agri-food sectors for various contexts. He has published widely on climate change, environmental policy, and international development, and sits on the editorial boards of several international journals.

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Introduction and Overview

1

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Abstract

This chapter provides an overview of 23 chapters included in the book. The book aims to present recent knowledge on issues and topics related to agriculture, livestock, and forestry systems across the three agroecological regions of Nepal. Chapters in the book are grouped into four themes: (a) Agriculture, horticulture, and post-harvest management;

(b) livestock and fisheries; (c) forest ecosystems, community forestry, and agroforestry, and (d) crosscutting topics. Chapters demonstrate how various components of the food systems—including agronomy, horticulture, agrobiodiversity, soil science, plant health, food toxins and food safety, seed innovation systems, post-harvest management, livestock production, ownership and health, aquaculture and fisheries production, urban agriculture, transhumance systems, and socioeconomics—have been researched and managed to provide foundations for food systems innovations in Nepal. The book also catalogues a wide range of solutions: need of increased investment in R&D to develop new climate resilient technologies and practices and promotion of locally adapted species and varieties for increased and sustained productivity of cereals, fruits, and vegetables, and aquaculture and livestock; development of market linkages with China, India, and other countries; development of robust national seed system; conservation and multiplication of native and neglected species and landraces; effective soil fertility management and soil health improvement; use of plant clinics for pest management; promotion of conservation agriculture and regenerative agriculture practices; promotion of urban agriculture; correcting infective institutional arrangements to minimize food toxins and post-harvest losses; adoption of multisectoral and collaborative one-health

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approach for integrated animal–human–environmental health; protecting transhumance systems in mountains; integrating ecosystem services in forest and agrobiodiversity management; active harvesting of trees and forest products; promotion of integrated agroforestry systems; managing water–energy–food nexus for research and policy planning and implementation; applications of simulation modelling in closing yield gaps and in climate change studies; and gender and socially inclusive technology development. Whilst these solutions are not entirely new, this book has unravelled why these solutions have not gained traction or how these can be taken forward in more contextually grounded way, not only in Nepal but generally in other countries with similar farming systems and terrestrial environmental issues.

Keywords

Agrobiodiversity • Agroforestry and community forestry • Conservation and regenerative agriculture • Ecosystems services • Livestock and fishery • Simulation modelling • W–E–F nexus

1.1 Background and Rationale

A landlocked country sandwiched between India and China, Nepal is divided into three east–west running agroecological regions or zones. These include: (i) the Terai and Inner Terai in the southern plains that run from the south-east to south-west at elevations typically below 800 m; (ii) the low-, mid- and high-hills in north of Terai and Inner Terai and south of the Himalayan range typically between 800 and 4000 m, and (iii) Himalayan range above 4000 m. Within each of the first two regions, a variety of crops, vegetables and fruits, and tree species are grown, and a range of livestock, poultry and fish species are raised, within an integrated crop-livestock-tree-based system. In the Himalayan region, however, farming (highland crops and livestock grazing) is limited due to extremely low temperatures (Dixon et al. 2001; Krupnik et al.

2021). These agricultural practices are supported by agroecosystems and natural resources which include rich biodiversity, forested landscapes, and abundant water resources.

The agriculture sector in Nepal contributes to about 26% of the national GDP and provides employment to about 60% of the labour force (MoF 2021). Most of the farmers in Nepal are smallholders and poor, and the food they produce is insufficient even for themselves. Nepal remains one of the food insecure countries, with more than 15% (4.6 million) people experiencing food insecurity (USAID 2019). Malnutrition and micronutrient deficiencies amongst children, pregnant, and lactating women are still prevalent, especially in mountainous areas. With current trends of increasing population, decreasing arable land, and low yearly increment in the rate of cereal productivity, Nepal has an annual deficit of >1.3 million tons of edible rice, wheat, and maize (Devkota et al. 2022). Fruits, vegetables, livestock, and fish are also insufficient to meet the demand of ever-increasing population (Neopane et al. 2022; Pandey et al. 2022; Shrestha et al. 2022). Moreover, the agriculture sector in Nepal contributes approximately 50% of the national greenhouse gas (GHG) emissions, rising to 60–70% if multiple points in the food value chains are considered (MOFE 2021). Clearly, increasing productivity and sustainability of agriculture is a major challenge, which is further escalated by increasing GHG emissions from agriculture and global climate change.

Forest and trees are important contributors to the local livelihoods and national economy. Trees grown in the forest or farmlands contribute about 15% of the national GDP and 9.23% of total national employment (World Bank 2016). Forests can protect the environment, provide various kinds of ecosystems services, sequester carbon in soil and biomass, provide timber and non-timber forest products for domestic use and export to other countries, and improve the livelihoods of people living around the forests (Ojha et al. 2022; Poudyal et al. 2022). Agroforestry systems integrating crops, livestock, and trees practised in farmlands in all agroecologies have significant potential to provide all these

benefits to farmers to improve their livelihoods (Dhakal et al. 2022). Whilst technological advancements in agriculture and forestry are important for increasing food productivity and meeting nutritional requirements, there are large socio-economic variations including gender differences, which call for a need to have gender and socially inclusive technology development and farming systems in the country (Bhattarai 2022). These all need to be operated under the nexus approach in policy at the ministerial level and the farming systems approach in research and development at the field level and in the context of global climate change. Application of digital predictive tools such as simulation models for crop yield prediction and decision support systems (DSSs) for crop, nutrient and water management and crop yield prediction and climate forecasting, and adoption of water–energy–food–land nexus as the dominant planning framework would play an important role in future (Amgain et al. 2022; Devkota et al. 2022; Maraseni et al. 2021; Upriety et al. 2022). Hence, the book showcases recent studies and experimental insights of issues on various components of agriculture, forestry and natural resources management and provides concrete research and policy implications and recommendations on the above topics.

1.2 Book Structure and Chapter Overview

Chapters in this book are grouped into four themes: Theme 1–Agriculture, horticulture, and post-harvest management (12 chapters); Theme 2–Livestock and fisheries (5 chapters); Theme 3–Forest ecosystems, community forestry, and agroforestry (3 chapters); and Theme 4–Cross-cutting topics (3 chapters). Each theme includes several chapters which highlight recent advances in research and development practices happening in Nepal. Chapters also draw on wider literature, discuss implications for policy and development and provide detailed recommendations for research and policy in Nepal as well as more broadly for South Asia. In this chapter, we offer

theme-wise overview of chapters integrating the knowledge from individual components of agricultural and food systems and provide key research and policy recommendations.

1.2.1 Theme 1: Agriculture, Horticulture, and Post-harvest Management

Cereals are a major source of food security, income, livelihood, and employment in Nepal. Gauchan et al. (2022) used compound growth rates and instability index techniques to assess the growth patterns and dynamics of cereal yields, production and import growth, and food demand and self-sufficiency in Nepal. They estimated the cereal production and demand growth and self-sufficiency ratios for 2050 using different scenarios and Auto Regressive regression model to analyse the relationship between domestic production and income growth with import. They found that the current cereal production is low to meet the current and future food demands of the increasing population. They concluded that the country cannot achieve cereal self-sufficiency by 2030 as envisioned by UN's SDGs and even by 2050. Thus, Nepal will continue to import a large quantity of cereals, particularly rice and maize in the foreseeable future.

Fruits and vegetables are rich sources of dietary fibre, vitamins, minerals, electrolytes, phytochemicals, and antioxidants, with high potential for improving food and nutritional security and peoples' livelihoods. Pandey et al. (2022) documented the status of fruits and vegetables research and varieties developed and recommended, and analysed their area, production, and yield growth rates and import and export situation in Nepal. Their findings showed that the development and release of hybrids and open-pollinated varieties using locally adapted genetic resources are limited in fruits and vegetables. They showed that despite the increase in area growth, the production has not increased resulting in rapid imports of fruits and vegetables in recent years to meet the increasing demands.

Citrus production is important for improving the rural economy in the mid-hill areas of Nepal. The citrus industry and citrus export have the potential to eliminate poverty, reduce hunger, and increase economic growth. The industry is however characterized by poor citrus quality resulting in a low profit. Aryal et al. (2022a) obtained information from actors in the current citrus value chain to explore its prospect for export from Nepal to the Tibet Autonomous Region of China. They described a potential supply chain in terms of actors and pathways, production areas, transport corridors, disease and pest management, cold treatment disinfestation, and other phytosanitary protocols. Khatiwada et al. (2022) discussed the current post-harvest practices and constraints and potentials for improved post-harvest management and quality regulations of fresh agricultural produce in Nepal. They found that the post-harvest loss of fresh produce of fruit and vegetables in the country ranges from 20 to 50% due to improper harvesting methods, inappropriate sorting and grading practices, delay in transport, and poor post-harvest storage and processing facilities. They suggested that the post-harvest management of horticultural crops requires systematic interventions to implement policies under general food safety and quality framework to meet the quality needs of the domestic consumers and for export to other countries.

The use of quality seed is important for increasing crop yield. In Nepal, seed production of most crops is done informally by individual farmers or in groups by farmers' communities, or formally by the government or the private sector. In on-farm situations, seed storage methods are improper, and, in most situations, there is a lack of both dry chain (e.g., hermetic storage bags) and cold chain (e.g., cold storage) facilities for storing seeds (Bradford et al. 2018; Ghimire et al. 2022). Ghimire et al. analysed the strengths and weaknesses of seed policies, programs and strategies and their implementation and found that seed replacement rates of most crops in Nepal are low. They suggested that the production and distribution of good quality seed is possible through a robust national seed system by

public and private sectors working together. Since the seed is produced and distributed both formally and informally, strong coordination amongst various partners is important.

Nepal has a long history of managing agrobiodiversity as a source of livelihood mostly in hills and mountainous areas. Such practice has withstood multiple forms of climatic, social, and ecological risks but also adapted in varying degrees to those risks. Joshi and Gauchan (2022) highlighted the importance of conservation and sustainable use of agrobiodiverse species and varieties of crops, animals, and forest emphasizing on native, neglected, and underutilized species (NUS) and landraces for reducing poverty and meeting the food and nutrition security of people, mostly in remote hills and mountains. They concluded that poor investment in research, education, and extension, and weak seed regulatory framework are the key 'policy' constraints for the promotion of NUS and landraces.

Healthy soil is fundamental to crop, livestock, and tree production and for survival of any living being. It is also important for carbon sequestration, reduce methane and nitrous oxide emissions, and mitigate climate change. Hence, soil health improvement is necessary to increase food production and meet food and nutrition security of the increasing population (Usman et al. 2018). Tripathi et al. (2022) reviewed the soil fertility status across various agroecological regions of Nepal, soil-related constraints to crop production, factors affecting soil fertility decline, farmers' current soil management practices and strategies for developing improved soil management practices, soil-related policies including the need for digital technologies for soil mapping and fertilizer recommendations, and contribution of soil to food and nutrition security in the country. Their findings revealed that soil fertility across the agroecological regions is in declining trend due to soil nutrient mining, depletion of soil organic matter, soil erosion, and inefficient or low use of chemical fertilizers.

Poor crop health is one of the main constraints for achieving high yields. In developing countries, extension agencies and agro-vets (agri-input dealers) provide agricultural services to

farmers based on visual symptoms in sick plants which could result in incorrect plant diagnosis. Farmers are then advised to use high doses of chemicals which result in high production costs and can also impact environment, food safety, and human and animal health. G.C. et al. (2022) discussed the use of Plant Clinics originally developed and piloted by Centre for Agriculture and Bioscience International, Netherlands, and now expanded to 34 countries including Nepal. In such clinics, farmers visit and meet with extension workers who are trained as plant doctors. Such doctors then diagnose the farmer's crop health problems and provide appropriate crop health management related advice to farmers.

Nepal is experiencing various issues related to fraud, adulteration, chemical contaminants, and toxins in food. Thus, the Government of Nepal has developed food safety policy and various Acts, Regulations and Standards related to food safety and quality. However, implementation of such legislation is often constrained due to poor governance, limited financial resources allocated to human resources development and laboratory facilities required for chemical and microbiological analysis. Chaulagain et al. (2022) discussed current policies and practices of food safety and quality and provided insights on major drivers for food safety regulations along with the initiatives that the local governments can take in formulating and strengthening such policies and regulations in the country. They concluded that a system for proactive governance system in developing and implementing comprehensive food safety and quality management rules and regulations is instrumental to minimize the toxins and contaminants and assure high quality food.

There are increasing concerns that conventional farming may not be profitable, and sustainable due to increased use of intensive tillage and farm inputs, resulting in high production cost, loss of soil organic matter, and increased GHGs emissions. Regenerative agriculture and conservation agriculture practices are found to be alternative and sustainable practices to conventional agriculture (Dixon et al. 2020; Elevitch et al. 2018; White 2020). Adhikari and Timsina

(2022) examined Nepal's agricultural policies considering the inadequate performance of Nepal's agricultural sector and then suggested a planning framework for 'regenerative agriculture', a nature-based farming with optimum use of local resources and reduced or no use of chemicals. They also presented a multiscale policy and planning framework for the development of regenerative agriculture that has potential to eliminate poverty, reduce hunger, and tackle climate change effects. They suggested that such a nature-friendly farming leads not only to sustainable agriculture through conservation of resources, but also to higher production and availability of diversified, safe, and nutritious foods, and helps generate more income and employment, ultimately leading to improved livelihoods of the farmers. Such a system also contributes to building resiliency to emerging environmental, climate change, and trade problems.

Conservation agriculture (CA) follows three principles in farming: minimum soil disturbance, residue retention on field, and diversified and sustainable crop rotations. CA and resource-conserving technologies (RCTs) have potential to sequester carbon and reduce CH₄ and N₂O emissions, improve productivity, reduce production costs, and increase farmer's income through reduced use of labour, energy, and other farm inputs (Dixon et al. 2020). Amgain et al. (2022) reviewed the application of CA and RCTs (e.g., dry direct-seeded rice, unpuddled transplanted rice, and zero-tillage maize, wheat, and legumes with the retention of crop residues) for improving productivity, profitability, and the sustainability of cereal-based cropping systems in Nepal. Their review demonstrated that the CA and RCTs can increase grain yield and profits and save labour and water use compared to conventional practices. No or minimum tillage along with residue retention can suppress weeds, increase crop diversification, improve soil physico-chemical and micro-biological properties, enhance nutrient- and energy-use efficiencies, reduce soil erosion in sloping hilly areas and undulating land with narrow terraces, and reduce GHGs emissions. They emphasized that there is

an urgent need to institutionalize the CA and RCTs to achieve the food, nutrition, and livelihood security of the growing population in Nepal.

Urban Agriculture (UA)—a system of producing foods within and around the cities—has potential to provide healthy, fresh, and quality food and achieve food and nutrition of increasing urban population in the developing countries (Bryld 2003). Kafle et al. (2022) discussed about the social, economic, and environmental well-being outcomes of the UA with broader policy implications for sustainable urban development, particularly focusing on the policy agenda for Nepal. They concluded that urban agriculture can end hunger, promote food and nutrition security, and can help develop sustainable agriculture.

1.2.2 Theme 2: Livestock and Fisheries

The livestock sector is one of the mainstays of Nepalese economy contributing to 11.5% of national GDP. Though majority of the livestock production system in Nepal is still subsistence-oriented with low production, trends in transition towards semi-commercial or commercial systems are occurring in some areas. Neopane et al. (2022) assessed the current and projected domestic production and availability of livestock products for future and identified key production constraints and issues for making the country self-reliant in livestock products and reducing their import. Using government reported livestock data from 1961 to 2019 and an Autoregressive Integrated Moving Average (ARIMA) model, they predicted livestock population and primary livestock products for 2029/2030. They showed that the projected growths of livestock population and products were likely to increase in 2029/2030 but were unlikely to meet the nutritional needs of people. Low productivity, higher production cost, marketing hurdles, climate change impacts, and inefficient institutions and policies are major issues in livestock production and marketing in Nepal.

Bhandari (2022) investigated the associations between land and livestock ownerships and food security at households using a sustainable livelihood (SL) framework and the nationally representative 2016 Nepal Demographic Health Survey (NDHS) data in Nepal. Based on the results from the multilevel regression (binary logistic and OLS regressions), he showed that the ownership of both land and livestock and farmer's education are significantly and positively associated with household level food security. He also suggested that whilst agriculture is important in addressing the food insecurity challenge, it's not sufficient and a household's access to other capital assets is equally important for solving the multifarious problems.

Though the livestock production system in Nepal is moving towards commercialization there are also concerns of emerging infectious diseases which are posing a severe impact on the sustainable development of this sector. Dhakal and Karki (2022) reviewed the current trend of livestock production and its contribution to achieving SDGs, zoonotic diseases of importance, and the impact of COVID-19 pandemic on livestock sector in Nepal. They found that the pandemic has negatively impacted all aspects of livestock sector including production, processing, transport, sales, and consumption, especially in commercial livestock production systems in Terai, and taught about the importance of the interconnectedness of animal-human-environmental health. They suggested that such interconnectedness requires a One Health approach, which combines the efforts of multisectoral professionals including human health, animal health, and environmental health to reach a common goal of health for all (Mackenzie and Jeggo 2019). They suggested that to prevent future epidemics or pandemics such as COVID-19 and to safeguard veterinary and public health from emerging pathogens, institutionalization and implementation of the collaborative, multidisciplinary and multisectoral One Health approach is necessary for Nepal.

Transhumance systems can play an important role in improving the food security, livelihoods, and overall well-being of rural households and

maintaining ecosystem services in the remote Himalayas and mountains of Nepal. There is however a limited understanding of the nature and extent of its existence and how this is contributing to household level food and nutrition security in the country. Aryal et al. (2022b) analysed the current states, drivers of change, and socio-ecological impacts from the current and emerging trends of transhumance system in Nepal using a Driver-Pressure-State-Impact-Response (DPSIR) framework. The drivers of changes to the transhumance systems come from global, national, and local scales, mainly resulting in labour shortage due to outmigration and reduced flexibility. The study showed a declining trend in transhumance systems in Nepalese mountains resulting in decreased crop production, increased food insecurity and livelihood vulnerability, and reduced biodiversity or ecosystem services. They provided a comprehensive knowledge and understanding for making important policy decisions on transhumance and discussed how the sustainability of long-standing transhumance systems could contribute to achieving different SDGs.

Aquaculture and fishery sector employs 0.6 million people and contributes about 4.25% of the agricultural GDP and 1.33% of the national GDP (Rijal and Jha 2020). Fish is the third most important animal protein source, contributing about 20% of the total animal protein intake in Nepal (MoALD 2020). Shrestha et al. (2022) assessed the status, trend and future scope of aquaculture and fisheries, and made policy recommendations for improved fisheries management and aquaculture development in Nepal. Due to illegal fishing practices and river water diversion, wild catch of fish has been declining whilst aquaculture has been growing annually in recent decades. Though the traditional carp polyculture in ponds accounts for almost 90% of the aquaculture production, commercial cultures of rainbow trout, tilapia, pangasius, and other catfishes are also spreading rapidly due to their high productivity. They found that shortages of fish seed and quality feed are the major constraints, but the sector has great potential to help solve poverty, reduce hunger

and malnutrition, improve health and well-being, maintain gender equality, and increase employment opportunities.

1.2.3 Theme 3: Forest Ecosystems, Community Forestry, and Agroforestry

In Nepal, national forests are protected and managed by the central or provincial government. On the other hand, the community forests, though owned by the government, are managed by the local communities with users' rights and benefits shared by them. In either case, conserving forests with optimum tree density and appropriate logging and regenerative practices are necessary for protecting environment and increasing revenues from forest. Also, integration of trees with crops and livestock in private and farm families' lands (i.e., agroforestry systems) is necessary for increasing farmers' income and livelihoods. Yet, very little research and scaling of agroforestry systems have been carried out in Nepal due to the lack of appropriate policies and commitments required for implementations.

Nepal's community forestry has improved the livelihoods of local communities to some extent, but the success of community forestry is not fully explored in terms of ecosystem services that such forests can provide. Ojha et al. (2022) assessed the potential of community forests for providing various kinds of ecosystems services (ES) and improving the livelihoods of the local communities managing those forests. Their analysis based on 14 cases of community forestry across the country showed that most of the cases have clearly sought to promote and develop new ES beyond the traditional products like timber and fuelwood, depending on ecological and economic contexts. They identified several emerging initiatives towards ecosystems-based management of community forestry, and a shift away from the subsistence-oriented to more holistic management of community forests. They concluded that increasing market value of ES has the potential to contribute further to poverty reduction if communities are granted secure tenure

rights over forests and if there is an enabling environment for networking, innovation, and learning amongst community groups.

The efficient use of forest goods and services is crucial for sustainable forest management. Selective logging is a dominant forest harvesting practice, contributing nearly 15% of global timber needs. However, due to increased global awareness and emphasis on need to conserve forests for climate change mitigation, there are contrasting views and opinions about the importance of selective logging in terms of environmental and economic impacts. Poudyal et al. (2022) assessed the policies and practices of selective logging in community forests and the implications of such practice on environmental, economic, and local livelihoods using primary data from a Terai district in central Nepal. They quantified the environmental impact of selective logging on timber production and carbon emissions along the production value chains from timber harvest to its processing. They found higher forest products recovery rates from the harvested trees and lower carbon emissions in logging processes as compared to other countries, which offer lessons even to the highly mechanized and countries of Asia and the Pacific for REDD+ (carbon payment in forestry sector) initiatives.

In recent years, the importance of integrating trees with crops and livestock has been increasingly recognized due to their potential in mitigation of and adaptation to climate change and carbon trading. Dhakal et al. (2022) provided several examples of agroforestry systems in Nepal in terms of improving farmers' livelihoods and food security, halting land degradation, agrobiodiversity conservation, utilizing the ecosystems services, and thereby positively contributing to poverty alleviation and climate change mitigation and adaptation. They concluded that integrated agroforestry systems could be an alternative to sole crop- or livestock-based farming systems in Nepal, though small landholding, lack of institutional setups and access to credit and markets for agroforestry, and farmers' indifference attitude towards environmental benefits accrued from agroforestry could be the

constraining factors for its adoption. Nevertheless, the adoption of less labour-intensive agroforestry practices could be an opportunity for farmers who are forced to leave their farmlands fallow due to labour scarcity resulting from youth outmigration for jobs.

1.2.4 Theme 4: Cross-Cutting Topics

Nepal has abundant sources of water required not only for irrigation of its agricultural lands, hydropower development, energy needs, and for industry and household requirements of its own people but also for sale of water and energy to neighbouring countries. Unfortunately, due to lack of political will and geo-political and transboundary situation, water resources in Nepal are not fully utilized, and Nepalese agriculture remains mostly rainfed. Moreover, the country follows a 'sectoral or silo' approach to development rather than an integrated multisectoral approach. An improved understanding and implementation of the relationship and linkages of water, energy, and food (W-E-F) nexus (Rasul 2016) from local to national level would be required to develop hydropower and generate energy, develop irrigation infrastructure, increase agricultural production, and protect environment. Uprety et al. (2022) identified problems and causes of low agricultural productivity and demonstrated that abundant water is available for irrigation of existing rainfed lands to increase agricultural productivity and meet multisectoral energy requirements of the country. They presented three case studies on the application of the W-E-F nexus framework: two studies (Sunkoshi Marin Diversion Multipurpose Project and Bheri Babai Diversion Multipurpose Project) pertain to multipurpose development projects of national importance whilst the third study (Conventional tillage vs. zero tillage in rice-based cropping systems in the eastern Gangetic plains) provides an example of CA-based sustainable intensification practice integrating water, energy, and food in two eastern Terai districts of Nepal. They provide a perspective on the importance of W-E-F nexus and suggest adopting such nexus

approach as the dominant planning framework by the National Planning Commission by replacing the existing sectoral framework. They emphasized that the nexus approach is critically important for Nepal because water is the only abundant resource available and must be utilized effectively integrating the development of hydro-energy, irrigation infrastructures, and human and industrial consumptions.

Global research has shown that crop simulation models can generate various recommendations related to biophysical factors such as crop, water, tillage, nutrient, and pest management, crop yield and weather forecasting, predict yield trends and yield declines in cropping systems, and predict the impacts of climate change on crop productivity (Timsina et al. 1995; Timsina and Humphreys 2006a, 2006b). Devkota et al. (2022) reviewed the development and application of crop simulation models for major cereal crops in South Asia, focusing on Nepal. Their analysis revealed that the average gaps between potential yields and farmers' yields of rice, wheat, and maize in Nepal are high (10–12, 5–8, and 11–15 t ha⁻¹, respectively), suggesting the large scope for yield improvement by research or by developing improved management practices. They demonstrated that for achieving self-sufficiency in cereal grains by 2030, the average national yield of rice, wheat, and maize needs to be increased to 5.7, 3.9, and 4.9 t ha⁻¹ by 2030 from the current low national average yields of 3.76, 2.85, and 2.82 t ha⁻¹, respectively. They concluded that the simulation models can be useful DSS tools for policy planning and implementation, determining the impact of climate change in crop yield, increasing efficiency in research, prioritizing research and extension interventions for increasing yields, helping achieve food and nutritional security, and addressing the effects of, and developing adaptation strategies to, climate change.

Asian women farmers play an important role in all aspects of farming. In the hills and mountainous areas of Nepal, women farmers are actively engaged in decision-making as well as participating in various on-farm activities related

to crop, livestock, and forestry. Combining a social-ecological systems approach with feminist political ecology lens, Bhattarai (2022) examined the interplay between gender equity and adaptation in the Nepalese Himalayas. From a case study of farm-level practices with a focus on rice cultivation in a mountain village, she showed how gender roles and relations were influenced by wider socio-economic changes and discussed how they could shape adaptation practices, as households adopt high-yielding lowland rice varieties and abandon upland rice cultivation practices. She concluded that agricultural modernization has exacerbated gender inequality and made the farming communities, particularly women, more vulnerable to climate change. She suggested for a more holistic approach to agricultural research and development, with gender-based differentiations in knowledge, management, and policy for agriculture to withstand the impact of climate change and adapt to the socio-economic changes.

1.2.5 Implications for Sustainable Development Goals

Various chapters included in this book have explored opportunities for enhancing contributions to several SDGs, especially goal (1) eliminating poverty, (2) ending hunger, (3) ensuring healthy lives and promote well-being, (5) achieving gender equality and empower all women and girls, (7) ensuring access to affordable, reliable, sustainable, and modern energy for all; (8) promoting sustained, inclusive, and sustainable economic growth, (11) making cities inclusive, safe, resilient, and sustainable, (12) ensuring sustainable consumption and production patterns, (13) combating climate change and its impacts, and (15) protecting, restoring, and managing terrestrial ecosystems, combating desertification, and halting reverse land degradation and biodiversity loss (United Nations 2015, 2016). Contributions of various chapters to achieve various goals are summarized in Table 1.1.

Table 1.1 Chapters contributing to different sustainable development goals (SDGs)

SDGs	Chapters	Description
1	Agrobiodiversity; Agroforestry systems; Aquaculture and fisheries; Cereal supply and demand projections; Citrus production and export; Conservation agriculture; Ecosystems services from community forestry; Fruit and vegetables production; Gender; One health approach; Regenerative agriculture; Robust seed systems; Simulation modelling; Water-Energy-Food nexus	Reducing poverty and promoting food and nutritional security
2	Agrobiodiversity; Agroforestry systems; Aquaculture and fisheries; Cereal supply and demand projections; Citrus production and export; Ecosystems services from community forestry; Food toxins; Fruit and vegetables production; Gender; Livestock production; Livestock ownership; One health approach; Plant clinics; Post-harvest losses of fruits and vegetables; Regenerative agriculture; Robust seed systems; Simulation modelling; Soil health and soil security; Transhumance systems; Urban agriculture; Water-Energy-Food nexus	Ending hunger and promoting food and nutritional security
3	Agrobiodiversity; Aquaculture, and fisheries; Food toxins; Fruit and vegetables production; Livestock production; Livestock ownership; One health approach; Post-harvest losses of fruits and vegetables; Regenerative agriculture; Transhumance systems;	Good health and well-being and promoting nutrition security
5	Aquaculture and fisheries; Gender	Gender equality and empowering women and girls
6	Agroforestry systems; Selective logging practices; Soil health and soil security; Water-Energy-Food nexus	Ensuring availability of safe water and improving water quality
7	Selective logging practices; Water-Energy-Food nexus	Ensuring access to affordable, reliable, and sustainable energy for all
8	Agrobiodiversity; Aquaculture and fisheries; Ecosystems services from community forestry; Gender	Decent work and economic growth
11	Urban agriculture; Water-Energy-Food nexus	Making cities inclusive, safe, resilient, and sustainable
12	Agrobiodiversity; Fruit and vegetables production; Plant clinics; Post-harvest losses of fruits and vegetables	Responsible consumption and production
13	Agrobiodiversity; Agroforestry systems; Conservation agriculture; Ecosystems services from community forestry; Fruit and vegetables production; Gender; Livestock production; One health approach; Regenerative agriculture; Selective logging practices; Simulation modelling; Soil health and soil security; Transhumance systems; Water-Energy-Food nexus	Climate change mitigation and adaptation; environmental conservation; Reducing GHG emissions
14	Aquaculture and fisheries; Plant clinics;	Improving life below water
15	Agroforestry systems; Regenerative agriculture; Conservation agriculture; Ecosystems services from community forestry; Fruit and vegetables production; Robust seed systems; Selective logging practices; Soil health and soil security; Plant clinics; Water-Energy-Food nexus	Sustaining life on land

1.2.6 Conclusions, Research Gaps, and Research and Policy Recommendations

Three agroecological/farming system zones (Terai, mid- and high-hills, and mountains) are well-known and clear characteristics of Nepalese agriculture. This chapter emphasizes that farming systems approach to research and development integrating crops, livestock (including fisheries and poultry) and forestry should be the major overarching, and achievable, research and policy recommendation for the country. Major research gaps and research and policy recommendations provided in each chapter are summarized below, which would be useful for researchers and policymakers in agriculture, forestry, and natural resources management sectors in Nepal and South Asia as a whole.

1.2.6.1 Theme 1: Agriculture, Horticulture, and Post-Harvest Management

- Government should increase investment in crops, fruits, and vegetables research and development to generate high-yielding technologies and production practices and facilitate their marketing. To materialize these, adequate policy support and services are required to ensure household and national level food and nutrition security, reducing import, and make the country self-reliant.
- There is a need to develop post-harvest handling guidelines, set ‘basic’ quality standards, and develop post-harvest storage and processing facilities that could pave the path for further development of horticulture sector.
- There is a need to sensitize consumers and create market to produce safe and healthy and nutritious food.
- Policy should encourage the small-holder farmers to participate in citrus value chains including their export potential to achieve high profit and improve their livelihood security.
- There is a need to promote use of dry and cold chains technologies to safeguard the seed quality, especially during harvesting and storage. Such technologies (e.g., hermetic storage bags and cold storage) should be upscaled to improve food and nutrition security, biodiversity, and disaster resiliency.
- Clear guidelines are needed to produce hybrid seeds and maintain their standards.
- Implementation of the seed sector policies and laws is essential through public and private sector partnership to fulfil the gap between seed demand and supply, improve the capacity of private sector stakeholders, and speed up the seed industry development.
- Digitization of the seed information system is required for efficient data sharing and information management.
- Local landraces and their genetic enhancement should be strengthened by using both conventional and molecular techniques and building human resource capacity.
- There is a need to develop site-specific staple, nutritious, and climate-resilient varieties and diversified products by utilizing rich agrobiodiversity of diverse neglected and underutilized species (NUS) of crops, livestock, and trees to achieve the long-term food, nutrition, and livelihood security.
- There is a need to develop policy and programs for mapping the farming systems zones of NUS species to develop site-specific species or landraces of staple crops, vegetables, spices, fruits, livestock, fish, and trees.
- Policy formulation is necessary to enhance and support household- to province-specific products focusing on neglected, underutilized, understudied, and unexploited crops and other neglected plant and animal species with high potential to raise the country’s economy.
- Research should focus on developing improved practices using integrated plant and soil nutrient management, growing food legumes or green manure crops in rotations, growing cover crops and mulching, practising in-situ manuring, strip-cropping, or agroforestry systems with hedgerow/alley-cropping, and with reduced or minimum tillage.

- Integrated nutrient management with combined use of organic and inorganic fertilizers is necessary to maintain soil nutrient balance and improve soil health, and enhance productivity, profitability, and sustainability of cropping systems.
- There is a continuing need for development of improved soil information systems using digital technologies such as digital soil maps, mobile soil testing labs, and DSS-based site-specific nutrient or fertilizer recommendations.
- Local government authorities need better integration of plant clinics services with the enhanced coordination of private and non-government sectors.
- There is a need to develop strong and well-developed farmers' institutions (farmers' groups and agriculture cooperatives) that can implement plant clinics at the local level. For this, systematic introduction and integration of plant clinics into the existing agricultural programs and their operation in cooperation with farmers' institutions is needed. This will help develop effective, fast, and reliable diagnostic tools for crop health issues.
- Development of online database for pest monitoring and surveillance and the integrated management of crop health problems should be the policy priority.
- Establishing, strengthening, and technology-based quality monitoring and surveillance system at the quarantine check points in airports and land borders should be strictly enforced to regulate the import of substandard or adulterated food stuffs.
- Effective implementation of food regulations locally and at the quarantine check points, formulation of legislative and policy measures, development of technical human resources, well-equipped laboratory facilities for food toxins testing, and allocation of financial resources from three tiers of government are necessary for food toxins minimization.
- Government needs to create a policy environment to enable and use the regenerative agriculture framework at different scales and planning agencies and people need to be trained to improve skills in this framework implementation.
- There is a need to create policy environment that enables communities of a landscape to come together to integrate their plans for regenerative agriculture. The federal structure and the devolution of power and resources to the sub-national levels can provide such an enabling environment.
- Government support in research and development and protecting farmers and their interest in promoting regenerative agriculture through incentives is required for quick adoption of this framework.
- Various CA and RCTs practices need to be tested, verified, and scaled-out across the mid-hills and Terai regions to increase productivity, profitability, and sustainability cropping systems.
- A concrete plan to initiate/establish machinery production units/industries and their value chains should be devised and implemented to facilitate the adoption of CA.
- There is a need to develop a joint plan of action by the federal and provincial line ministries and associated research and extension bodies to scale-out the currently available CA and RCTs and make the local government a prime implementer of the plan.
- CA and RCTs need to be mainstreamed in agricultural educational institutions, agriculture ministry's planning and implementation units, and in climate change-related policies, planning, and management mechanisms.
- There is a need to select and implement proper well-being indicators and formulate robust policies and programs for promotion of urban agriculture.

1.2.6.2 Theme 2: Livestock and Fisheries

- There is a need to strengthen market infrastructure and support services, technology development and dissemination, building capacity of institutions and stakeholders, and

enable policy environments for livestock and poultry breed improvements and development.

- There is a need to prioritize conservation and improvement of local livestock and poultry breeds.
- Effective policies on breeding, feeding, and animal health need to be formulated for sustainable livestock and poultry production.
- There is an urgent need for revising conservation policies in higher Himalayas due to ongoing adverse ecological impacts of grazing and declining trends of transhumance systems.
- DPSIR framework needs to be recognized as an important methodological tool in the study of social ecology of the transhumance systems in Himalayan ecosystems.
- There is a need to develop policies to provide the ownership of land and animals to the households to help lessen food insecurity problem.
- Aquaculture and fisheries need to be integrated in education, research, and development institutions.
- Aquaculture and fisheries management policies need to be fully developed and implemented.
- An institutional set up for effective implementation of multisectoral one health policy needs to be established.
- To prepare for next generation of experts and facilities to tackle future disease outbreaks, biosafety laboratories and animal health services in different provinces need to be established and veterinary and public health curricula need to be updated with inclusion of zoonotic diseases, epidemics and pandemics, and their preventive measures.
- Veterinary laboratories should be equipped with molecular diagnostic facilities for timely and precise surveillance of pathogens and effective regular treatments.
- Livestock insurance policy needs to be developed to reduce the risk of diseases and natural disasters.
- Investment in infrastructure such as cold chains and powder milk plants in public-private partnership in strategic locations needs to

be made to preserve perishable livestock products.

1.2.6.3 Theme 3: Forest Ecosystems, Community Forestry, and Agroforestry

- Policy and action plans should prioritize the timely harvesting of mature trees and minimal damage to neighbouring plants.
- Improvement of natural forest harvesting guidelines should be the first important step in improving the recovery of forest products and to minimize harvesting damage to the forest undergrowth.
- Reducing bureaucratic burden and minimizing involvement of the state forest agency in day-to-day harvesting activities should be ensured to ease forest harvesting operations.
- Provisioning of single long-term periodic permits for tree harvesting should be made to reduce transaction costs compared to the current multistage tender process in Nepal's forest harvesting system.
- Occupational health and safety codes of conduct and forest harvesting code of practice specifying technical requirements and compliance mechanisms in natural forests are urgently needed.
- Legislation and regulations that contradict the Agroforestry Policy 2019 should be amended.
- Agroforestry practices need to be mainstreamed in agriculture, livestock, and forest and environment ministries.
- Forest user groups of community forests and leasehold forests should be motivated to adopt location-specific and economically viable agroforestry systems.
- Environmental and ecosystems services from agroforestry systems should be quantified, monetized, and paid to the farmers for adopting the agroforestry systems and involving them in the carbon credit mechanisms.
- Mapping agricultural lands suitable for growing trees under agroforestry systems should be prioritized to scale-out agroforestry practices across the country.

- Policy should prioritize collective farming and providing land use rights for crop-tree-based farming in the abandoned farmland.
- There is a need of holistic management of forest ecosystem for maintenance of ecological integrity, poverty reduction, and livelihoods improvements.

1.2.6.4 Theme 4: Cross-Cutting Topics

- Government should apply the W–E–F nexus framework for planning at the Ministerial level and integrated farming systems approach in research and development activities at field level to meet the growing needs of water, energy, and food, and to maintain the sustainability of the natural resource base for the current and future generations.
- There is a need to calibrate, validate, and apply crop simulation models to increase crop productivity, profitability, and achieve food and nutrition security under current and future climate change conditions.
- There is a need to apply crop models for breeding climate resilient varieties, improving resistance against biotic and abiotic stresses, and in agronomic research for improving crop's resilience against stresses.
- Agricultural research and development need to integrate the socio-economic (including gender) and biophysical issues to develop integrated farming systems strategies to address food and nutrition security under varying socio-economic environments.
- There is a need to consider the dynamic links between social, ecological, and agrobiodiversity management to achieve gender equitable adaptation in agrobiodiversity management.
- Agriculture and rural development need to be supported by a nuanced view of the interplay between gendered forms of knowledge, power, and decision-making practices in specific social, political, and environmental contexts.
- There is a policy need to address gender inequity through the analysis of intersectionality based on caste, ethnicity, and class.

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Part I

Agriculture, Horticulture, and Post-harvest Management

Cereal Demand and Production Projections for 2050: Opportunities for Achieving Food Self-Sufficiency in Nepal

2

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Abstract

Cereals are a major source of food security, income, livelihood, and employment in Nepal. However, there is a lack of time-series data for cereals to have a full understanding of the level of production, productivity, and self-reliance in food production in the country. The objectives of this chapter are to assess patterns and dynamics of cereal production, productivity, and import growth, and analyze

food demand and self-sufficiency in Nepal. The major data sources for the chapter came from the national statistics, published and unpublished research papers, and policy documents. We used a compound growth rate estimation, coefficient of variation, and instability index techniques for analyzing dynamics and variability of the growth of food production and productivity over time. In addition, production and demand growth of cereals and self-sufficiency ratios were estimated for the next three decades until 2050 using different scenarios of production, population, demand growth, and the effect of climate change. Autoregressive regression model was used to analyze the relation between domestic production and income growth with import. The findings revealed that present production and productivity of cereals are low to meet current and future food demands of increasing population. Moreover, limited marketable surplus available at household level is the fundamental reason for steady increase in food imports. As a result, the country will continue to import a large quantity of cereals, particularly rice and maize in the future too. The country cannot achieve cereal self-sufficiency until 2030 under current growth rate of production, population, and negative effects of climate change. We suggest that government increase investment in agricultural research and development (R&D) to generate new and higher-level technologies

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and production practices for sustainable intensification of cereals with adequate policy support and services for ensuring national and household-level food and nutrition security to meet SDGs 1 and 2 by 2030.

Keywords

Cereal production • Food security • Food import • Productivity growth • Self-sufficiency

2.1 Introduction

Cereal crops are major food staples that play a significant role in food systems transformation and poverty reduction in developing countries. They are vital for human diets and livelihoods of a large proportion of smallholder farmers as well as crucial to meeting increasing food demand of growing populations throughout the world. To meet the food demand of the projected global population of about 10 billion people by 2050, food production should be increased by 50% above the current level without damaging the environment and by reducing greenhouse gas emissions (FAO 2017; WRI 2018). Estimates show that about 60% of the global dietary energy is currently supplied by three major cereals—rice, wheat, and maize (FAO 2017).

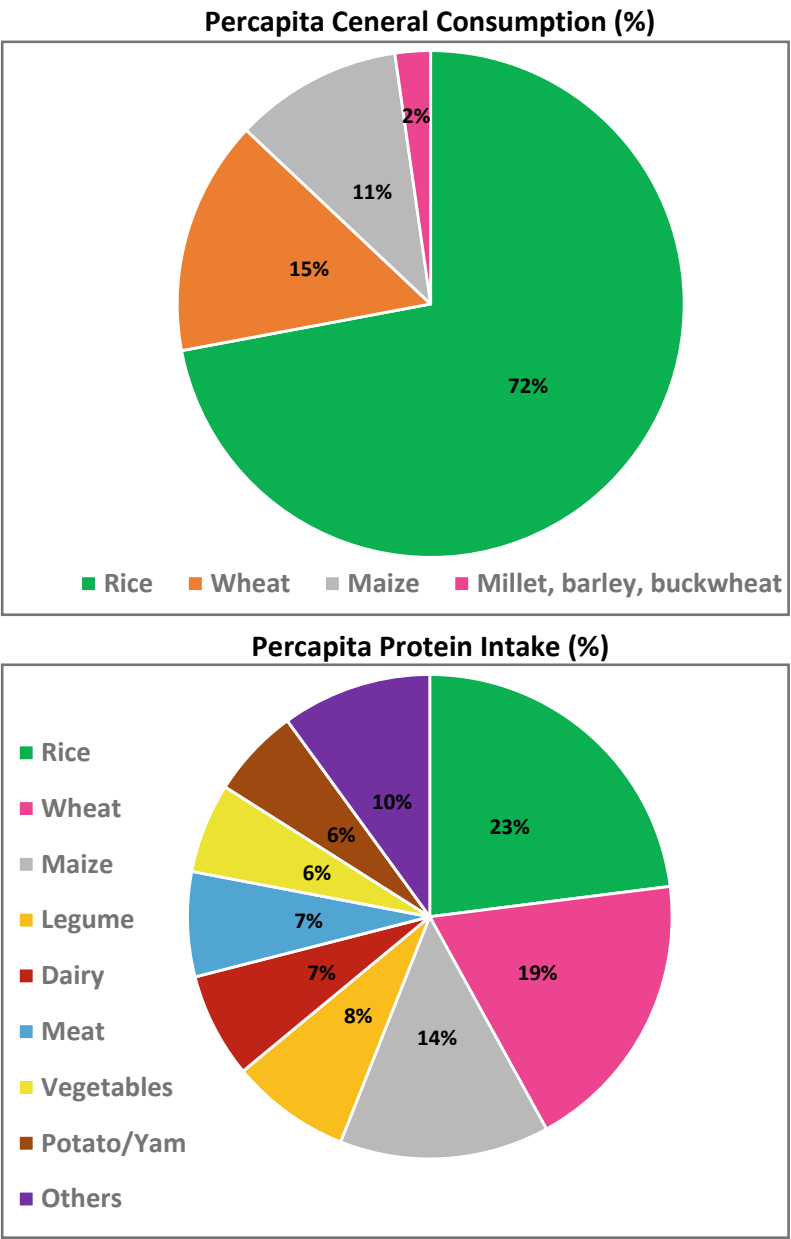
Six cereal crops—rice, maize, wheat, millet, barley, and buckwheat—currently account for about 80% of the total cultivated area and grain produced in Nepal, supporting livelihoods of about half of the population and are vital for food security and livelihoods of the smallholder farmers and urban poor (MoALD 2020). Cereals are major food sources in Nepal, where per capita cereal consumption is about 187 kg/year (NRB 2016); they also provide about 70% of the dietary energy supply (MoAD/FAO 2016; MoF 2020). Of all cereals, rice is vital in terms of meeting calorie needs as well as protein intake (Fig. 2.1). Rice alone meets 67% of the cereal requirement and 23% of the total protein intake from different food sources consumed by the people (CBS 2016). The three major cereals (rice, wheat, and

maize) alone meet 52% of the total protein needs of the people. The cereal consumption in the country is projected to grow further as a large section of population is still food insecure suggesting for the need for intensification of the sustainable cereal production. Compared to other agricultural commodities, the production of cereals has relatively lower environmental impact (Lancet Commission 2019).

The situation of food security and nutrition of the people in Nepal is extremely poor as the country ranks 79th position out of 113 countries in Food Security Index (Economic Intelligence Unit 2019) and 73rd position out of 135 countries in Global Hunger Index (GHI) in 2019 (von Grebmer et al. 2020). Currently, about 37% of the population is malnourished with high incidence of stunting of children under 5 years of age (NPC 2016). With increasing trends of population and income growth and urbanization, the country has been importing large volumes of foods from foreign countries, mainly India, in recent decades to meet the country's escalating food demand. Recent statistics show that Nepal imported food grains amounting of NPR 52 billion (US\$ 450 million) in 2018/19 out of which share of rice alone was 63% of the actual value (DoI 2020; TEPC 2019). This has serious implications for socio-economic development of the country.

Nepal, a net exporter of rice until early 1980s, has now become a net importer as the country's rice productivity is lowest in South Asia (Tripathi et al. 2018). Similarly, sluggish productivity growth of other cereals is also posing great challenge for feeding the country's growing population. With rising imports of food staples, there is a huge challenge for Nepal to meeting national food security and reducing vulnerability through timely availability of food with affordable prices. Unstable cereal productivity is another characteristic feature of Nepalese agriculture. This is because the farmers are yet to use improved technologies in cereals farming and weather extremes largely affect cereals performance over seasons. It is ironic that, even in the favorable year for crop production such as 2020, the country was still deficient in food grains with import requirement

Fig. 2.1 Contribution of major cereals to per capita food consumption and protein intake in Nepal. *Source* CBS (2016)



of 1.2 million tons, mainly rice, to meet the domestic demand (FAO 2020). The country’s ability to increase cereal productivity at a reduced cost and to produce enough food for achieving food and nutrition security and better livelihoods of smallholder farmers is largely constrained by lack of rightly focused cereal production programs and activities integrating science, technology, and

business models. High production cost, small farm sizes, insufficient support to farmers in terms of access to new and climate-resilient technologies, low input use and low or no new skills, and technical know-how (Adhikari et al. 2020) collectively contribute to low crop productivity in the country. Total factor productivity (TFP) growth, which is a measure of collective contribution of

non-conventional inputs in agriculture, is also extremely low with a growth rate of 0.06% per year (1981–2013), lowest in South Asia (Thapa et al. 2019).

Increasing food production by increasing cereals productivity and reducing production costs is critical for meeting the various sustainable development goals (SDGs), especially contributing to reducing poverty (SDG #1), maintaining food security, and achieving zero hunger (SDG #2). Failure to prioritize investment on research and development for cereals production in the past was a major weakness in achieving the self-reliance in food production, reducing vulnerability from food insecurity risks, and reducing import dependency. A recent study from South Asia (including Nepal) shows that for every 1% increase in cereal production and yield, there will be 0.84% lower incidence of under-nutrition (Mughal and Fontan Sers 2020). Recently, increased demand for cereals triggered due to (i) rise in income growth (mainly due to remittances) that pushed also demand for fine and aromatic rice (ii) improvement in road connectivity and income growth also led to drastic increase in rice consumption in the hills and mountainous areas by reducing the consumption of coarse grain cereals, e.g., maize, millets, barley and buckwheat (iii) rapid growth of poultry, which triggered demand for maize as livestock feed, and (iv) population increase. Enhanced cereal production and productivity is directly related to meeting SDG 2, with its two targets - ensuring access to safe, nutritious, and sufficient food for all people all year round (2.1) and eradicating all forms of malnutrition (2.2). The food and nutritional securities are of prime concern for the people of Nepal as the food security and food sovereignty are important components of the human rights as envisaged by the constitution (GoN 2015). In addition, increasing food production is needed to meet the national goal of achieving self-reliance in agriculture by doubling food production by the end of 15th plan period (2022/23) and meeting the Zero Hunger Challenge Initiatives and ensuring sustainable food and nutrition security by 2025 (MoAD 2016a, b). Nepal currently lacks any technology-intensive

programs and activities that can bring transformative change in cereals production and productivity in the country. Therefore, it is unlikely that the country can achieve these highly ambitious targets. Although the Government of Nepal (GoN) has recently developed and launched some food production programs such as Prime Minister Agriculture Modernization Program (PMAMP)¹ to make country self-reliant in agriculture by focusing on priority cereal crops and other commodities (<https://pmamp.gov.np>), it has yet to show its meaningful impact for ensuring national food and nutrition security. Lack of real-time data on area coverage by cereals and their production, productivity growth, and import is another challenge for developing a reliable model for estimating cereal supply and demand in the country.

This chapter aims to assess patterns and dynamics of cereal production, productivity and import growths, and supply and demand growths to analyze self-sufficiency scenarios in food production for the next three decades until 2050 in Nepal. It then suggests priority areas for improving national food and nutrition security in the country, which may equally have relevance to other South Asian and other developing countries in the world.

2.2 Data Sources and Methods

Most information for this study came from the review and analysis of secondary data from the government and other sources. We used compound growth rates² analysis for estimating annualized growth rate of cereal yield for the last 30 years (1991–2019) which is commonly used

¹ Production program in PMAMP is organized in pockets (50 ha), blocks (100 ha), zones (500 ha) and super zones (1000 ha) particularly in favourable areas in the country with a total coverage of rice in the project (31 districts) is only about 50,000 ha in total (<https://pmamp.gov.np/>) with very high operational cost per unit of area.

² Compound annual growth rate (CAGR) is the annualized average rate of growth (constant growth) over multiple years assuming growth takes place at an exponentially compound rate. This is commonly used in economics research and analysis.

in economics and agriculture (Chandran and Prajneshu 2004; Gairhe et al. 2021a, b). The Instability Indices are used for analyzing dynamics and variability of the growth of agricultural production and productivity (yield) and food demand over time. The instability index technique is used to assess fluctuations or instability in time-series data. In this study, instability in area, production, and yield of cereals is mainly measured by the coefficient of variation (CV), though there are other measures of instability (e.g., dispersion, Cuddy Della Valle Index (CDI), Coppock Instability index, etc.). In addition, production and demand growths of cereals and self-sufficiency ratios were estimated for 2030, 2040, and 2050 using six different scenarios combining edible cereal production and demand in the country. These include three production scenarios viz. (a) at normal current growth rate (2.26% per annum) of cereal production (b) at 10% increase (2.49% per annum) in the normal current growth rate of cereal production after 2025 (c) 10% decrease (2.03% per annum) in current normal growth rate of cereal production after 2025, and two demand scenarios viz. (a) at population growth rate (1.30% per annum) of the last three decades (1991–2019) and (b) at population growth rate (0.57% per annum) of the last one decade (2009–2019). Self-sufficiency ratio (SSR), an index of self-sufficiency in cereals, expresses food production as a proportion of available supply (FAO 2016; Timsina et al. 2018) and is estimated as:

$$\text{SSR} = \frac{\text{production}}{\text{production} + \text{imports} - \text{exports}} \times 100$$

Prais-Winsten AR(1) regression models (Generalized least-squares (GLS) estimator) were used to estimate the effect of different explanatory variables (Culas and Timsina 2019). Four different Prais-Winsten AR(1) regression models were used to estimate the effect of domestic production and per capita GDP on the import of three major cereals and total for all cereals. Models with Durbin-Watson statistic (transformed) close to two were selected to avoid autocorrelation in the sample. Timsina et al. (2018), on the other hand, showed how Bangladesh could achieve self-sufficiency in cereals in 2030 and 2050 using crop simulation models-based yield gap analyses and SSRs of cereals under various scenarios instead of regression models used in this study. Statistical programs (STATA16.0) were used for statistical analysis of the data.

2.3 Results and Discussion

2.3.1 Area, Production, and Productivity of Cereals

The average cereal yields data for 2018/19 for the mountains, hills, and terai, indicate that the

Table 2.1 Comparative average yields (t/ha) of cereals by agro-ecology in 2018/19

Cereals	Mountain	Hill	Terai	Average
Rice	2.34	3.12	3.50	3.36
Maize	1.94	2.53	4.15	2.84
Wheat	1.64	1.07	2.61	2.85
Millet	1.07	1.16	1.06	1.19
Barley	1.18	1.08	1.19	1.25
Buckwheat	1.22	1.02	1.03	1.11
Nepal (Average)	1.98	2.66	3.68	3.10

Source MoALD (2020)

productivity was highest for rice (3.36 t/ha) followed by wheat and maize, while that of millet, barley, and buckwheat were very low, around 1 t/ha. When compared among the agro-ecological zones, yields of rice, maize, and wheat were highest in terai, moderate in hills, and lowest in the mountains, while those of millet, barley, and buckwheat were almost similar in all zones (Table 2.1).

The current aggregate cereal productivity is 3.10 t/ha, which is lower than the global average of 4.07 t/ha, Bangladesh (4.79 t/ha), Sri Lanka (3.76 t/ha), Bhutan (3.46 t/ha) and India (3.2 t/ha) (World Bank 2020). The low productivity of cereals is due to low use of improved technologies, limited availability and use of production inputs, and limited investment in agriculture (MoAD 2015; Gauchan 2018; Thapa et al. 2019; Gairhe et al. 2018, 2021b). For instance, the average use of chemical fertilizers is only 76 kg/ha in Nepal (Takeshima 2019) due to a lack of their timely availability during the cropping season. Seed replacement rate, an indicator of use of improved quality seeds, is also low in Nepal (Gauchan 2019; Gairhe et al. 2021c). Furthermore, the use of modern farm machinery is limited resulting in inefficiency in farming and high cost of production (Gauchan and Shrestha 2017).

2.3.2 Growth Rates of Area, Production, and Productivity

The growth rate of cereal production is an important factor that indicates domestic food

availability and food security. The estimations of compound growth rate per annum for cereals for the last three decades (1990/91 to 2018/19) showed that the rate of growth in area for all cereals was incredibly low. The production and productivity growth of major cereals were increasing modestly. Production and yield growth rates per annum during the last three decades were highest for wheat, followed by maize and rice (Table 2.2).

Despite the gradually increasing trends in the yields of major cereals, the national average yields are still below 50% of the attainable yield in the farmers' fields resulting in high yield gaps (Krupnik et al. 2021; Timsina et al. 2021a, b). Declining soil fertility with continuous monocropping, soil erosion, and poor soil management is promoting degradation of farmlands leading to reduced cereals productivity (Chalise et al. 2019). Research in northwest Indo-Gangetic Plains of South Asia has shown that the rice–wheat (R–W) system yields have either stagnated or decreased due to declining groundwater tables, deteriorated soil health, and micronutrient deficiencies (Bhatt et al. 2021). Similar soil, water, and nutrients-related issues are also prevalent in R–W and other cropping systems across Nepal (Tripathi et al. 2022).

2.3.3 Production Variability and Instability

Area, production, and productivity of crops vary by season, year, and location due to fluctuations in climate, technology, and management factors.

Table 2.2 Compound growth rates per annum of cereals in Nepal from 1990/91 to 2017/18

Crops	Area (ha)	Production (t)	Yield (kg/ha)
Rice	0.12	1.77***	1.65***
Maize	0.75***	2.76***	1.99***
Wheat	0.93***	3.56***	2.61***
Millet	0.85***	0.92***	0.07
Barley	-0.97***	-0.05	0.93***

Note ** and *** denotes significance at 5 and 1% level of significance, respectively. Data for buckwheat was only available for the period 1991–2010 so it was excluded from the analysis

Table 2.3 Instability index of cereals in Nepal from 1990/91 to 2017/18

Crops	Instability index		
	Area	Production	Yield
Rice	4.78	8.26	5.32
Maize	1.87	3.74	3.37
Wheat	3.17	6.48	5.45
Millet	6.03	4.56	2.61
Barley	10.65	13.20	6.98
Buckwheat+	2.49	3.55	2.58

Note + indicates data from 2010/11 to 2017/18

Temporal and spatial variations in production and productivity raise the risk involved in farm production and affecting farmers' decision to adopt modern technologies (Senapati and Goyar 2018). Such variations not only affect production stability but also price stability, and hence increase the vulnerability of low-income households to market. Table 2.3 presents the instability index of cereals from 1990/91 to 2017/18.

The instability in production, measured using the instability index, showed the highest instability for the area, production, and yield of barley followed by millet and rice area. On contrary, lowest instability for the area was observed for maize and buckwheat, and for production and yield, it was observed for buckwheat and maize. These data indicate that maize and buckwheat are least affected by fluctuations of climate, technology, and farmers' management factors. Weather-induced instability of production is more prevalent in food staples like rice, millet, and barley.

Climate change effects, in particular the increasing incidence of drought, rainfall extremities, hailstones, landslides in the hills and mountains, and flooding in terai, are emerging challenges for increasing production stability and increasing productivity. The country has seen an annual average temperature increase of 0.056 °C and is expected to increase further in future (DHM 2017). Small and marginal farmers are more vulnerable to climate change due to limited options for diversification to food production (Joshi and Joshi 2019). Climate-smart and resource conservation technologies that help to stabilize production and adapt to changing climates are limited in the country (Amgain et al. 2022).

2.3.4 Import and Export Trends

The import of food grains in Nepal is escalating in the recent decade resulting in trade imbalance

Table 2.4 Trends of cereal import and export and share of rice import (2011–2018)

Year	Total cereal imports value (000NPR)	Total cereal exports value (000NPR)	Share of rice imports in total cereal imports (%)
2011/12	11,972,435	8,422	77.58
2012/13	20,047,598	39,446	71.52
2013/14	28,161,992	18,373	61.27
2014/15	35,670,123	16,804	69.62
2015/16	39,025,913	16,303	58.95
2016/17	40,148,372	30,072	59.45
2017/18	45,414,446	16,517	64.76
2018/19	51,802,396	25,396	62.92

Source Department of Custom (2020); 1 US\$ = 112 NPR

Table 2.5 Compound growth rates per annum of import and export of food products from 1990/91 to 2017/18

Cereals (1000 t)	Import growth (%)	Export growth (%)
Milled rice	24.10***	
Maize +++	31.72***	
Wheat +	14.58***	−2.33
Millet & millet seed ++	1.46	
Barley & barley seed ++	54.98	
Buckwheat ++	33.72	−11.24**

Note ** and *** denote significance at 5 and 1% level of significance, respectively, + indicates data from 1995/96 to 2017/18; ++ indicates data from 2009 to 2018; +++ indicates data from 2005/06 to 2017/18

and high vulnerability to import dependency. Data from 2011 to 2018 indicate that the export value of cereal only accounted for a very tiny proportion of total imports (Table 2.4). During that period, only small quantity of wheat was exported to Tibet (China) and buckwheat to Japan. Escalating imports and limited exports of low-value-added products have resulted in surging trade deficits and food instability (Sharma 2019). Analysis of annual compound growth rates revealed that the import growth rates of milled rice, maize, and wheat are increasing at 24%, 32%, and 14% per annum, respectively (Table 2.5).

Limited marketable surplus for cereals available at household level is the main reason for continuous rise in food imports. This is because farmers largely practice subsistence farming, with half of the workforce employed in the sector producing only for own consumption that comprises more than 70% of the farm households, while more than 40% sell only when there is a surplus and less than 10% are farming mainly to sell (ADB, 2019).

The increased import growth rate of rice was mainly due to changes in food habits toward rice from coarse grains for human consumption (Dhungel and Acharya 2017; Gairhe et al. 2021a), wheat as a processed flour for the preparation of different food items, and maize mostly due to its use as poultry feed. The increase in production and productivity of cereal crops over the last three decades was inadequate to meet the growing demand for food. Analysis of imports of major cereals as affected by domestic production and income (per capita GDP) using the Autoregressive regression model showed that rice is more income elastic as compared to wheat and maize (Table 2.6).

The analysis reveals that if we increase domestic production by 1%, the import will be reduced by more than unity in wheat and maize and by unity in rice. This suggests that if we increase domestic production, particularly rice, without considering consumers' preference and their income, the achievement of the targeted import substitution will not be possible. However, there is a lack of empirical studies and

Table 2.6 Effect of domestic production and per capita GDP on import of major cereals

	Rice	Wheat	Maize	Total cereals
Production	−1.02 (1.62)	−1.402 (1.16)	−1.51 (1.90)	0.47 (2.24)
GDP per capita	2.77 (0.49)***	2.52 (0.78)**	2.15 (1.16)*	3.74 (0.93)***
F(2, 31) Value	21.43***	15.76***	5.12**	27.63***
R-squared	0.39	0.31	0.10	0.69
DW statistics (transformed)	1.67	1.77	1.51	1.78

Note *, ** and *** denote significance at 10, 5, and 1% level of significance, respectively, + indicates log-transformed data from 1990/91 to 2019/20. Figures in parentheses indicate semi-robust standard errors

assessments about the amount and volume of consumer-preferred cereal varieties for targeting production planning and marketing and assessing the availability of marketable surplus at the household level. Minimum support price for major cereals (rice and wheat) is being introduced recently with specific premium prices for fine and aromatic rice, but it is not being effectively implemented. As a result, producers are not able to reap the benefits of price support programs for increased production and marketing of consumer-preferred varieties.

2.3.5 Projections of Production and Demand of Cereals

The food demand in Nepal has always been higher than the domestic production, requiring huge imports and loss of revenue. The analysis of the past three decades (1991–2019) of edible cereal production and human population data showed the production growth rate of 2.26% per annum and population growth rate of 1.3% per annum (CBS 2016; MoALD 2020). To get clear insights and understanding of the likely situation of self-sufficiency in cereals for the next 30 years, we estimated the production and demand of cereals and self-sufficiency ratios (SSRs) under different scenarios of production, population growth, and climate change for three periods (2030; 2040; 2050). Various assumptions were made to create six scenarios to estimate cereal demands and self-sufficiency situations combining three production and two demand scenarios. The three production scenarios include: (a) current growth rate of edible cereal production (2.26% per annum) (b) 10% increase in the current growth rate of cereal production with the availability and use of new and improved technologies, and (c) 10% decrease in current growth rate of cereal production due to projected climate change effect. The two demand scenarios include: (a) population growth rate (1.3% per annum) for the last three decades (1991–2019) and (b) population growth rate (0.57% per annum) for the last one decade (2009–2019). Unlike estimation of self-

sufficiency situation for cereals in Bangladesh context where cropping land was decreasing over time (Timsina et al. 2018), we assumed that land used for cereals remains constant for the projected period. In Nepal, though there is some decline in cultivated area under major food staples (mainly in rice and wheat) in recent decade (MoALD 2020) due to urbanization and infrastructural development, the decreased area will be compensated by the increased area under spring (*Chaite*) rice and hybrid maize in winter and spring seasons and increased irrigation facilities. In addition, it is highly likely that increased emphasis will be given to minor cereals (buckwheat, barley, and millets) in future for meeting local food security and nutritional needs of the growing population.

We projected cereal production and demand and resulting surplus or deficit of cereals for the next three decades until 2050 for six scenarios. The scenarios were: (i) P1D1: current constant growth rate of edible cereal production (2.26% per annum) and population growth rate (1.3% per annum) for the last three decades (1990–2019); (ii) P1D2: low growth rate of population (0.57% per annum) for the latest decade (2010–2019) with current constant growth rate of cereal production; (iii) P2D1: increased cereal production growth rate (10% per annum) after 2025 over the current growth of cereal production with the availability and use of new and improved technologies and population growth rate for last three decades (iv) P2D2: low population growth rate of the latest decade and increased cereal production growth rate (10% per annum) (v) P3D1: declined cereal production growth rate (10% per annum) due to negative effect of climate change and the current population growth rate of last three decades, and (vi) P3D2: declined cereal production growth rate (10% per annum) due to negative effect of climate change and low population growth rate (0.57% per annum). The first two scenarios were static while the remaining four were dynamic (Table 2.7). The estimated demand is total domestic demand based on both direct household food consumption demand and indirect demands for livestock feed, seed, and industrial uses (gluten, liquor, etc.).

Table 2.7 Estimated edible cereal production and demand for the next three decades until 2050 under various scenarios (1000 t)

Scenarios ^a	2019/20				2029/30				2039/40				2049/50			
	Production	Demand	Surplus/Deficit		Production	Demand	Surplus/Deficit		Production	Demand	Surplus/Deficit		Production	Demand	Surplus/Deficit	
P1D1	6750	7782	-1032		8440	8854	-414		10,554	10,075	479		13,197	11,464	1733	
P1D2	6750	7782	-1032		8440	8237	204		10,554	8718	1836		13,197	9228	3969	
P2D1	6750	7782	-1032		8536	8854	-319		10,916	10,075	841		13,960	11,464	2495	
P2D2	6750	7782	-1032		8536	8237	299		10,916	8718	2197		13,960	9228	4731	
P3D1	6750	7782	-1032		8346	8854	-509		10,204	10,075	128		12,475	11,464	1010	
P3D2	6750	7782	-1032		8346	8237	109		10,204	8718	1485		12,475	9228	3246	

^aScenarios are described in detail in the preceding two paragraphs * The figure are for edible portion (1000 t) estimated from milling ratio of different cereal crops

Data revealed that Nepal produced about 6.75 million tons of edible cereal grains with a deficit of about 1.0 million tons in 2019/20. The analysis showed that the estimated demand for edible cereals will be 9.23 to 11.46 million tons in 2049/50, 8.71 to 10.07 million tons in 2039/40, and 8.23 to 8.85 million tons in 2029/30 for various scenarios. This is similar to that of Kumar et al. (2019), who projected a need of 8.47 million tons of edible cereals by 2035 to meet the food needs of the increasing population based on the data using the Nepal Living Standards (NLS) survey of 2011, food demand elasticity, income growth, and population. Further Analysis showed that the country will achieve self-sufficiency in cereals only by 2040 with the current edible cereal growth rate (2.26% per annum) and population growth rate (1.3% per annum) based on the growth rates derived from the past three decades (1990–2019). But if the population continues to grow at the lower rate (0.57% per annum) as in the recent decade, the country can achieve self-sufficiency in 2030 itself even with the current cereal growth rate. For the optimistic scenario, if cereal production increases by 10% per annum over the current cereal growth rate assuming that new improved technologies and irrigation are available and used widely, then the country can achieve self-sufficiency in 2030 with the low population growth rate but not in 2040 with the current population growth rate of 1.3%. Furthermore, self-sufficiency is unlikely to be achieved by 2030 under the current population growth rate, if production declines by 10% from the current growth rate due to the negative impact of climate change such as increased incidence of drought, flooding, and disease and pest outbreaks. Some studies also reveal the negative effect of climate change on cereal yield, which is expected to decrease by 4–10% by the twenty-first century in South Asia (Lal 2007). Similarly, Bocchiola (2017) reported that the yield of major crops in South Asia under climate change would decline by 8% by 2050. Karn (2014) estimated a likely decrease of rice yield by 4.2% in Nepal based on an analysis made for 20 major rice-growing districts in the country. Estimates of the demand for the cereals,

Table 2.8 Estimated self-sufficiency ratios for cereals under static and dynamic scenarios (%)^a

Year	Static scenarios		Dynamic scenarios			
	P1D1	P1D2	P2D1	P2D2	P3D1	P3D2
Baseline situation (2019/20)	86.74	86.74	86.74	86.74	86.74	86.74
2029/30	95.32	102.47	96.40	103.67	94.26	101.33
2039/40	104.75	121.06	108.34	125.20	101.27	117.03
2049/50	115.11	143.01	121.76	151.27	108.81	135.18

^aScenarios are described in detail in the preceding section

especially the indirect demand (seed, feed, and wastage), however, suffer from uncertainties due to the lack of appropriate data for Nepal (Prasad et al. 2011; Kumar et al. 2019). Furthermore, the estimated growth rate of edible cereal yield, projected production and demand growth for the different periods is based on the reliability of the available official sources of data in the country.

2.3.6 Projections of Cereal Self-Sufficiency

Achieving self-sufficiency in cereal production is a major concern for Nepal to achieve the food and nutrition security needs of a growing population. The analysis showed that the current SSR of cereal in Nepal is 87%, indicating that 13% of the demand is met through imports.. The estimated SSRs for cereals under the two static and four dynamic scenarios for the next 10, 20, and 30 years are presented in Table 2.8.

Rice is the main imported commodity for household consumption while maize is imported as livestock feed. The projections showed that self-sufficiency in cereals can only be achieved in 2030 under a low population growth rate (0.57% per annum) and increased technology development and dissemination. As indicated in P3D1, climate change will have a negative effect on achieving self-sufficiency in 2030 under the current growth rate of population (1.3% per annum). To mitigate the negative effect of climate change, an increase in the 10% growth rate of cereals, which translates into 2.49% from the baseline situation of 2.26% per annum growth, is not adequate to achieve self-sufficiency by 2030.

This requires at least an annual growth rate of edible cereals by 3% per annum until 2030, while a slightly lower growth rate will likely meet self-sufficiency after 2030 under a normal scenario (with no additional increase in consumption demand).

However, achieving self-sufficiency and economy of scale in cereals is the biggest challenge due to the dominance of small marginal and fragmented land holdings, difficult mountain topography, and high cost of production. Furthermore, the possibility to increase cereal crop areas in the future is low due to the rapid conversion of premium agricultural land for industries and urban development in terai, river basins and valleys, and land abandonment in hills and mountains. The urbanization process in terai during the recent decades is taking place at around 12%, implying that about 65,000 ha of premium land suitable for cereal cultivation has been converted into urban areas (Rimal et al. 2018). Likewise, around 70% of farming households have been underutilizing their cultivated land resource in the middle hills (Kc and Race 2019). Furthermore, labor scarcity and high production costs are also critical constraints to food production and achieving food self-sufficiency in Nepal (Gauchan 2018). Mechanization and modernization of agriculture including the use of resource- and labor-saving technologies to reduce cost and improve production efficiency are limited. Devkota et al. (2022) reported 2.58 t/ha exploitable yield gap of rice across the terai of Nepal and suggested that the major gains (1.86 t/ha) are achievable through the adoption of good agronomic practices. Moreover, the principal drivers of yield

Table 2.9 Projected edible cereal demand and increment in cereal productivity needed to meet food self-sufficiency by 2030, 2040, and 2050

Period	Projected demand (1000 t)	Cereal productivity required to meet demand (t/ha)	Increment required in cereal productivity from the current level (%)
2030	8.854	4.06	24
2040	10,075	4.62	33
2050	11.464	5.25	41

outcomes can be irrigation intensity, rainfall, and nitrogen and phosphorus fertilizers.

2.3.7 Estimated Cereal Productivity Needed for Achieving Food Self-Sufficiency

The projected cereal demand and increments in cereal productivity (yield) needed for the country to be self-sufficient in food by 2030, 2040, and 2050 are presented in Table 2.9. The projected edible cereal demand based on the baseline year (2019) level of productivity (3.10 t/ha) and with the constant growth rate of production (2.26% per annum) and population (1.3% per annum) is 8.854, 10.075, and 11.46 million metric tons in 2030, 2040 and 2050, respectively.

The estimations showed that to achieve food self-sufficiency, yield increment in cereals is needed by at least 24% by 2030, 33% by 2040, and 41% by 2050 from the current growth rate of production. The analysis also revealed that the projected demand can be met with increased average cereal productivity of 4.06 t/ha by 2030, 4.62 t/ha by 2040, and 5.25 t/ha by 2050. The estimated demand can be met either through expansion of the current cereals area from 3.45 million ha to over 4.0 million ha or by increasing the current productivity of 3.10 t/ha to a higher level of 4–5 t/ha or combination thereof. Considering the land becoming a constraint for further expansion, the only option to increase cereal productivity would be to increase productivity by diversifying the use of high-yielding hybrids, climate-resilient inbred as well as open-pollinated varieties, and better soil, water, and crop management practices (Devkota et al. 2021, 2022; Krupnik et al. 2021; Timsina et al. 2022).

For rice crop, Timsina et al. (forthcoming) has estimated the demand and supply of rice for coming 30 years for various scenarios and suggested that demand can be met through increasing the current productivity by at least 27–43% by 2030 and 42–85% by 2050.

It should be emphasized that focusing on increasing productivity of major cereals (rice, maize, wheat) alone cannot meet yield growth required for food self-sufficiency. There is a need to emphasize increasing productivity of minor but nutrient-dense crops such as millet, barley, and buckwheat as their current productivity is very low (1 t/ha). Increased focus on research should be given to exploit and increase their potential high productivity growth. A recent field survey carried out in Jumla in the far-western mountains shows that farmers are already obtaining yields of about 2 t/ha from barley and finger millet using their local varieties under farmers' traditional management practices (Palikey et al. 2016). With the use of high-yielding varieties and improved management practices, there is potential to obtain their crop yields even higher- to about 3 t/ha. However, these minor crops are currently least prioritized by national research, extension, and agricultural development programs such as PMAMP and other pockets and mission programs making them neglected and underutilized species (NUS) crops (Gauchan et al. 2020). In addition, there is inadequate emphasis on the research and development (R&D) of specialty rice varieties such as fine and aromatic rice, low-yielding local red *Marshi* variety of rice, and low-yielding unique local varieties of wheat, maize, and other cereals, whose consumers demands are increasing rapidly in recent years. Moreover, investment in cereal research in Nepal accounts for only 30% of the

total agricultural research budget, despite its 70% share in the dietary needs of the people (MoF 2020). The evidence also shows that current investment in agricultural research, which is a major source of new technologies, is only 0.42% of the agricultural GDP (Stads et al. 2019). The agriculture (including irrigation and forestry) sector currently receives only about 5% of the total national budget share in the country (MoF 2020). The investment in research and extension is not only low it is also imbalanced across production environments (Gauchan and Pandey 2011; Shrestha and Gairhe 2016). Similarly, private investment in agriculture is also limited because of high risks, and the lack of a conducive environment for investment (Thapa et al. 2019). Lack of critical mass of agricultural professionals in local, provincial, and federal governments and the national research system, and poor linkages among research, extension, and education systems are hindering the development and dissemination of technologies. Both public and private sectors in Nepal have underinvested in food crop production, input supply, and marketing technologies and presently farmers and private sectors lack right skills, capacity, and management practices that are vital for the food security and livelihoods of the poor and small-holder farmers. Private sector companies in agriculture are predominantly family-run businesses only few of those have limited qualified staff, agriculture R&D facility, and understanding and other necessary infrastructure.

2.4 Conclusion and Policy Recommendations

Three major cereals rice, maize, and wheat are the key components of agri-food systems for ensuring food and nutrition security in Nepal. However, they are characterized by low productivity growth and high production instability, resulting in food deficiency each year to meet the increasing food demand of the growing population. As a result, the country is importing a large quantity of cereals, particularly rice and maize each year. Our results demonstrated that under

the current growth rate of production and population and potentially negative effects of climate change, the country cannot achieve self-sufficiency in 2030 and meet the targets of SDGs. To mitigate the negative effect of climate change, an increase of more than 20% growth rate of cereals from the current growth rate is essential to achieve self-sufficiency in 2030. The estimations showed that to achieve self-reliance in food, cereal yield increments are needed by at least 24% by 2030, 33% by 2040, and 41% by 2050 from the current growth rate of cereal production. The analysis also revealed that the projected demand could be met with increased average cereal productivity of 4.06 t/ha by 2030, 4.62 t/ha by 2040, and 5.25 t/ha by 2050.

The main limitation of the current analysis is that the scenarios chosen are not comprehensive to cover all possibilities that are likely to affect demand and supply situations of cereals in the country. Since the recent data are based on guess estimates, our analysis and predictions can only be reliable to the extent that the data are factual and accurate. Due to data limitation and complexity of the analysis, it mainly assumed that land availability for growing crops will be declining over the decades due to conversion of agricultural lands for non-agricultural use as well very high abandonment of cultivated lands in hills and mountains and consumers' preference remain constant. This assumption was made due to limited availability of land for future expansion and likely increased consumer's demand for cereals will be neutralized by future increased shift toward non-cereal products like pulses, fruits, and vegetables respectively. However, there is a need to assess the demand and supply scenarios also using potential changes in cultivated land availability, land-use practices (e.g., cropping system, water availability, etc.), and dietary shifts of the consumers as used in Bangladesh study (Timsina et al. 2018).

The study makes important recommendations to improve the production and productivity of cereals to meet increasing needs of the growing population in the country. There is a need to make a higher investment in R&D with adequate policy support for the development, promotion, and

adoption of new, high-yielding climate-resilient varieties and technologies and practices. This also necessitates identifying and closing the cereal yield gaps at the farm level by using advanced technologies and practices together with appropriate business models that motivate smallholder farmers to maximize cereal productivity under the prevailing climate change. Special priority should be given to promote increase area and productivity (i.e., yield per unit area) of spring (*Chaita*) rice and of winter and spring maize with irrigation in terai and lower valleys and increase cropping intensity in fully and partially irrigated areas employing sustainable intensification approaches. Novel crop management decision support systems tools such as Nutrient Expert based recommendations for cereals (Amgain et al. 2021; Timsina et al. 2021a, b, 2022), good agronomic management practices based on the principles of conservation agriculture (Brown et al. 2021; Krupnik et al. 2021; Devkota et al. 2022; Magar et al. 2022a, b), and women and youth-friendly mechanization with sustainable crop intensification (Paudel et al. 2020) can increase productivity, save resources and promote modernization in cereal production. The adoption of sustainable mechanization requires policies to enhance better access to markets, extension services, and enhanced access to credits and training (Aryal et al. 2021; Brown et al. 2021). Similarly, providing necessary incentives for producing locally adapted varieties of nutrient-dense indigenous crops (millets, buckwheat, barley, etc.) that have location-specific advantages and potentials and can contribute to increased household income and food self-sufficiency in the hills and mountains. However, to achieve this, new science and business innovations are needed for enterprising major and minor nutrient-dense cereals and other indigenous crops in Nepal.

Based on the findings of this study, the following recommendations and policy implications are identified, which could also be important and relevant for other countries in South Asia and other developing countries.

- Strong need is identified for producing empirical data on net area coverage, crop yield estimations, and identification of yield gaps using crop simulation models (Devkota et al. 2022; Timsina et al. 2021a, b), and on household-level food consumption and marketable surplus available for each of the cereal crops.
- The future demand and supply projection needs to cover whole food commodities including pulses, vegetables, and livestock products covering all important variables (including changes in land use, dietary shift, consumers' preferences, etc.) affecting demand and supply under dynamic scenarios.
- Increased investment in R&D is needed for the development and dissemination of high-yielding hybrids, climate-resilient varieties, and crop, soil, and water management technologies. Special focus should be given to sustainable intensification of cereals, conservation agriculture, and good agronomic practices (Krupnik et al. 2021; Devkota et al. 2022; Magar et al. 2022a, b), and sustainable soil and nutrient management (Amgain et al. 2022; Tripathi et al. 2022).
- Increased collaboration and strategic partnership are needed with private sectors, civil society organizations, and research and development agencies for increased piloting and dissemination of available productive, profitable, and sustainable technologies and innovation and for promoting their adoption and commercialization. Specific focus should be given to strengthen linkages and collaboration with international research centers such as CGIAR and universities in the developed countries for collaborative R & D so as to have regular access to new technologies and innovative production practices.
- Strong emphasis on developing in country capacity of National Agriculture Research Systems partners (Agricultural Universities, NARC, federal and provincial extension system) is needed in higher-level technologies, high throughput research methods to develop next generation of scientists that are trained on advanced science, technologies and innovations.
- Improving the productivity and value chain and enterprising underutilized nutrient-dense

cereals and traditional specialty varieties by utilizing their local potentials and locational advantages is essential to meet the increasing nutritious food needs of a growing population.

- Policies and institutional support, credit, insurance and input policies, and investment and support services for easy and enhanced access, and timely delivery and use of quality inputs, machinery, credits, insurance, and irrigation are vital for increasing cereal productivity and profitability and for adaptation to changing climate.

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Fruits and Vegetables for Food and Nutrition Security and Income Generation in Nepal

3

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Abstract

Fruits and vegetables are rich sources of dietary fiber, vitamins, minerals, electrolytes, phytochemicals, and antioxidants. These crops can improve food and nutritional security and improve livelihoods of people living in diversified physiographic regions of Nepal. The objective of this chapter is to assess and document the status of fruits and vegetables research and varieties developed and recommended, and analyze their area, production, yield growth rates, and import and export situation in Nepal. It also explores major gaps, issues, and challenges to increase productivity and improve self-sufficiency in fruits and vegetables in the country. The findings showed that the development and release of hybrids and open pollinated varieties using locally adapted genetic resources are limited in fruits and vegetables. The trends in area and production of fruits and vegetables are increasing in the last two and half decades.

Despite increased growth of area, production has not increased. Hence, the import of fruits and vegetables is increasing rapidly in recent years to meet the increasing demands. Considering the limited options for increasing area under fruits and vegetables, the only option available is to increase their yield which is necessary to reduce import for making country self-reliant in fruits and vegetables. Increased investment in research and development is needed for the development and dissemination of new technologies and marketing of fruits and vegetables in priority commercial production pockets including local nutrition gardens which would enable to improve food and nutrition security and livelihoods of the people of Nepal.

Keywords

Agro-biodiversity • High value •
Micro-climatic zones • Nutrition security •
Self-sufficiency

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3.1 Introduction

Nepal has comparative advantages of growing diverse fruits and vegetables due to prevalence of diverse agro-climatic conditions ranging from 60 m in eastern Terai (Kechana, Jhapa) to the highest summit of the world—the Mountain Everest (8848 m). The country is bestowed with

wide agro-climatic variations having five physiographic regions, four distinct seasons (spring, summer, autumn, and winter), four aspects of hills and mountain (south, north, east, and west) providing vivid micro-climatic zones with rich agro-biodiversity. From the agricultural production practices, there are three main production seasons: dry season from mid-February to mid-June; rainy season from mid-June to mid-October, and winter season from mid-October to mid-February (Rohwerder 2016). Due to varied geographical and climatic conditions, more than 100 indigenous and exotic species of fruits have been reported in Nepal (Regmi and Shrestha 2005). Similarly, more than 100 vegetable species are reported both in farmer's fields and in the wild conditions. Despite such a large agro-climatic advantage, Nepal remains a food deficit and nutrition insecure country. The vicious cycle of malnutrition in Nepal is persistent from children and adults to senior citizens and from one generation to the next (NLSS 2011). This cycle is associated with poverty and poor nutritious food availability, inadequate basic nutrition education and imbalanced food intake (NDHS 2016).

Fruits and vegetables are high value crops with the rich sources of dietary fiber, vitamins, minerals, electrolytes, phyto-chemicals, and antioxidants. United Nations General Assembly has designated 2021 as the International Year of Fruits and Vegetables (IYFV) (FAO 2021). The IYFV is a unique opportunity to raise awareness of the important roles of fruits and vegetables in human nutrition, food security, increasing income, and in achieving the UN Sustainable Development Goals. A balanced human diet consists of safe food stuffs with sufficient quintiles of carbohydrates, proteins, minerals, fats, and vitamins. Fruits such as papaya, pineapple, strawberry, mango, guava, banana, avocado, apple, apricot, peach, plum, etc., and vegetables like cole crops (cabbage, cauliflower, etc.), tomato, eggplant, okra, cucurbits, and green leafy vegetables must be included in the meal to meet all required nutrients. Vegetables like spinach, leafy salad (lettuce), cucumbers, turnips, sweet potato, radish,

cabbage, cauliflower, and onions are alkaline in nature so they can help in neutralizing acidity and cleansing the body (FNSP 2012). Fruits and vegetables are vital for healthy diets, but their intake in low-income countries including in Nepal remains lower than the recommended intake (400 g/day) by WHO for maintaining health and nutrition of the global population (WHO 2003). Low fruit and vegetable consumption is among the top-5 risk factors for poor health, with over 3.5 million deaths and 100 million Disability-Adjusted Life Years (DALYs) attributable to low intake of fruits and vegetables globally each year, and particularly in low-income countries (EAT-Lancet Commission 2019).

Fruits and vegetables are high value crops for income generation. In subsistence agrarian economy, promoting production, consumption, and marketing of fruits and vegetables can promote nutrition security and income generation. There is a wide range of flexibility in the selection of fruit and vegetable crop species by the people of all ecological regions of Nepal to increase income through commercialization and marketing. Commercial vegetable production and marketing give 3–5 times more income compared to traditional cereal crops from the same piece of land (HMG/FAO 1995; Katovich and Sharma 2014; Timsina and Shivakoti 2018).

Cultivation of fruits and vegetables can help achieve several Sustainable Development Goals (SDGs): (1) end poverty, (2) end hunger, (3) ensure healthy lives and promote well-being, (12) ensure sustainable consumption and production patterns, (13) combat climate change and its impacts, and (15) protect, restore and manage terrestrial ecosystems, combat desertification, halt reverse land degradation and biodiversity loss (United Nations 2016). These SDGs can directly be addressed by year-round production of fruits and vegetables in home and verandah garden and commercial production and marketing. Growing fruits and vegetables also improves the environment by increasing greeneries and helps in carbon sequestration (Maraseni et al. 2010; Thapa 2013). Both fruit and vegetable

crops are of high value and give better income compared to the traditional cereal crops (Kato-vich and Sharma 2014). The income generated from the sales of fruits and vegetables can provide multiple livelihoods needs of farmers such as ensuring food security and nutrition, meeting regular household basic expenditure needs and combating poverty and improving the life on land. Fruit trees protect terrestrial ecosystems, halt land degradation, and maintain biodiversity.

3.2 Objectives and Scope

The main objectives of the chapter are to (i) review current situation of research on fruits and vegetables and analyze variety release, registration, and seeds/sapling production and their availability (ii) assess status of fruit and vegetable production, import and export in the country (iii) analyze current gaps, issues and challenges in fruit and vegetable production and (iv) suggest potential interventions and recommendations to improve fruit and vegetable production for ensuring food and nutrition security.

3.3 Methodology

This chapter was prepared by using secondary data and information from various published and unpublished sources, especially those from Central Bureau of Statistics (CBS), National Planning Commission, Statistical Information on Nepalese Agriculture (MoALD 2019, 2020), research reports from various public and private agencies and donor funded projects (FAO 1995; FNSP 2012; CEAPRED 2014; FDD 2017; VDD 2018). In addition, information was collected from review of government plans and programs and other official documents. The study also assessed number and status of variety release and registration for different vegetable crops and fruits for the last three decades (SQCC 2020). To assess the annual average growth rates of area, production and yield of fruits and vegetables for the last 25 years (1995/96 to 2019/20), compound growth rate¹ analysis was carried out

using ordinary least square (OLS) regression technique. Compound growth rate is commonly used in agriculture as an indicator to assess area, production, and productivity (yield) growth (Chandran and Prajneshu 2004). The data collected from various sources were analyzed and presented in tabular and graphical forms.

3.4 Results and Discussion

3.4.1 History of Research and Extension Organizations for Fruits and Vegetables

The official record of fruits and vegetables research from local selection, introduction of exotic germplasm and variety development could be traced back to mid-nineteenth century. Horticulture section was established under the Department of Agriculture (DoA) in 1952 and initiated planned research and development on fruits and vegetables (Mallick 1982; Acharya 2019). From 1963 to 1972 separate Department of Horticulture carried out researches on horticultural crops establishing horticultural farms/centers at different ecological regions of Nepal (MPHD 1991; Acharya 2019). However, from 1972 to 1990, a single Department of Agriculture was responsible for agricultural research and development including horticulture. A commendable research and development took place in horticulture during 1972 to 1990 with the establishment of several horticultural farms, research stations, and centers in Nepal. During 1990/91, Nepal Agricultural Research Council (NARC) was established to give impetus in agricultural research (NARC 2019) and the horticultural farms/centers in the country were divided between NARC and DoA. The major fruits and vegetable research farms/centers such as Temperate Horticulture Station Marpha, Warm

¹Compound annual growth rate (CAGR) is the annualized average rate of growth (constant growth) over multiple years assuming growth takes place at an exponentially compound rate. This is commonly used in economics research and analysis.

Temperate Horticulture Center Kirtipur, Tropical Horticulture Center Sarlahi, Central Vegetable Development Center Khumaltar, Vegetable Seed Production Center Rukum, Vegetable Seed Production Center Dadeldhura, and Horticulture Farm Kritipur Farm/Horticulture Development Centre, Kirtipur were kept under DoA without research mandate. NARC got very few and less important horticulture farms/centers such as Horticulture Farm, Malepatan (Pokhara), Horticulture Farm Dailekh and Horticulture Farm, Vijayanagar (Jumla). As a result, fruits and vegetables research and variety maintenance was slowed down. However, recently with the limited farms/centers and limited human and physical resources the National Horticulture Research Center under NARC has initiated some research on fruits and vegetables.

3.4.2 History of Fruit Varieties Released and Registered

Release and registration of fruit varieties started only after 2015 despite research and development work started in the early 1960s. After 2015, only seven varieties of three crops mainly, lime, orange and banana are released and registered in different agroecological zones. These include release of three varieties of lime (e.g., Sun Kagati 1, Sun Kagati 2 and Terathum local) and one variety of mandarin (Khoku local). Three varieties of banana are registered which include: Willian hybrid, G-9 and Malbhog local. These are mainly released and registered for lower hills and Churia range from 700 masl to middle hills of 1600 masl. Major fruits cultivated in mountain regions such as apples and in Terai such as mangoes are not yet released and registered. Despite very limited number of official notification (released and registered) in fruit crops, there are many popular varieties that are being commercially grown in different agroecological zones and many of them are also found in wild state without much research (Thapa and Dhimal 2017). Fruit varieties are imported from India, China, USA, Japan, Italy, Turkey and other countries and are being cultivated in government

farms and private orchards. Many indigenous and exotic fruit varieties of mango, papaya, guava, apple, avocado, pear, plum, peach, pineapple, citrus, areca nut, litchi, etc. are being grown commercially and most of them are performing well but they are not registered/released to date (Shrestha et al. 2017; Thapa et al. 2017). The limited status of variety release and registration has hindered official promotion and commercialization of many indigenous varieties of locally popular fruit crops.

3.4.3 History of Vegetables Varieties Developed, Released, and Registered

Release and registration on vegetables started only after beginning of 1990s, though Government initiated research and development in vegetable sector since 1940 with the testing of some exotic and indigenous vegetables in Kathmandu Valley's Tahachal, Balaju, Singha Durbar and Godawari Nurseries (VDD 1993). Nepal started planned development from 1955/56 when the first five-year plan (1955/56-59/60) was implemented. From first to fifth plan (1975/76-1980/81), Vegetable Development Section under the DoA tested different indigenous and exotic vegetable germplasms and recommended for cultivation. During sixth to eighth five-year plans (1980/81 to 1994/1995), Fresh Vegetable and Vegetable Seed Production Project (FVVSP) funded by the Swiss Government through FAO worked in three phases as the counter part of Vegetable Development Division (VDD) of the Department of Agriculture of the Government of Nepal and identified 72 varieties of 30 vegetable crops (FAO 1995). With the establishment of NARC in 1990, variety development activities that was carried by VDD of the DoA was shifted to NARC. Based on the work done by VDD and FVVSP, Seed Quality Control Centre (SQCC) of the Ministry of Agricultural and Livestock Development (MoALD) released 35 varieties until 1995 (SQCC 2020). During 1980 to 1995 VDD with the support from the same FAO Vegetable

project evaluated 350 new germplasms of different vegetables collected from exotic and indigenous sources and 72 varieties were identified by 1991. Based on these research results, 35 vegetable varieties were released in 1995 (FAO 1995). From 1995 to date additional five new varieties were released and 13 registered including one hybrid tomato variety Sirjana by NARC (Gautam et al. 2020). NARC was put in low key in the process of vegetable varieties development including hybrids.

In recent decade with the liberal seed policy mainly after amendment of Seed Act 1988 in 2008, the participation of private sector increased in seed business with the introduction, testing, and registration of crop varieties (Gauchan 2019). To meet the increasing demand of high-quality vegetable seed including hybrids, private seed companies imported promising vegetable varieties from abroad, tested with the help of NARC, and registered for seed marketing in Nepal for commercial vegetable production. As per the record from SQCC (2020), a total of 314 varieties of 38 vegetable crops were released and registered (excluding de-notified ones) by 2020 that are developed and introduced by government and private sectors (Table 3.1). The list includes key vegetables excluding of potato and sweet potato.

Among total varieties officially notified (released and registered), 215 are hybrids and the rests are open pollinated varieties (OPVs).

Hybrids account for 68% of the total notified (released and registered) in Nepal. The share of released varieties account for only 13% of the total notified varieties. Since 2010 registration of varieties are introduced as a fast-track option requiring only two years field data with the liberal policy of introduction of registration provisions and requirement of relatively less research and requirement time (2 years) by the amendment of Seed Act 1988 (amended in 2008). Despite last 7 decades of initiation of vegetable research and 3 decades of variety release and registration process occurring in Nepal, analysis showed that about 95% of the notified varieties so far are of introduced from overseas (both exotic hybrids and OPV). To date only 5% of the total released and registered varieties are of local origin (domestic selection from local vegetables) to Nepal. These include green leafy vegetables such as broad leaf mustard (e.g., local Marpha and Khumal broad leaf), Kathmandu local cauliflower, and Pyuthane *rato* local variety of radish. This indicates poor state of domestic research in utilizing rich local indigenous genetic resources in the development of vegetable hybrids and OPVs and their release and registration to provide diverse options to farmers and entrepreneurs. Moreover, the recent introduction, registration and promotion of exotic hybrids without considering their performance and regular monitoring in farmers' fields has been

Table 3.1 Number of vegetable varieties released and registered in the last 3 decades (1990–2020)

Vegetable crop groups	Released	Registered	Hybrids	Total
Cruciferous vegetables	5	81	72	86
Solanaceous vegetables	7	48	44	55
Cucurbitaceous vegetables	6	87	78	93
Leafy green vegetables	6	20	5	26
Root and tubers vegetables	8	23	13	31
Leguminous vegetables	7	9	0	16
Others miscellaneous vegetables*	1	6	3	7
Total vegetables	40(13)+	274(87)+	215(68)+	314(100)+

Note The other miscellaneous vegetables* mainly refer to minor vegetables like asparagus and pakchop. The number in ()+ indicates percent of total notified (released and registered) varieties

Source Estimated from SQCC (2020)

displacing large number of local and indigenous ones.

3.4.4 Fruit Saplings and Vegetable Seeds Production and Supply Situation

3.4.4.1 Fruit Sapling Production and Supply Situation

Nepalese farmers were accustomed to produce fruit plants from seeds, cuttings, and runners from very ancient time. Production of grafted/budded plants started in 1960 when government farms came into existence. From 1960 to 1975 fruit saplings were produced in small quantities in government farms and major quantities were imported from India (NCFD 2020). In 1975 “Agriculture Year” was celebrated and huge quantities of saplings were imported and at the same year private nurseries were also established in different agro-ecological zones of Nepal. Both government farms and private nurseries are producing fruit saplings at the present. According to National Center for Fruit Development (NCFD), there are 21 Government owned horticultural farms and 375 private nurseries producing tropical, subtropical, and temperate fruit saplings. The NCFD Record 2020 shows that about 80% demand of fruit saplings are fulfilled by private nurseries and remaining 20% through the government farms and imported from abroad. The imported saplings were mostly high yielding

varieties of apple, kiwi, and walnut (NCFD 2020). The current focus of the Government is mainly on supply of exotic fruit saplings by direct importation from overseas rather than giving priority for local research and investment on production and distribution of locally adapted fruit saplings.

3.4.4.2 Vegetable Seed Production Trend and Estimated Demand and Supply Situation

With globalization and liberalization of trade process, import of vegetable seed is increasing rapidly. Though small quantities of seed import started since 1990, the trend increased from 2002 (Paudyal 2010), and especially hybrid seed import has been increasing during the recent decades. Vegetable seeds particularly hybrids are being imported from Japan, India, Thailand, Korea, and China. During the fiscal year 2018/19, Nepal imported 424.4 mt of vegetable seeds worth \$4 million (NCPVSCD 2019). Since 1975/76, vegetable seed production increased continuously in farmer’s field through contract production between farmers groups/cooperative and seed traders. Vegetable seed production in government’s farm is almost constant around 10 mt and it is decreasing during the recent years as farms/centers mostly concentrated in breeder’s and foundation seed production. Improved seed production by private sector is however increasing in farmer’s field with its share of less than 1% in 1975 to 99% in 2018 (Fig. 3.1). Until 1985, the country’s own seed production

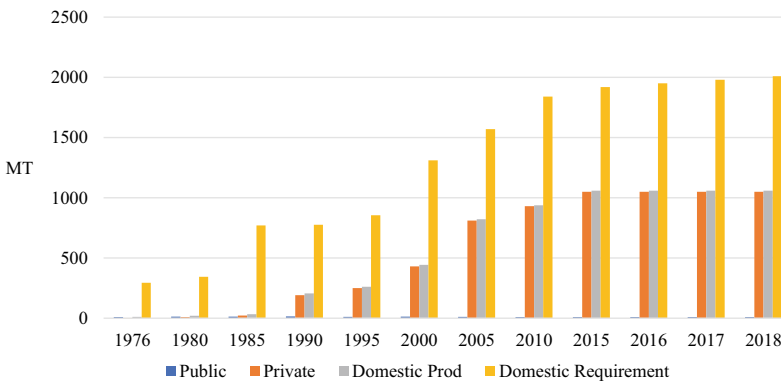


Fig. 3.1 Trend of vegetable seed production with domestic production and demand (1976–2018). *Source* MoALD (2021); CEAPRED/VSP (2014). *Note* The sum of public and private production includes domestic production

met almost over 95% of its demand. However, even though vegetable seed production has increased from about 300 mt in 1975 to about 1000 mt in 2018, it is meeting less than half of its demand in recent years. Currently half of the seed demand (1000 mt) is met by import. This indicates that there is growing demand of vegetables seeds due to increased shift of farmers toward commercial vegetable cultivation.

3.4.5 Trends of Commercial Production of Fruits

Fruits are long-term crops having gestation period from 3 to 5 years. Therefore, general area and productive area varies with lower proportion of productive area. The productive area mainly refers to actual fruit bearing area, i.e., area with mature fruits trees. Figure 3.2 provides area (ha), productive area² (ha) production (tonne) and yield (t/ha) of fruits. In the last 25 years total area and productive area of fruits has increased by about 190% from 41,016 ha in 1995–96 to 119,025 ha in 2019–2020 and the production has gone up by about 2405% from 367,490 tons to 1,249,764 tons (MoALD 2020). However, the yield of fruit remained stagnant around 9–10 t/ha with no growth in the last 25 years due to the poor orchard management, low use of improved technologies, loss by wild animal attack specially monkey, and post-harvest losses.

To understand the actual per annum growth of fruit area, productive area, production and yields of fruit, a compound growth rate analysis was carried out for the last 25 years (1995/96–2019/20) using ordinary least square regression technique that is commonly used in agriculture (Chandran and Prajneshu 2004). The analysis showed that area, productive area, and

production increased by about 4–5% per annum for the last 25 years (Table 3.2).

The growth was statistically highly significant ($P < 0.01$). However, the yield (t/ha) growth that was about 10 t/ha in 1995/96 it remained stagnant until 2019/20. This indicates that the increase in production is mainly due to the increase of the area under fruit trees over the same period from the several fruit productions programs of government of Nepal. The latest 2019 data show that the yield of citrus fruits (e.g., Orange) of Nepal (10.84 t/ha) is nearly half of the average yield of developed country such as Israel (18.62 t/ha) and that of China (18.57 t/ha) a neighboring middle-income country (FAOSTAT 2021). Therefore, there is a high potential to increase yield of fruit crops with the use of high yielding varieties and good management practices as further land expansion may not be possible.

3.4.6 Trends of Commercial Production of Vegetables

Commercial production of vegetables started after early 1990s with the adoption of liberal economic policies in the country. Emergence of private sectors particularly seed entrepreneurs (seed companies, Agrovets) and the emergence of non-governmental organizations (NGOs) and community-based organizations played important role in introduction, promotion, and commercialization of vegetable production programs in Nepal. The area (ha) production (tons) and yield (t/ha) of vegetables is presented in Fig. 3.3.

The data show that the area and production of vegetables increased by about 95%, from 144,368 ha in 1995/96 to 281,132 ha in 2019–2020 and the production increased by about 198% from 1,327,298 tons in 1995/96 to 3,962,383 tons in 2019–2020. Likewise, yield has also slightly increased from 9.19 t/ha to 14.09 t/ha during the same period (MoALD 2020). Table 3.3 presents that analysis of compound growth rate of vegetable area, production, and yield for the last 25 years using the ordinary least square regression technique that is

² The “productive area” refers area under productive fruit bearing trees, while “area” refers general fruit planted area that may have both young unproductive trees/saplings and matured fruit bearing trees. The “productive area” is therefore always smaller than general fruit planted area. The official statistics in Nepal provides both general “area” and “productive area” for fruit trees and “productive area” is used for estimating yield/ha (MoALD 2020).

Fig. 3.2 Trend of fruits production in last 25 years in Nepal

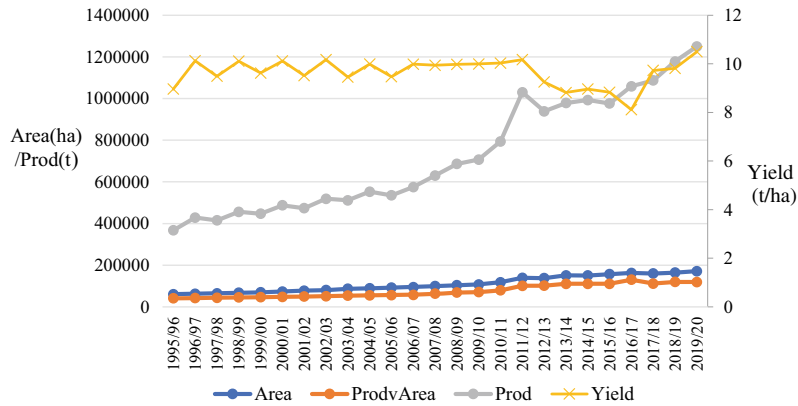


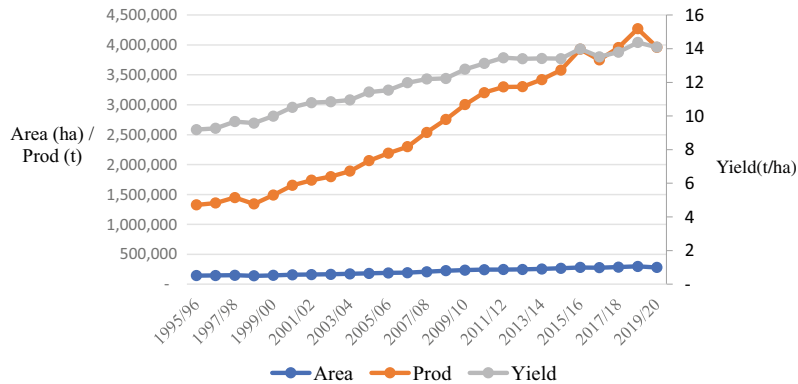
Table 3.2 Growth of area, productive area, and production of fruits in Nepal (1995/96–2019/20)

Statistical parameter	Area (ha)	Productive area (ha)	Production (tons)	Yield (t/ha)
Coefficient	4.69***	5.27***	5.08***	−0.17 ns
Standard Error	0.00123	0.00258	0.020557	0.016756
t-value	37.99	20.59	24.76	−1.05

Note Compound growth rate estimation using Linear Regression from log-transformed data

***, **, and * indicate 1%, 5% & 10% level of significance, respectively

Fig. 3.3 Trend of vegetable production in last 25 years in Nepal



commonly used in agriculture (Chandran and Prajneshu 2004).

The analysis revealed that per annum growth of area, production, and yield of vegetable is increasing at the rate of 3.44%, 5.35%, and 1.91% respectively in the last 25 years. The growth of production was higher (5.35%) while the growth of yield was lower (1.91%) per annum with lower level of current yield of 14 t/ha (MoALD 2020). This current yield of vegetable is lower than many developed countries

such as, Canada (26.08 t/ha) and that of China (15.87 t/ha) a northern neighbor of Nepal. For tomato, the current yield in Nepal is less than one third of the yield of China (57.98 t/ha) and Israel (63.53 t/ha) and one fifth of Canada (83 t/ha) (FAOSAT 2021). This lower growth in yield indicates that still there is potential to increase yield by using hybrids and improved high yielding OPVs with good management practices.

Table 3.3 Growth of vegetable area, production, and yield from (1995/96–2019/20)

Statistical parameter	Area	Production	Yield
Coefficient	3.44***	5.35***	1.91***
Standard error	0.00125	0.00177	0.00084
t-value	27.59	30.23	22.89

Note Compound growth rate estimation using Linear Regression from log-transformed data

***, **, and * indicate 1%, 5% & 10% level of significance, respectively

3.4.7 Trends of Import and Export of Fruits

Fruit trees, being long-term plantation crops, are specific to agro-ecological zones (MPHD 1991). Though, there is steady increase in area and production of fruits and vegetables, yet the import of fruits and vegetables are also increasing during last five years in terms of volume and values (Table 3.4). Similarly, the export of fruits has also been decreasing from 1612 tons in 2015/16 to 481 tons in 2017/18.

The volume of imports is high for all type of fruits but summer fruits (mango, banana, litchi etc.) import is much higher than other fruits in the country. However, the share in terms of values is relatively higher for import of winter fruits. A small volume of all types of fruits is also exported to other countries from Nepal. The import of fruits has increased nearly 76%, from 235,274 tons in 2013/14 to 414,744 tons in 2019/20, and the export decreased by 31%, from 1636 to 1120 tons during the same period. This rising import and declining export is mainly due to low yield of fruits which is hovering around 9–10 t/ha.

3.4.8 Trends of Import and Export of Vegetables

Despite increasing production and yield of vegetables, the import is in increasing trend in the last five years. The volume of import doubled (105%) from 424,144 mt to 870,644 mt and export increased by 32% from 12,015 to 15,956 mt over that period (Table 3.5). The increased import for vegetable is largely contributed by dry vegetables such as dry onion, garlic, mushroom, peas, gram, beans, kidney beans, broad beans, and other dried leguminous vegetables.

3.4.9 Assessment of Availability of Fruits and Vegetables

Nepal's estimated population during 2019 was 28.61 million. The production of fruits and vegetables in the same year was reported 1.17 and 4.27 MT respectively. Based on these figures the availability per capita fruits and vegetables per year from domestic production comes to be 41 kg fruits and 149 kg vegetables respectively. Based on the dietary research, 280–375 g of

Table 3.4 Import and export trends of fruits for the last five years

Year	Fruits by volume (tons)		Fruits by values (USD '000)	
	Import	Export	Import	Export
2013/14	235,274	1636	105,918	228
2014/15	189,158	1256	91,562	170
2015/16	190,979	1588	94,080	1612
2016/17	196,273	940	97,733	253
2017/18	414,744	1121	126,263	481

Source TEPC (2019)

Table 3.5 Import and export trends of vegetables for the last five years

Year	Vegetables by volume (tons)		Vegetables by values (USD '000)	
	Import	Export	Import	Export
2013/14	424,144	12,015	114,214	19,175
2014/15	449,335	20,650	108,743	2458
2015/16	413,987	16,481	104,822	5284
2016/17	525,352	12,565	146,772	9832
2017/18	870,644	15,956	165,832	9912

TEPC (2019)

vegetable and 100 g fruits are required per day (24 h food cycle) per average adult person (Acharya and Kc 2017). An average adult person needs different food components per day to balance the diet as prescribed by dieticians which includes carbohydrate, protein, minerals, vitamins and fats (DFTQC 1994). Based on these recommendations the annual requirements of fruits and vegetables come to be 36.5 kg fruits and 102–136.8 kg vegetables which seems sufficient from the reported domestic production. The fruit and vegetable imports during 2017/18 are reported to be 414,744 tons and 870,644 tons respectively. If these import figures are also added to the domestic availability, 55 kg fruits and 132–166 kg vegetables per annum per person seems available to the total population of Nepal. But there is a lack of assessment of data and information on post-harvest loss assessment of fruits and vegetables as estimates show that a large proportion of fruits and vegetables are lost during post-harvest handling and marketing which account for 20 to 30% for fresh fruits and vegetables that could exceed up to 50% of the total production for highly perishable fruits and vegetables (Devkota et al. 2014).

3.5 Challenges, Gaps, and Issues

3.5.1 Limited Information and Database in Fruits and Vegetables

Currently, there are poor information and database in fruits and vegetables for proper planning

and program implementation to ensure food and nutrition security of growing populations. The data on area, production, yield as well as the crops and varieties used in different agro-ecological zones and their suitability is lacking. There is also lack of assessment of data and information on post-harvest loss assessment of fruits and vegetables for proper planning for unavoidable import. The system of actual data collection from local level via province to national system is still lacking. Unofficial import of vegetable seed from India has posed a problem for critical analysis of real demand and supply of vegetable seed. The production and import data of fresh fruits and vegetables data are inflated and not reliable when analyzed critically for availability and consumption. Such data discrepancies are the main challenge for analysis, planning, and program development.

3.5.2 Institutional Gaps

Frequent institutional changes have hampered the smooth and continued functioning of research, education, and extension in fruits and vegetables. The recent restructuring and institutional linkages among federal, provincial and local governments have not yet been developed. NARC has not been restructured in the context of federalization. Horticulture research wing is weak and has no research linkages with universities and farm/centers under DoA (Kaini et al. 2020). The institutions involved in research, education, and extension are working independently without significant functional coordination and

collaboration, which is the most crucial institutional gaps in horticultural development sector in Nepal (Thapa et al. 2020). Poor linkage with international research institutions/universities for fruits and vegetables exists for research and germplasm exchange. National horticulture research center under NARC does not have a direct line of command to other NARC entities at provincial and local level. Furthermore, no adequate collaboration between private sector and public sector exists for promoting production, marketing, and business operation of fruits and vegetables.

3.5.3 Policy and Program Gaps

Fruits and vegetables include many crop commodities, and research and development needs vary for each fruit and vegetable crop commodity. Fruits are long-term crops and need long-term research period and specific procedures for variety registration and release. However, policy and specific programs for fruit research is lacking. Consequently, only little number of varieties are recently registered for commercial cultivation, despite their large demand in the production and marketing in the country. The low release and registration of fruit varieties are due to limited policy focus and priority given in scientific research and lack of adequate donor funding and private sector investment on fruit crops as they require long time to achieve results. In case of vegetables also policy is lacking for specific crop ecology requirements for diverse vegetables and their screening of many germplasms, their general and specific combining ability test for parental lines development and hybrid seed production. Moreover, concrete policy on hybrid research in vegetables is lacking to develop locally adapted domestic hybrids through public–private partnership as envisaged by the National Seed Vision 2013–2025 (MoAD 2013). Consequently, large numbers of exotic hybrids are imported and registered by private seed companies but programs for development and release of domestic hybrids are not the priority (Gauchan 2019). Such poor policy and programs are the

major gaps in research and development (FDD 2017; VDD 2018).

3.5.4 Investment in Research and Development Gaps

Presently most international funding support and national priority on budget allocations are given for cereal crops to meet immediate food security needs rather than on nutritional and health needs of the population and achieving SDGSs. Fruits and vegetables funding on research is in low priority. Current public investment in R&D for fruits and vegetables in Nepal is very low which is less than 20% of the total budget allocated for agriculture. Investment of the time of researchers and academicians is also not directed to carry out research on fruit crops. There are no funding and investment programs to use modern techniques of plant breeding to develop hybrids including biotechnology in fruits and vegetables. Government of Nepal also lacks strong political will and commitment for funding R&D in fruits and vegetables production to reduce imports, increase self-reliance, and meet nutritional needs of the growing population. Private sector investment and attraction is also very much limited in this sub-sector.

3.5.5 Human Resource Gaps

There is no team of different experts for fruit and vegetable variety development and maintenance in NARC. Due to insufficient human and physical resources endowment, there has been limited effort for selection and development of climate resilient and high yielding hybrid and open pollinated varieties in Nepal. Presently plant breeders lack adequate motivation and incentives to produce varieties based on farmers' changing needs. Lack of critical mass of professionals in fruits and vegetables research and poor linkages among research, extension and education systems are also hindering the development and dissemination of promising fruit and vegetable technologies. The present level of staff positions,

their deployment and disciplinary expertise are not sufficient to respond to the varietal and technological development as per the demand.

3.6 Conclusions and Recommendations

This study shows that though the growth of area and production of fruits and vegetables is increasing, the import of fruits and vegetables is also increasing rapidly in Nepal in recent years. This is due to the low yield of fruits and vegetables, release and registration of only a few high yielding hybrids and OPVs and increasing demand of fruits and vegetables in the country with increase in population and income growths, urbanization, and changes in food habits as a result of increased nutritional awareness. The major gaps, issues and challenges are due to the low policy priority given in R&D of these crops, poor institutional linkages and coordination among research, extension and education system, gaps in program formulation for promoting fruits and vegetables for nutrition security, and lack of adequate human resources in horticulture sector. In addition, specific constraints and disincentive in research and development in fruit crops occur due to their perennial nature of crops. Therefore, there is less policy, program and political priority for fruits and vegetables, despite they are being high value crops and give more economic return to the growers and agroentrepreneurs and contribute to income generation, livelihood improvement, and environmental conservation.

In the light of the huge agriculture trade deficit and country's comparative advantages in fruits and vegetable production, there is a scope of domestic production by increasing productivity and value chain development of diverse species of fruits and vegetables which would help reduce import and improve self-sufficiency. There is expanding demand for fresh fruits and vegetables in the local, provincial, and federal markets with the increase in population and income growth and awareness of the nutritional value of fruits and vegetables. The recommended actions to promote commercial production and marketing

of fruits and vegetables and combat the problems of food and nutrition insecurity are briefly outlined below.

3.6.1 Priority Fruits for Commercial Production and Marketing

Nepal has comparative advantages to grow diverse species and group of fruits (tropical, subtropical, and temperate) successfully in different ecological regions from lowland of Terai to mid hills and high mountains. Special priority should be given for mangoes and bananas as commercial tropical fruits in the country's hot valleys and plain areas, citrus fruits in mid-hill areas, and apples and other temperate fruits in high mountains. Especially, Jumla and Mustang apples have made their specific identity for their qualitative characters like size, color, flavor, juice, crispiness, and sweetness. Similarly, lime, mandarin and sweet oranges are extensively grown all over the mid hills for home consumption and commercial marketing. Likewise, peaches, plums, pear, and walnut are the other deciduous fruits that grow extensively as wild and homestead garden and have potential for commercial production. Persimmon, pomegranate, kiwi and dragon fruits are also showing commercial promise recently in many parts of Nepal. Special pocket package production and marketing programs of mango and banana in Terai and lower valleys, citrus in mid hills, and apple and walnuts in high mountains need to be promoted to increase their production, meet domestic needs, and reduce escalating import in the country.

3.6.2 Priority for Commercial Vegetable Production and Marketing

From the nutrition and income generation point of view more than a dozen kinds of different vegetables should be prioritized in terms of fresh and processed products as well as expanding

production of high value low volume temperate vegetable seeds due to country's ecological diversities. The diverse hills and mountain regions have comparative advantages to produce high value and low volume temperate vegetable seeds such as carrot, radish, broad leaf mustard, cabbage, cauliflower, etc. due to suitable climatic and soil conditions as well as natural barriers for maintaining purity and high-quality seeds. Some vegetable crops are affected by thermal induction (vernalization) and photoperiodic condition. The home garden and commercial production pockets for vegetables depend upon ecological belts, micro-climates, seasons and road accessibility for marketing. Commercial vegetable production in the accessible areas in the periphery of cities and along the north south and east west road corridors need to be expanded with production and linkage with major market centers. There is further need of strengthening of commercial production of vegetables in special pockets and zones by developing partnership between value chain actors. Furthermore, marketing linkage and management between producing farmer's groups/cooperatives and traders at destination market needs strengthening. Proper cool rooms and cool bots at production points and regular refrigerated van transport of produce from production point to the main markets will minimize post-harvest loss with the principles of "Make it cool and keep it cool" till it reaches to the consumer's basket. Trainings on production technology, plant protection, and soil test services for municipality technicians at the production area along with rapid residual test of pesticides before transporting the produce could be promoted for safe product marketing (Pandey et al. 2017; NCPVSCD 2019). Promotion of diverse species of fruits and vegetables including indigenous and neglected and underutilized species can help maintain both healthy diets and agrobiodiversity (Harris et al. 2022). Increased linkages and collaboration with relevant international research centers such as the World Vegetable Center (<https://avrdc.org/>) and universities in developed countries is essential for regular access of diverse species of new high yielding stress-tolerant varieties and technologies to increase production,

productivity, and improve resilience of the vegetable production system.

3.6.3 Promotion of Nutrition Gardens for Household Food and Nutrition Security

Fruits and vegetables are also to be prioritized for nutrition gardens³ at the household and community level for meeting food and nutrition security who have limited lands and options for commercial production (Suri 2020). Nutrition gardens can be promoted for year-round consumption of fruits and vegetables in both rural and urban areas, and hence they can be a sustainable model for providing food security and diversity to combat malnutrition at the household or community level. They can be in the form of home gardens, backyard/kitchen gardens, school gardens, community gardens, roof tops, and veranda gardens to produce and supply fresh fruits and vegetables to meet household and community food and nutrition security (Acharya and Kc 2017; Gauchan et al. 2013; Lal 2020). Governments at the local and national level can develop suitable policies and programs and incentivize to mobilize individual households and communities to promote these gardens by utilizing limited available lands and spaces in household and community level. Fruits and vegetables can be produced utilizing household and community wastewater and homemade compost and family labor utilizing both traditional system as well as use of high-tech protected system in poly house and green house round the year. Together with production technology, nutrition education for cooking, consuming, and preserving the produce for lean season must be combined. The residents of cities

³ Cultivation of fruits and vegetables in small pieces of land available in households is known as "Nutrition Garden". The nutrition garden ensures access to healthy diet with adequate macro and micronutrients at doorstep. This includes home gardens, kitchen gardens, school gardens, roof top gardens, and community gardens maintained in small area for meeting nutrition needs of the local people.

and towns and rural areas, who have limited land or no land for ground home garden, may go for rooftop and verandah gardens as well as maintain community gardens to grow vegetables and small sized dwarf fruits for household food and nutrition security (Thapa 2016; Pandey 2013). The home gardens, school gardens, roof top and community gardening may also be adopted for aesthetic amusement, environmental conservation, and meeting consumption needs. In these gardens, vegetables which give multi harvest for long time and grafted dwarf fruits like mandarin, peach, muntala (Kumquat), Japanese persimmon, dragon fruit, Pepino melon, etc., may be planted. Multipurpose Resource Nursery (MRN) establishment as local enterprise in the vicinities can ensure the supply of quality planting materials and growing media. Agriculture Knowledge Centers, government farms/centers and municipalities should identify progressive entrepreneurs and support to establish MRN. Such MRN should be established at least one in each present municipality ward. MRN can also be used as training venue for the new clients.

3.6.4 Policy and Institutional Reforms and Increased Investment in Horticulture Sector

Nepal must reform/amend the existing policies such as Agriculture Development Strategy and National Agricultural Policy or formulate and implement the new policies on integrated research, extension, and education in fruits and vegetables to contribute to food and nutrition security and generate rural income through local employment. Formation of high-level Research Coordination Committee (RCC) at the ministry level represented by NARC, DoA, Universities (TU and AFU), Nepal Academy of Science and Technology (NAST) and private institutions is needed to coordinate research at national level to increase the functional collaboration and avoid duplication. There is a need of revision of functional policies of horticulture farms/centers

belonging to NARC, DoA, universities and private sector and provide research mandate to all the farms/centers in all ecological zones to carryout research, variety development and maintenance and planting material production of fruits and vegetables under the supervision of RCC. Likewise, farms need to be developed as the center of excellence to demonstrate people to see ongoing research and developmental works and generation and demonstration of new technologies. For this an increased investment is needed in generating and releasing improved and high yielding hybrids and OPVs using native genetic resources, develop better crop management technologies, and building capacity of professionals to increase productivity and adapt to changing climate.

In the short term, favourable policies and programs to support modern technologies for production (e.g., precision and protected horticulture) and appropriate storage and post-harvest handling technologies employing good agricultural practices (GAPs) can increase productivity, reduce post-harvest losses, and enhance farm profitability. This will require increased partnership and linkages with the R&D organizations and private sectors for the better access to and scaling out modern technologies and innovations to increase production and promote commercialization. Specific focus should be given to generate reliable data and information system and increase linkages with international research centers and universities for collaborative R&D for facilitated regular access to new technologies and production practices to address changing market needs and adaptation to climate change. Enabling access to a wide range of fruits and vegetables through promotion of neglected and underutilized fruit and vegetable species, is essential to maintain both healthy diets and agrobiodiversity (Harries et al. 2022). A sound system of smooth, timely, and holistic information flow from local government to the provincial and federal government and their functional linkages need to be strengthened employing smart digital system and innovation.

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Potential for Citrus Export from Nepal to Tibet

4

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Abstract

Citrus production is important to the economy of the mid-hill areas of Nepal, bringing an estimated return of more than five billion rupees. However, the industry has been characterized by low profitability, with fragmented and short value chains delivering product of variable quality to local markets. This study adopted a critical case study approach based on information from actors in the current value chain. It explores the prospect for citrus export from Nepal to the Tibet Autonomous Region based on the foundation of a phytosanitary agreement between China and Nepal, which was effective from 13 October 2019. The study also describes the potential market in terms of price and volume and a potential supply chain in terms of actors and pathways, including production areas, trans-

port corridors and procedures for disease pest management, cold treatment disinfestation, and other phytosanitary protocols. Finally, policy recommendations are made to (i) allow small-holder farmers to participate in such a value chain, achieve higher profit, and improve livelihood security and (ii) support the nation to achieve sustainable development goals (SDGs) related to poverty, hunger, economic growth, and industry, innovation and infrastructure related to citrus export.

Keywords

Citrus export • Livelihood security • Phytosanitary • Small-holder farmers • Supply chain • SDGs

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4.1 Introduction

Citrus is a major fresh fruit globally. Global orange production for 2018/19 was estimated at 54.3 million tons, with annual production increased continuously over the last eight years (USDA 2019). Global mandarin/tangerines production was estimated at 32 million tons, with China contributing 22 million tons (USDA 2019). However, China still depends on imports for nearly 20% of the citrus consumption (USDA 2019). This situation opens an opportunity for Nepalese farmers and exporters to serve the Chinese market.

China is aggressively pursuing trade opportunities worldwide for fruits, often trading rights of import of some commodities for the right of export of others (Reporter 2019). Recent examples include: (i) an agreement on the export of melons from Brazil to China was finalized in November 2019 during the visit of Chinese President Xi Jinping to Brazil (Maxwell 2019); (ii) a Chinese delegation visited Chile in late 2019 to inspect citrus orchards and packhouses, a step toward protocol approval for export of citrus from Chile to China (O'Callaghan 2019b); (iii) In late 2019, Chinese inspectors monitored the Cambodian mango industry in terms of pest control and chemical pesticides use and recommended Cambodia to be eligible to export fruit to China (O'Callaghan 2019a).

A trade agreement unlocks the door to trade, but much further work is required to open and maintain a profitable trade. For example, an Australia–China free trade agreement which included rights of export of Australian citrus to China was enacted in late November 2014, in the 21st round of negotiations which spanned almost a decade (Qi and Zhang 2017). Australian citrus covers 28,000 ha of land involving 1,900 growers in the production of 715,000 tons of fruit (5-year average) worth AUD \$627 million (Plant Health Australia 2019). The value of Australian citrus exports to China increased from AUD \$202 million in 2014 to AUD \$435 million in 2018 (CitrusAustralia 2018). There is a certain drop off percentage (16% drop of oranges in 2019/20) export due to COVID-19 pandemic but Australian citrus producers have consistently worked at developing this export market, changing varieties, agronomic practices, and marketing strategies (Landline 2013). For example, Australian producer group regularly visits Chinese markets to monitor market status and quality standards to further develop strategies that maintain a higher price for their produce (O'Callaghan 2019c).

Citrus has been promoted as a cash crop for the mid-hill districts of Nepal, with the Lumle Agricultural Research Center active in this area in the 1980s. Among fruit trees cultivation in Nepal, citrus is a number one in terms of area coverage, production, and income for mid-hills

farmers. Citrus was cultivated in 42 districts with total land coverage of 46,412 ha, productive area of 28,406 ha, and annual production of 271,908 tons of fruit (MoALD 2020). Of this production area, mandarins cover 27,951 ha contributing 177,381 tons of production, while sweet oranges and lemon are cultivated on 6,646 ha and 1,114 ha, respectively, producing 43,061 tons and 6,075 tons of fruits respectively (MoALD 2020). This makes citrus the most cultivated and highest producing fruit crop in Nepal covering around 32% share in cultivation area and 37% in production. However, all production is consumed domestically, and all production occurs within a relatively narrow window of October to January. In consequence of this domestic consumption, increase in production results its price decline. This calls for an opportunity to export the product so that increase in production does not result in decline in price. A potential export market is Tibet—a proximate market—where a typical price for mandarins is NPR 200/ kg.

China and Nepal ratified an agreement in late 2019¹ that allows export of citrus from Nepal to Tibet on condition that phytosanitary measures are respected, especially in the context of the problem caused by fruit fly species and other diseases/pests. A National Preparatory Working Group (NPWG)² was also established to develop a protocol for the implementation of the agreement (MoALD 2019). China is also taking the problem of fruit fly species seriously in trade agreements with other countries. These agreements are briefly reviewed in this chapter, with treatments proposed that comply with these parallel agreements. Such an approach can avoid the need to invest in further research for the development of new protocols.

This Chapter also explores market and pricing details in Tibet, the likely treatment and transport

¹ https://www.fmprc.gov.cn/mfa_eng/wjdt_665385/2649_665393/t1707507.shtml includes the joint statement between the People's Republic of China and Nepal dated 2019/10/13.

² This NPWG group was formed in 2020 by the Government of Nepal, Ministry of Livestock and Agriculture Development to prepare an action plan for implementation of the protocol.

pathways, and costs to establish a likely return on investment and sustainable pricing on citrus fruit. With such information, this Chapter is expected to help National Preparatory Working Group, which was formed by Government of Nepal to prioritize and work on export trade. A critical case study approach is adopted, based on information from actors in the current value chain with the potential market in terms of price and volume. The potential is explored in terms of the actions needed to meet the phytosanitary conditions of that agreement, likely transport pathways and value chain actors and market size and value. It is also hoped that this information will inform growers and traders considering investment in such a trade and benefit relevant government agencies considering actions to facilitate such trade.

4.2 Livelihood Improvement and Sustainable Development Goals

Poverty alleviation directly targeted to disadvantaged groups often produces only a localized and relatively short-term benefit. In contrast, lifting economic activity of the whole population can have generalized and long-term benefit to rural peasant and disadvantaged groups. China offers an example of the success of such an approach.

The removal of barriers on international trade results in improved market efficiencies and thus increased economic output and improved livelihood security (Victor 2007). However, the removal of barriers can be initially disruptive if imports displace non-competitive domestic production. It is argued that in the longer-term economic effort shifts to sectors that are competitive in international markets, with efficiency of that sector improved by access to the best supply of inputs, whether that be domestic or imported. This improves the general welfare of the country (Victor 2007).

International horticultural trade has grown dramatically in recent decades, with notable increases in trade between South American and

African countries and the relatively wealthier northern hemisphere countries (Barrientos, Dolan, and Tallontire 2003; Olaitan et al. 2019). Such trade has contributed to livelihood improvement across the globe. Successful trade can result in improved rural economies and enhanced livelihood, but success requires correct choice of commodity and improved practices in horticulture value chains that deliver product quality at reasonable prices (Kumar and Gupta 2015).

A useful example is provided by the Swift Co., Ltd. group in Thailand as a sustainable fresh produce business practice (Suthavivat 2018). A group of managers out of the airline industry in Thailand established grower groups focused on air freight export of asparagus and mango fruit. The increased profit from the export markets supports a range of benefits to the small producers as part of ethical business.³ They have also managed to maintain a traceability system even if the produce is gathered from group contract farming (Deyi 2005).

A similar grower co-operative model could be used to support citrus export from Nepal, with the aim of higher returns to Nepalese citrus enterprises. This aim addresses SDG goal 1, poverty reduction, hunger (goal 2), economic growth (goal 8) and is relevant to industry innovation and infrastructure (goal 9) (Stevens and Norichika 2016; Liu et al. 2015).

Nepal has two neighboring countries each with populations over 1 billion. At present export of citrus product (fruit, fresh or dried) to India is valued at only \$USD21,000 (<https://trendeconomy.com/data/h2/Nepal/0805>; doa 21/07/2021), and no citrus is exported to China. Citrus export to India is problematic as India produces citrus in the same period of the year as Nepal. Though, Nepal exports citrus through formal and informal sources, Indian market does not entertain a huge quantity of export either it be citrus, other fruits or vegetables. In addition, the official export channel is not open with distinct protocols in place compared to China which have specific protocols and clear description

³ <http://www.thaifreshproduce.com/en/company-overview/ethical-business/>.

in place. This chapter focusses on prospects for citrus trade into Tibet, China.

4.3 Prospects of Nepal to China Citrus Trade

China is a major importer of citrus. The import of citrus to China is expected to exceed export by 4,650,000 metric tons (Chunjie 2000) by 2030 AD (Table 4.1). In recent years, with the increase of disposable income of Chinese residents and the increase in the living standards, Chinese quality of life has also risen steadily, subsequently the demand for fruit continues to increase. Data shows that in 2020, China's citrus market demand was 48.22 million tons with average yearly increasement rate of 10.91% (Table 4.1). The China Commercial Industry Research Institute predicts that the market demand for citrus in China will reach 51.568 million tons in 2021 (data not shown). Liu (2000) reported that the per capita demand of total fruit, apple, and citrus in China in 2015 was 60.0, 16.0, and 11.7 kg per person per year with total demand of 87.1, 23.2 and 17.0 million tons, respectively. The per capita demand was projected to increase to 93.6, 20.0 and 16.0 kg per person per year with total demand of 149.8, 32.0 and 2.56 million tons, respectively in 2030.

China is a potential market for Nepalese citrus fruit. Goods can be exported to China from Nepal through India, transiting by sea via the Indian port of Kolkata. However, custom issues and shipping time have precluded such export.

The direct export of Nepalese citrus to neighboring Tibet region is a more achievable goal. Under the “Protocol on Implementing the Agreement on Transit and Transportation between Nepal and China” (MoALD 2019) which became effective in February 2020, Nepal can export through six dedicated transit points between Nepal and Tibet. Also, an MoU was signed between Nepal and China on the 13 October 2019 to undertake a “Feasibility Study of China–Nepal Cross-Border Railway Project” (Pandey 2020). These agreements are indicative of increasing trade prospects.

Nepal boasts a comparative distance advantage in the supply to the Tibet market, even relative to the citrus production areas of China. Tibet has negligible citrus production and relies entirely on the import. While Tibet is a modest market, with a population of approximately 3.3 million, the major urban centers hold market promise, with a population of around 1 million in Lhasa and 0.7 million in the Shigatse area. Within the population, relatively well paid ethnic Chinese government employees and military and a rising middle class are target markets for a slightly more expensive product offer (Fischer 2011).

Table 4.1 Estimated balance of fruit supply and demand in China (units of 10,000 ton)

Fruit type	Items	2015 Actual	2016 Actual	2017 Actual	2018 Actual	2019 Actual	2020 Actual
All fruit	Consumption	24,654	24,441	25,337	25,904	27,665	28,956
	Production	24,525	24,405	25,424	25,688	27,401	28,692
	Difference	129	36	−87	216	264	264
	Share in Demand	0.52	0.15	−0.34	0.83	0.95	0.91
Citrus	Consumption	3547	3527.7	3786.3	4093.1	4539.8	4822.5
	Production	3617.5	3591.5	3816.8	4138.1	4584.5	5121.9
	Difference	−70.5	−63.8	−30.5	−45	−44.7	−299.4
	Share in Demand	−0.02	−0.02	−0.01	−0.01	−0.01	−0.06

Source China Business Intelligence Network (<https://www.163.com/dy/article/GN07PV2P051481OF.html>)

At the consumption rate of 2015, the annual market for citrus in Tibet would be around 8,190 metric tons for Shigatse, 11,700 metric tons for Lhasa, and almost 38,610 metric tons for Tibet as a whole. This amount is equivalent to 15% of the current citrus production of Nepal; 246,269 MT in 2017 (Knoema 2020).

4.4 Nepal–China Phytosanitary Agreement on Citrus

A phytosanitary trade agreement for the export of citrus from Nepal to Tibet was first enacted in 2012. This protocol was the first such agreement entered into by Nepal government for the export of agriculture products with another government, and therefore presents a model for establishing similar specific trade agreements for other products.

This agreement lapsed at the end of its two-year life. No exports occurred in this period. The agreement contained a clause requiring “the fruit (to be) from an area free of pests and diseases” (Table 4.2). This condition could not be met as the listed pests, including the fruit fly species, *B. dorsalis*, *B. zonata*, *B. cucurbitae*, *B. tsuneonis*, and *B. correcta*, are endemic in citrus production areas of Nepal. Various protocols were developed for survey and surveillance of disease and insect pests, orchard management, pest control, farmer, and orchard registration.

A new agreement (MoALD 2019) was signed on 13th October 2019 during the visit of Chinese president Xi Jinping to Nepal. This agreement allows for the export of “pest-free product”, i.e., the product and not the production area must be free of designated pests, with the product to be from designated production areas and pack-houses practicing control measures. The agreement is set to automatically extend in its current form unless the parties enter negotiations for alterations.

The agreement, however, does not stipulate the disinfestation treatments to be used for elimination of the listed pests. These conditions must therefore be proposed to, and agreed by, Chinese authorities. The Nepal–Tibet agreement

involves the same fruit fly species as is covered in the China–Mexico, Pakistan–China, and the Egypt–China agreements (Table 4.2).

4.5 The Phytosanitary Rationale for Chinese Requirements

Citrus greening disease (or yellow dragon disease), citrus canker, and several fruit flies listed in Nepal–Tibet agreement are already present in China, including the Chinese provinces neighboring Tibet. *Bactrocera dorsalis* and *B. minax* are present in the neighboring provinces of Sichuan and Yunnan (Biosecurity Australia 2009) (Fig. 4.1). *Bactrocera cucurbitae* and *B. correcta* were recommended to be monitored in Yunnan (a neighbor province to Tibet), Guangxi, Hainan, and Guangdong provinces (Qin et al. 2015).

The pests included in the Nepal–China agreement are unlikely to occur in Tibet, given its climate. *Bactrocera dorsalis* and *B. minax* are reported as not present in Tibet (CABI 2019). The possibility of the establishment of fruit fly in three low altitude pocket areas in Tibet of relatively milder climate was considered (Yu et al. 2011), with Chayu (900 km east of Lhasa) being reported as a moderately suitable district for the fruit fly species *B. zonata*.

Given that these pests and diseases occur in China and are unable to establish in Tibet, the requirement for product free status in the Nepal–Tibet trade agreement could be questioned in future negotiation rounds.

4.6 Treatments for Fruit Fly Control

Conditions (cold treatment durations) are slightly harsher in the China–Mexico agreement than the Egypt–China agreement (Table 4.3). Nepal should propose the conditions of the Egypt–China agreement for the Nepal–Tibet trade because of lower holding day (only 16 days) requirement in this agreement compared to others.

Table 4.2 List of pests and diseases included in various phytosanitary agreements for the export of citrus fruit to Tibet/China

Pest/disease	Nepal to Tibet 2012 (<i>Citrus reticulata</i> , <i>C. sinensis</i> , <i>C. limon</i>)	Nepal to Tibet 2019 (<i>Citrus reticulata</i> , <i>C. sinensis</i> , <i>C. limon</i>)	China to Mexico 2014 (<i>Citrus reticulata</i> , <i>C. sinensis</i> , <i>C. hybrids</i> , <i>C. maxima</i> , <i>C. grandis</i>)	Egypt to China 2006 (Citrus fruits)	Australia to Thailand 2011 (<i>Citrus reticulata</i> , <i>C. sinensis</i> , <i>C. limon</i>)	Pakistan to China 2005 (<i>Citrus reticulata</i> , <i>Citrus sinensis</i>)
<i>Xanthomonas spp. pv citri</i>						
Citrus greening disease						
<i>Bactrocera correcta</i>						
<i>Bactrocera cucurbitae</i>						
<i>Bactrocera dorsalis</i>						
<i>Bactrocera tsuneonis</i>						
<i>Bactrocera zonata</i>						
<i>Bactrocera minax</i>						
<i>Bactrocera tryoni</i>						

4.7 Potential Market

The main potential markets for citrus in the Tibet region are the urban areas, which are relatively close (848 km) to the Nepalese border. The population of the urban region of the capital Lhasa is approximately one million. Shigatse, which is on the Nepal to Lhasa transport corridor, holds a population of 0.7 million. Lhasa has a large resident population of Han Chinese who fill

government and military roles. The potential for premium pricing for the more affluent local middle class and higher paid ethnic Chinese government workers and military should be explored.

Trade border between Nepal and Tibet was not regulated until early 1960s (the Sino–Nepal boundary agreement was enacted on 21 March 1960). Nepalese citrus fruit was transported through the border crossing at Zhangmu to Lhasa and other parts of Tibet. According to a trader who was involved in that trade (Buddha Ghising,

Fig. 4.1 Distribution and potential establishment areas for *Bactrocera dorsalis* in China. Source Biosecurity Australia (2009)

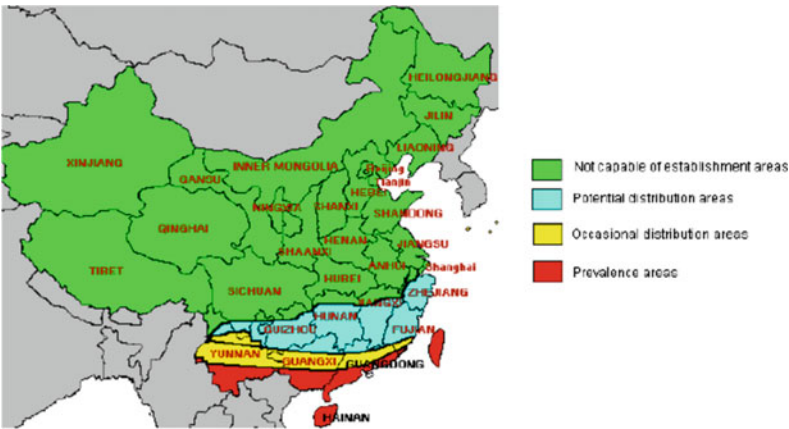


Table 4.3 Cold treatment temperature ranges for fruit fly in citrus, as stipulated in trade agreements

Protocols	Temperature range (°C)	Duration (Days)	Fruit fly species
Egypt–China (2006)	< 0	10	All economically significant Tephritidae fruit flies (<i>Bactrocera zonata</i> included)
	0–0.55	11	
	0.55–1.11	12	
	1.11–1.66	14	
	1.66–2.22	16	
China–Mexico (2014)	<1.11	14	<i>Bactrocera correcta</i> , <i>B. cucurbitae</i> , <i>B. dorsalis</i> , <i>B. tsuneonis</i>
	1.11–1.67	16	
	1.67–2.22	18	
Pakistan–China (2005)	<1.67	17	<i>B. zonata</i> , <i>B. dorsalis</i> ,
	<2.22	22	
Australia–China (2017)	<1.00	16	<i>B. tryoni</i> , <i>Ceratitidis capitata</i> , Queensland fruit fly, (total 20 pests of quarantine concern for China) 3° for 16 days is valid only for lemons
	<2.10	21	
	<3.00	18	
	<3.00	16	
Nepal–China (2019)	n/a	n/a	All five species mentioned above in Egypt–China, China–Mexico, Pakistan–China protocols

pers. comm.), competition with fruit from mainland China came after the railway between Xining and Lhasa came into operation in 2008. Nevertheless, Nepalese fruit always achieved a minimum price of 5 RMB per kg (NPR 100 per kg).

A market study tour visited the markets of Shigatse and Lhasa during the period 13–19 December 2013 (DMEGA, Parbat 2013). The Lhasa market price for citrus was recorded at 16 Yuan (260 NPR; 3.33 AUD)/kg for seedless

and half that price for seeded fruit. A price of 12 Yuan (195 NPR; 2.5 AUD), 10 Yuan (162 NPR; 2.07 AUD), and 8 Yuan (130 NPR; 1.66 AUD)/kg for Nepalese A, B, and C grade seeded citrus, respectively, was recommended. The 2020 market prices for oranges in Beijing are 3.96 Yuan per 0.3 kg bag (13.18 Yuan/kg) (Numbeo 2020). A trader based in Lhasa, contacted in August 2021, reported citrus fruit remains the most popular fruit in Tibet, with

around 300 tons traded per day in the Lhasa market at a typical price above 5 RMB/kg. It was also noted that premium price was paid for 60–80 mm diameter citrus fruits. According to the trader, the Nepalese fruit were larger than the fruit from mainland China, providing opportunity for export into Tibet. It is recommended that the Nepal embassy in Tibet collect seasonal prices and volumes of citrus sales in Lhasa and Shigatse.

4.8 Treatment Options

To meet the phytosanitary conditions in the Nepal–China agreement, the product must be treated to be fruit fly free. The Agreement does not specify treatments; it only states that “the treatment should be done according to international standards”. Methyl Bromide fumigation is a short and effective fumigant (for an example protocol see DAF 2015), but this treatment is being phased out worldwide due to the toxicity of the chemical. Low-temperature treatment (Table 4.3) may be presumed to be acceptable under the Nepal–China agreement.

Mandarins and lemons are considered “soft” citrus, being less tolerant of low-temperature conditions compared to sweet oranges. In Australia, mandarin fruits are held at 2.5–3 °C for 16 days to achieve fruit fly pest-free status for the product. Mandarins from the southern cooler regions are cooled directly to 2 °C whereas fruit from warmer northern regions are initially held at 7 °C for 24 h and then cooled to 2.5–3 °C. Mistakes made in the de-greening process, in terms of holding fruit at higher than recommended temperatures or ethylene levels, render fruit more vulnerable to chilling compared to fruits de-greened with 5 ppm ethylene at 24 °C (*pers. comm.* Noel Ainsworth, DAF, Australia).

The procedures used in Australia to bring the fruit temperature down are recommended for use in Nepalese export to Tibet, i.e., fruit should be brought to 7 °C for approximately 24 h to cold harden, then chilled to 3 °C within 48 h. This would normally be done in a forced-air chilling room (Rao 2015). The design of a typical forced

air cold room is described by Ferrua and Singh (2009). A typical establishment cost for a unit capable of holding fruit equivalent to two 20 ft shipping containers is AUD\$4600 (HomeGuide 2020). If this facility is lacking, modest volumes of fruit could be treated using an ice water bath.

After reaching 3 °C, fruit can be moved to shipping containers (Fig. 4.2) to hold this temperature for the required treatment period of approximately 16 days (Table 4.3). Refrigerated shipping containers can hold temperatures as low as –20 °C, however, the product entering container must already be at the desired temperature, i.e., the container cannot lower the temperature of the product. Given the use of a forced-air chilling room treating two shipping containers of fruit every 48 h, use of 16 shipping containers is recommended, with loading of two containers every second day for a 16-day treatment period.

The major running cost of such a facility is electricity. The electricity required to maintain a 120 m³ cold room at 7 °C for approximately 24 h and 3 °C for 48 h is estimated at 149 kWh/day (Evans 2017). At a cost of AUD\$0.15/kWh, this is a cost of \$7.44 per container per day or AUD \$0.00075 per kg of fruit per day. The electricity required to operate a 20 ft shipping container at 3 °C is estimated at 50 kWh/day (Evans 2017). At a cost of AUD\$0.15/kWh, this is a cost of \$120 per container over a 16-day holding period or AUD\$0.012 per kg. The total electricity cost for cold storage treatment is thus estimated at AUD\$0.012/kg.

Internal fruit temperature should be logged using an insertion thermometer (e.g., Instrument Choice 2020). To comply with Nepal to Tibet agreement, temperature records would need to be maintained and subject to an on-site inspection by MOALD/PQPMC assigned quarantine officers.

4.9 Transport Options

There are six entry points to Tibet from Nepal, but only two are suitable for substantive vehicle traffic. These crossing points are at Tatopani and Rasuwagadhi (Fig. 4.3). Dry ports are under



Fig. 4.2 Right panel: refrigerated container (20ft) capable of holding 24 tons of fruit. Left panel: insertion thermometer with data logger

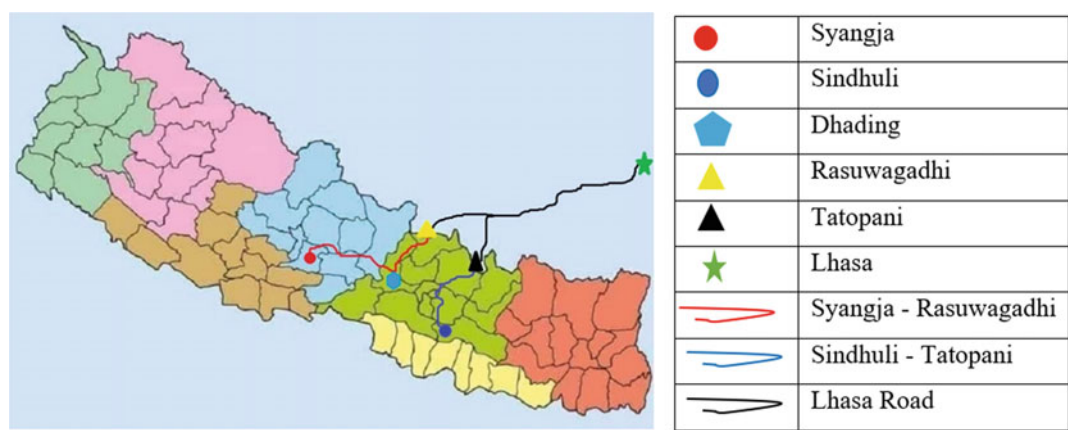


Fig. 4.3 Main citrus production areas (Syangja and Sindhuli) and border exit points (Rasuwagadhi and Tatopani) to Lhasa, Tibet. Map source: Google maps (2020)

construction at both crossing points. At Rasuwagadhi, the 8.5 ha dry port will have parking space for 350 trucks and associated containers, with 5000 m² land set aside for a five-story administrative building (quarantine office, customs office, banks, and post office). Two customs clearance areas on 2080 m² land with a 750 m² warehouse are included in the plan (Devkota 2019). The dry port construction was slated to be ready by May 2022, but the work is

on hold⁴ due to COVID-19 outbreak. For citrus from the Syangja production area, both routes present a similar distance, at ≈1289 km via Galchhi-Rasuwagadhi and ≈1234 km via Kathmandu-Tatopani. For Sindhuli citrus, the Tatopani route is shorter, at 1050 km (Fig. 4.3).

⁴ <https://kathmandupost.com/money/2021/03/19/construction-of-rasuwa-dry-port-on-hold-since-virus-outbreak> provides information related to the pause in dry port construction due to COVID-19 outbreak.



Fig. 4.4 An example of a fruit flies netted pallet from Profresh⁵ and labeled carton ends from Syangja (2015) providing information on variety and source

With an existing trade imbalance, many trucks importing goods from China to Nepal return empty to the border. Trucks are closed bodies, with goods protected from sunlight and rainfall, but there is no use of refrigerated containers. There is a large trade in apples from China through Tibet into Nepal and India, and the use of these trucks in backloading citrus from Nepal to Tibet should be considered (*pers. comm.* Mr. Buddha Ghising; an importer, and Mr. Bharat Khanal; a fruit wholesaler/supplier in Kathmandu).

During the Nepalese citrus production season, temperatures in Tibet ranges from -1°C (average night temperature) to 15°C (average daily high temperature). These minimum temperatures could lead to citrus fruit damage if the non-insulated trucks are left parked for prolonged periods. Transport should be arranged to avoid overnight parking, or insulation should be added to truck sidewalls.

The location of a cold treatment facility is critical in terms of its sustainability and secondary utility for crops other than citrus. The site must also have continual electrical power supply. With Nepal Electricity Authority (NEA) now able to supply power without load shedding, this should not be a problem in any location across Nepal.

A potential site for a cold treatment facility is in Dhading in the Galchhi area (Fig. 4.3). This is a major vegetable producing area, with potential for the cool store to serve both industries. Vegetables such as cauliflowers, cabbage, radish, carrot, and

peas could be stored during the peak season to supply into shoulder seasons, i.e., over the window of February–August, achieving higher prices for producers. Usage for the citrus season would involve the months October to February.

An alternative is to place a relocatable cold treatment facility in the production areas of Syangja and Sindhuli for the duration of the citrus season. Another alternative is to place a transportable treatment facility at the border, with seasonal relocation of the facility to vegetable production areas.

If the treatment facility is at the border, in areas free of the fruit fly, boxed fruit could be moved from refrigerated containers to transport trucks in the open place. However, if the treatment facility is in an area known to the harbor fruit fly, the fruit will need to be in fruit fly proof netted boxes or pellets, allowing for safe transport from the treatment facility to the border (Fig. 4.4).

Fruits should be transported in cardboard cartons to allow for the labeling required under the Nepal–Tibet agreement (Fig. 4.4). An AusAID Public Sector Linkage Project (PSLP) implemented through the Micro-Enterprise Development Program (MEDEP) sponsored the local production of such cartons in 2015 (PSLP, 2012–2016). The production of such cartons was undertaken in Pokhara by Goshali Print Pack Pvt. Ltd.

⁵ <https://www.profreshsystems.com/pallet-wrapping-systems> provides details on pallet wrapping systems.

Recent years the province and local governments also supporting growers and traders through flagship Prime Minister's Agriculture Modernization Project by supplying carton packs for packing for domestic transportation.

4.10 Nepalese Phytosanitary Arrangements

Officers assigned by the Ministry of Agriculture and Livestock Development (MOALD), Plant Quarantine and Pesticide Management Center (PQPMC), and Department of Agriculture (DOA) are responsible for the implementation of the phytosanitary conditions of the Nepal–China agreement. Therefore, PQMC should be in regular and direct communication with the Chinese phytosanitary counterpart to confirm a clear understanding of required arrangements. The National Plant Protection Organization (NPPO) should also have regular contact with its counterpart in China.

Nepalese government-certified phytosanitary officers will need to be available to inspect and sign off on documentation at the treatment facility. This could involve the inspection of two containers of product and temperature records every second day, i.e., a very part-time role. MOALD/ PQPMC should establish the cost of this service and decide if this cost will be borne by the Government or by exporters. If the latter, a charge per container should be set, to allow for exporters to factor this cost in when estimating the viability of the trade.

Site visits of proposed production areas, packhouses, transport, and treatment facility design by the Chinese phytosanitary group should be set before each citrus season.

4.10.1 Preparatory Documentation

The following documentation is required in support of a visit by a Chinese phytosanitary group:

- List of proposed registered infrastructures (orchards, packhouses, storage facility, cold treatment facility, transport vehicles)
- Standard Operating Procedures (SOP) for grower registration, packhouse registration, farm and packhouse inspection
- Surveillance report and integrated pest management documentation
- Training and certification of PQPMC officers to issue a phytosanitary certificate
- Phytosanitary certificate issue.

4.10.2 Standard Operating Procedures (SOP)

SOP for Packhouse registration and grower registration by packhouse:

A Packhouse must demonstrate the following processes are in place to be accredited for export:

- (a) Maintenance of a list of growers supplying the product, with name, phone contacts, geolocation (latitude/longitude).
- (b) Provision of training provided to these growers on orchard health and hygiene (e.g., training manual).
- (c) A system at Packhouse for visual inspection of all fruit and all fruit surfaces, e.g., rolling of fruit along with a table, with the removal of all defect fruit, augmented by inspection aids (posters with images of fruit with various disorders).
- (d) A system for training of grading staff.
- (e) Evidence that staff can recognize diseases and pests.
- (f) Maintenance of shed hygiene: removal of waste fruit, separation of graded export quality fruit from other fruit.
- (g) Labeling of the export product with grower and Packhouse details (as in Fig. 4.4).
- (h) Procedure to notify PQPMC of intent to ship when accredited shed has product ready.

⁵ <https://www.profreshsystems.com/pallet-wrapping-systems> provides details on pallet wrapping systems.

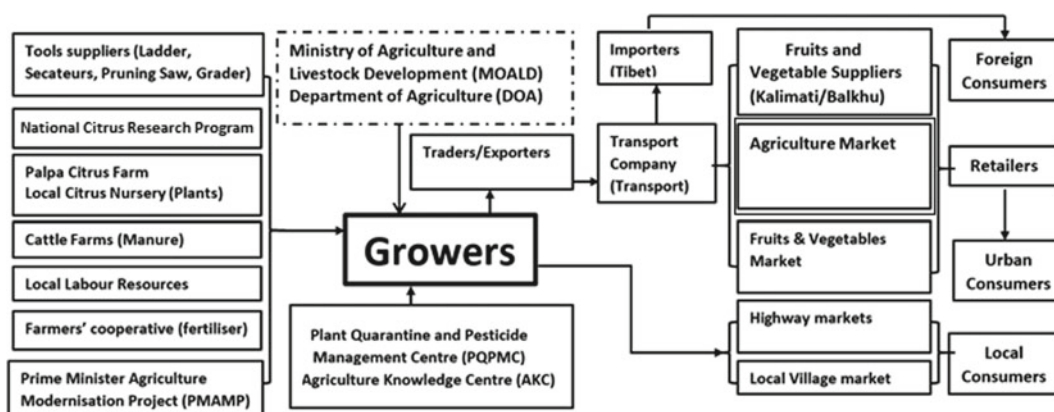


Fig. 4.5 Value chain actors in Nepalese citrus value chain including a potential chain of citrus export to Tibet (Source Own sketch based on Ahmad et al. (2018))

4.10.3 Responsibility Allocation

A Nepal to Tibet citrus value chain would contain the following main actors: (i) growers; (ii) packhouse/co-operative; (iii) transport company; (iv) trader; (iv) government agencies involve in pest inspection and certification; (v) cool room suppliers/maintainers and others associated with the supply of citrus production, promotion, and marketing accessories. A summary of the citrus value chain actors is presented below (Fig. 4.5). Packhouse/co-operative would assist small growers with management tasks.

4.10.3.1 Growers

- Orchard registration with packhouse/cooperative
- Documented integrated pest management with packhouse/cooperative support
- Implementation of integrated pest management Export quality fruit production.

4.10.3.2 Packhouses/Cooperatives

- Assist growers
- Registration for export
- Documentation (packhouse & orchards supplying fruit)
- Packaging and labeling requirements
- Truck/Container loading.

4.10.3.3 Government of Nepal, Ministry of Agriculture and Livestock Development Plant Quarantine and Pesticide Management Center/, Department of Agriculture

- Communication with China phytosanitary office,
- Support area-wide pest management plans,
- Orchard inspection and Packages of Practices verification.
- In-season requirements.
- Cold treatment consignment sample inspection and phytosanitary certification,

4.11 Cost–benefit Analysis

Most critically, financial analysis of cost of production, transport, and export marketing from Nepal to Tibet is important, to support (or discourage) private investment. This will also help to account for specific costs of production, transport, storage, treatment, handling, export

Table 4.4 Cost–benefit analysis of proposed citrus trade

Particulars	Cost (NPR/kg)	Remarks
The current cost of production	9.0	Subedi et al. (2008) reported NPR 4 for the cost; with adjustment for inflation
Loading for extra work and disease control 20%	1.8	
Packhouse costs including cartons	8.5	Syangja carton cost around NPR 80 for 10 kg size
Transport	6.0	Including Tibet transport cost
Cold treatment	1.0	assumption based on other calculations
Phytosanitary inspection	0.2	Government could subsidies, otherwise minimum cost for growers
Total cost	26.5	
Proposed sale price	210.0	Current value ⁶
Gross Profit	183.5	
Taxes	27.5	Assuming 15% taxes
Net Profit	~ 156.0	

taxes, and other unknowns. A tentative estimate of the cost–benefit analysis for a per kg of mandarin orange showed that it is highly beneficial to export mandarin in Tibet (Table 4.4). An average Nepal market sale per kg of citrus fruits is around NPR 56, which sets an extra income of around NPR 150 per kg of fruits if exported to Tibet at current market price in Tibet (12 RMB/kg). The estimated net benefit from exporting citrus by deducting cost, transport, treatment, packaging, phytosanitary inspection, and export tax is NPR ~156/kg. This is an overwhelming price and benefit for small-holder growers and Nepalese traders if proposed trade of citrus is implemented timely and effectively to improve the livelihood status of the people living in mid-hill region.

4.12 Conclusions and Policy Recommendations

Citrus production has provided a cash flow to the mid-hill farmers of Nepal. There is potential to improve returns through export of product to

Tibet, given proximity of this market relative to production areas in China and based on the foundation of the phytosanitary agreement between China and Nepal allowing such export.

The potential market is described in terms of price and volume. A potential supply chain is described in terms of actors and pathways, including production areas, transport corridors and procedures for disease pest surveillances, management, cold treatment disinfestation, and other phytosanitary protocols. Key requirements for such a value chain include (i) development of packhouses with management skills to support grower groups achieve pest management and related documentation, to implement sorting procedures and cold treatment procedures, (ii) development of transport options, ideally involving back-loading of trucks delivering goods into Nepal from Tibet, and (iii) development of a phytosanitary certification service by MoALD. To catalyze investment into development of this value chain: (i) a system of recording citrus prices in Tibet is required, perhaps collected through the Nepalese consulate in Tibet; (ii) the proposed pest management and certification procedures should be communicated to and agreed upon by the Chinese authorities.

The estimation of cost–benefit analysis of citrus trade from Nepal to Tibet revealed that it is

⁶ https://www.numbeo.com/cost-of-living/country_result.jsp?country=China includes price of oranges around 12 RMB per kg, conversion rates applied.

highly beneficial to export citrus from Nepal to Tibet (China). The per kg of citrus is nearly four times higher in Tibet (NPR 210) as compared to current farm gate price (NPR 56/kg) in Nepal. By accounting for all the transport, treatment, storage, handling, inspection, and export tax, it is possible to get an extra NPR 150 per kg of fruit in the current trade scenario. This is an overwhelming price benefitting small-holder growers and traders if proposed trade of citrus is implemented timely and effectively.

Despite high export potentials and benefits, currently no citrus is exported from Nepal to China. A small quantity of citrus is exported to India, but this export is problematic as India produces citrus in the same period of the year as Nepal. Moreover, Indian market does not entertain a large quantity of export due to lack of the official export channel with distinct protocols in place compared to China which has specific protocol and clear description in place.

A recommendation is therefore made to capitalize export opportunities to Tibet (China) by developing Syangja district as mandarin production site and Sindhuli district as sweet orange production site with establishment of cold disinfestation treatment facilities in a feasible distance (Dhading or Kathmandu) and transport into Tibet through the border crossings at Rasuwagadhi or Tatopani. Use of cold disinfestation protocols agreed to by China in phytosanitary agreements with Egypt is recommended. Further advice should be taken from these agreements that China did with other countries for the design and operation of appropriate cold treatment or cold chain facilities. For increasing the volume of export, other prospective neighboring districts in Nepal such as Baglung, Parbat, Myagdi, Ramechhap can also be promoted as citrus production sites and protocols of production, packing and transportation can be agreed upon in subsequent negotiations.

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Postharvest and Quality Management of Fruits and Vegetables in Nepal

5

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Abstract

This chapter outlines current practices, major drivers of change and existing impediments and potentials of better postharvest management and quality regulations of fresh agricultural produce in Nepal. Various research studies indicate that the general postharvest loss of fresh produce in Nepal ranges from 20 to 50% because of improper harvesting methods and postharvest handling, insufficient sorting and grading practices and poor infrastructures and facilities. On the other hand, quality and safety of the product is neither asked for by large section of consumers nor assured by government through strict imple-

mentation of available legislative measures. Being a highly potential area of national economy, horticultural sector requires systematic interventions to implement policies aimed at improved production and postharvest management of fresh produce to ensure safety and quality as envisaged by Agricultural Development Strategy. This chapter provides a broad overview of the development of horticulture industry with policy recommendations and practical approaches for improving postharvest management of fresh produce and its quality assurance under a general food safety and quality framework in Nepal. Developing postharvest handling guidelines for horticultural crops with high economic potential and setting their ‘basic’ quality standards and guidelines can pave the path for further development. Sensitizing the consumers and creating the market for ‘safe and quality’ produce are basic goals to be considered by all stakeholders in an open economy of Nepal.

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Keywords

Perishables • Supply chain • Cold chain • Packhouse • Food quality • Postharvest management

5.1 Introduction

Postharvest management is a science and art of managing postharvest losses, which indicates the measurable quantity and quality losses of any crop during and after harvest until its consumption (Buzby et al. 2014). As fruits and vegetables are prone to quick deterioration following harvest owing to their high moisture content and dense nutrients attracting spoilage microorganisms (Tripathi et al. 2013), postharvest management is becoming an important aspect in horticulture. Such losses can happen at any stage along the supply chain from harvesting to distribution, especially when there is insufficient technical understanding among the stakeholders and lack of postharvest management skills (FAO 2016). Such loss or waste of food is a major concern that impacts global food security (FAO 2011). For example, about one-third of food is wasted globally (FAO 2011). United Nations' Sustainable Development Goal (SDG) 12, target 12.3 stresses on reduction of postharvest losses and sets a clear target of halving the per capita food waste by 2030 at retail and consumer levels and reducing food losses along the food production and supply chains emphasizing postharvest loss reduction (World Bank 2020). Postharvest management of fresh produce and its safety and quality are highly interconnected. Composition and nature of fresh fruits and vegetables (fresh produce) make it a difficult task to retain the harvest-stage quality while they reach to consumers (Mayani et al. 2016). A systematic intervention is warranted using a 'system' approach from production to consumption with a need to follow the recommended practices for production, harvesting, storage, marketing and transportation, retailing and consumption (Prussia and Shewfelt 1993). Such a 'system' approach is adopted by safety and quality assurance schemes like Global Good Agricultural Practices (GlobalGAP), *codex alimentarius*, Safe Quality Food (SQF), British Retail Consortium (BRC) or Freshcare, which examines fresh produce at each stage from their production until they reach consumers with detailed

documentation of activities and inputs into the system and third-party audit (CAC 2005; Walsh 2014). The conscious and dedicated efforts of each stakeholder are very crucial. The other equally important dimensions are the facilities, infrastructures and consumer communities asking for safe and quality fresh produce. In any open economy, the price and quality determine the market viability of any product but the proactive government's efforts in setting national standards and developing guidelines along with facilitation, encouragement, regulation and strict implementation in postharvest management and quality regulations are imperative.

Nepal has great agro-climatic variability and distinct seasonality providing potential for growing a wide range of horticultural crops (Thapa and Dhimal 2016). The unique agro-ecological zones with different altitudinal, edaphic and topographical variations and distinct summer and winter seasons provide opportunities for cultivating a wide range of fruits and vegetables (Gautam et al. 2021). As a result, horticulture is important to national economy. Out of 22.96% of contribution of agriculture, forestry and fishery sector to national Gross Domestic Product (GDP), contribution of fresh vegetables and fruits sector stands at 4.79% and 2.17% respectively, in Nepal (MoALD 2021).

The Government of Nepal (GoN) has developed and implemented several policies and programmes to promote fruit and vegetable development in the country. From Agriculture Perspective Plan, APP (1995–2015 AD) to recently implemented Agriculture Development Strategy, ADS (2015–2035 AD), horticultural sector has received significant attention for its commercialization and value addition and linking it to better markets. For example, apple for high hills; mandarin, lime and oranges for middle hills; and mango, banana and litchi for tropical terai and inner terai areas are being promoted through commodity-specific programmes (Thapa and Dhimal 2017; Acharya 2017). Production packages for all these crops remained primary focus while improving the postharvest handling and reducing losses were also considered under

those programmes (ADS 2015). The GoN has implemented fruit decade programme since 2016–2017 Fiscal Year with an aim of promoting the potential fruits with a focus on supply of quality fruit saplings and investing on infrastructure development for quality sapling production. Postharvest management of fruits is also emphasized in this programme. The ADS as a guiding strategy has given considerable emphasis on postharvest management and quality regulations by stressing reduction in postharvest losses, promotion of postharvest technologies and development of value chain infrastructure to reduce postharvest losses and encourage quality assurance (ADS 2015).

Besides, the National Centre for Fruit Development (NCFD) under the Ministry of Agriculture and Livestock Development (MoALD) has implemented various fruit-specific and targeted projects to enhance the productivity and quality of fruit crops depending on the local weather conditions. Postharvest management of quality along the supply chain particularly regarding correct harvesting methods and stages and suitable transportation, handling and cold storage issues were integrated into various initiatives.

Nepal is experiencing high postharvest loss of fruit and vegetables which impacts on the availability of food. Qualitative and quantitative losses during postharvest periods of fruit and vegetables are preventable losses with adoption of proper postharvest management during harvesting, handling, storage and transportation. This increases availability of fruit and vegetable for consumption and contributes to food and nutrition security. This chapter aims at understanding the postharvest losses and in identifying gaps in the implementation of techniques in reducing those losses based on review of relevant published research articles, reports and papers related to postharvest management of fruit and vegetables at different stages of supply chain. Insights of authors based on the experiences of working on research and development in horticulture sector for few decades are also integrated. As loss of food and improvement in its quality relates to SDG 12 'ensure sustainable consumption and production pattern' particularly its target

12.3, i.e. 'halving per capita global food waste at the retail and consumer levels by 2030 and reduce food losses along production and supply chains, including postharvest losses', recommendations made here are aimed at achieving that SDG. Furthermore, this chapter, as it aims at increasing the availability of food through proper postharvest management of fruit and vegetables, contributes to SDG 2 'end hunger, achieve food security and improved nutrition' by providing the technical and policy guidelines to reduce postharvest losses. Also, it contributes to SDG 3 'ensure healthy lives and promoting wellbeing of all at all ages' by increasing the availability of fruit and vegetables through proper pre and postharvest management.

5.2 Fundamentals of Safety and Quality of Fresh Produce

Safety and quality are two important considerations in fresh produce. Safety in fresh produce refers to sense of assurance that no harm will happen after consumption of fruits and vegetables due to presence of contaminants (Klementina et al. 2013). This includes contaminants of physical, biological or chemical origin (Abadias et al. 2008). Physical contaminants in fresh produce are any nonliving stuff like dirt, hair, metal pieces, plastics, glass, stones, feathers, etc. that can be seen by our naked eyes. Recently, microplastics in fruits and vegetables like apple, carrot and lettuce have been a major safety concern since they are easily absorbed by plants roots along with other nutrients and water from soil but needs to be seen their toxicity to human health (Conti et al. 2020). Biological contaminants are living organisms present in food and include bacteria, viruses and parasites. Examples of bacteria include *Salmonella*, *Escherichia Coli* and *Stephylococcus* (in all fresh produce) through wash water or irrigation water, viruses like rotavirus, norovirus (in lettuce or raspberries) or Hepatitis A (in salads, strawberries, blueberries, raspberries) and some other parasites (Thompson 2003). Chemical agents are naturally occurring toxins or intentionally added to fresh

produce (pesticides), or non-intentionally used such as cleaning agents and sanitizers.

Fresh produce quality refers more to overall excellence and includes its nutritive value, overall appearance and internal characteristics (Nicolai et al. 2007). The external quality features include size, shape, colour, appearance, flavour and external surface defects, while internal quality features include dry matter, internal defects, total soluble solids (TSS), titratable acidity (TA), texture, or other micronutrients and pigments like lycopene in tomato or carotenoid in carrot. The world is now moving from increasing productivity to increasing quality as quality consciousness among consumers is increasing (Jongen 2000). Hence, crop improvement practices and breeding efforts have now been devoted to enhancing fresh produce quality (Wehling 2000). Similarly, economics of quality has increasingly been researched and linked to increased market value, which is achieved through systematic efforts of assigning into different grades and standards. Impact of better postharvest management (Nilsson 2000), consumer preference over perceived quality features and environmental impacts (Schreiner et al. 2000) on quality characteristics of fresh fruit and vegetables have widely been studied since 1990s. Developed economy and countries that focus on fresh produce exports have systematically aligned with these quality concepts as an integrated model from production, postharvest operations and logistics management. Management of temperature along the supply chain is fundamental aspect of fresh produce postharvest management. Depending upon the nature of crops, low and high-temperature injuries are common, which affect the ultimate quality of fresh produce.

5.3 Postharvest Research and Management in Nepal

At present, postharvest research and management are looked at from commodity-wise programmes from GoN's Nepal Agriculture Research Council (NARC) and Department of Agriculture (DoA)

—former looking at research and the latter at extension. However, Nepal is yet to observe systematic and sole postharvest management research programmes on fresh fruits and vegetables. Researchers engaged in postharvest management of fresh produce are mainly researching on quantifying the postharvest loss and assessing the effect of harvesting methods, crop maturity stages, distance to the market, method and mode of transportation and effect of wrappers and containers for holding the produce along the supply chain (Devkota et al. 2014). Recent studies have reported overall postharvest loss of around 20–35% in fruit and vegetables; however, it can reach as high as 50% for some crops (Bhattarai 2018; Gautam et al. 2021). Gautam et al. (2021) also reported a loss of 15–35% in horticultural produce and includes all losses during harvesting, handling, packaging, transportation, storage and retailing points. In earlier study, Gautam et al. (2004) reported a postharvest loss of 20–25% in apples due to inappropriate harvesting and packaging and lack of transportation. Subedi et al. (2016) observed a loss of around 24.3% due to spoilage when transported in bamboo baskets without liner and a minimum loss of 7.2% with grass liner during apple transportation. Gautam et al. (2004) recommended use of fruit-clippers for harvesting apples, use of 5-ply corrugated paper boxes with 160 PSI strength for packaging for air transportation and 10 kg corrugated paper boxes. They further recommended two boxes in a sac inside iron cages in two sides of mules for transportation by mules. Similarly, Chaudhary et al. (2004) reported use of paper as cushioning materials during normal room storage of 'Delicious' group of apples. Subedi et al. (2016) reported a varietal difference on loss by using cushion material during transportation with incidence of bruising of 20.3% in 'Golden Delicious' and 13.3% in 'Red Delicious' variety. Grass liner resulted in only 11.3% of bruised fruits but 24% of fruits were bruised without liners during transportation from orchard to collection centre. Grass and woollen cloths were considered as potential cushioning materials for apple transportation from orchard to collection

centre in the environment of high hill of Nepal. Lack of storage facilities to extend shelf life of the mandarin orange forced farmers to sell it at low price. In this situation, Subedi and Bhattarai (1993) recommend low-cost cellar storage facilities to get an increased price up to 300% by February onwards. A plethora of research has been conducted on postharvest management (increasing shelf life, packaging materials, transportation methods, storage, treatments with fungicides) of apple and mandarin orange (Bastakoti and Gautam 2007; Bhattarai and Shah 2017), banana (Basnyat and Shrestha 1997; Tiwari et al. 2008) and cauliflower (Bhattarai and Budhathoki 2005). Khatiwada (2020a, b) has compiled most of the research conducted in and around postharvest management of fresh produce in Nepal.

A concept of market-oriented production system and selling at distance markets is slowly evolving in Nepal. Harvesting at improper stage and use of wrong methods are basic problems in Nepal (Gautam et al. 2021). Rokaya et al. (2020) observed the physiological weight loss of 15.8% and decay loss of 80% in mandarin oranges after 90 days in cellar storage in case of the fruits were harvested by hitting with stick. But for the fruits harvested using the fruit-clippers, there was loss of only 3.1% and 8.3%, respectively, in the same storage method and period. Similar results of low decay loss were seen in different fruits harvested using clippers—as reported by Postharvest Loss Reduction Division (PHLRD 2003) in mandarin, Singh et al. (1993) in mango, Sonkar et al. (1999) in Nagpur mandarin and Purbiati and Supriyanto (2013) in mandarin oranges. Bhattarai et al. (2013) reported the postharvest loss of 46% from harvesting to distribution in mandarin oranges in eastern Nepal where segregated loss of 7%, 25%, 3%, 1% and 5% was reported during harvesting, transportation, grading, packaging and marketing, respectively.

To reduce the losses in transportation, different packaging materials are commonly used with varying consequences on quality of the produce. A most common practice is packing with

inedible wrapper leaves, which was seen to increase total load during transport and handling by up to 35% (Gautam et al. 2002). Sorting and grading are not commonly practiced in Nepal. Even in the situation of using semi/rigid structures, overfilling in the container is a common challenge. Packhouse concept has not yet been established for fresh produce. Because of poor hygiene in collection points (collection centres, market centres), good hygiene practices (GHP) are poorly implemented. The situation is worse in case of root crops, where polluted water is used to remove soil from the produces which results in incidence of biological hazards of *Giardia* or *E. coli* in fresh raw vegetables (Ghimire et al. 2020).

Transportation system of fresh produce is still primitive in Nepal. In hilly terrain, the fresh produces are transported by putting the produces in Doko (bamboo basket) and carried on human-back up to road heads. Bicycles, tricycles and carts are used on the plains to transfer fresh produce to the collection centres and then dispatching to the end markets. Generally, ordinary trucks (for long distance) and vans (for short distance) are also used to carry fresh produce from collection points to the end market. In this process of transportation, the produces are very prone to mechanical and overheat damage. In the commercial vegetable production areas, however, dedicated vehicles are used for transport of fresh produces. Use of refrigeration for fresh produce at the retailing is rare but has now started at few departmental stores like Bhat Bhateni supermarket chain. However, they are not practicing entire cold chain from the point of production to market outlet.

Various stakeholders in the supply chain of fresh produce now realize the importance of better postharvest management. They are encouraged to adopt better management practices as they now see new retail chains supplying quality fresh produce to consumers (Devkota et al. 2014). Use of plastic crates has increased in recent years for transportation and handling of fresh produce owing to its benefit in reducing bruises, wounds and injuries to fruits and

vegetables. Promotion of indigenous and traditional storage technologies including cellar storage, zero energy storage and rustic storage are gaining priority and attention in recent years (Acharya 2017; Bhattarai 2018).

In the absence of adequate cold storage or warehouse facilities at local level, farmers are obliged to sell their perishable produce at distressed prices which otherwise can be stored to regulate market glut and supply at appropriate time of fair pricing. Construction and establishment of major market infrastructure with basic facilities of docking of trucks, receivals of produce, its proper cold storage, quality inspection and control services, laboratories for checking chemical residues and heavy metals among other quality parameters and spaces for major wholesalers for packing house facilities and selling to retailers are very important (Bhattarai 2018).

5.4 Major Drivers for Improved Postharvest Management

5.4.1 Production Scale and Technology

Volume of production is a prerequisite not only for the market but also to implement the suitable production and postharvest technologies to spread the total cost across each unit and bring down the total cost of production (Acharya 2017). This is true for fresh agricultural produce as well—right from establishment of packing house or installation of sorting/grading or packaging facilities for fresh produce. Seasonal nature of production scattered production across villages and economy of scale are hindering the design and implementation of suitable postharvest management (Bhattarai 2018). To alleviate these impediments, government has introduced the concept of pocket, block, zone and super-zone for particular commercial commodity crops so that farmers can assemble their products at one collection centre to make it sizable and economical for transportation to the market (ADS 2015). However, due to lack of proper

production planning to make use of those collection centres around the year, efforts and investments made to reap the benefit of this concept in horticultural crops are yet to be realized. It is expected that the new technology and mechanization can accelerate the adoption of better postharvest operations and improvement in reduction of qualitative and quantitative losses of fresh produce.

5.4.2 Supply Chain Stakeholders and Consumers

Consumers and other supply chain stakeholders including all traders, middlemen, wholesalers, cold store operators, transporters and retailers are the key drivers in open economy where quality and price determine success or failure. Other institutional stakeholders including Agro Enterprise Centre/Federation of Nepalese Chambers of Commerce and Industries, all tiers of government, farmers institutions (cooperatives and groups) are instrumental in driving the better management of postharvest and quality of fresh produce. Development of guidelines for harvest/picking, cold chain management, handling, transportation, storage for fruits and vegetables is the key for better postharvest quality management. Encouragement for adoption of those guidelines should be embedded through incentivizing for the safe and quality produce. Existence of niche markets like star hotels and tourist hotspots, rapid urbanization combined with health consciousness among consumers and increasing trend of shopping in supermarket chains are paving the path for better quality regulations. Mass sensitization for consumers on safety and quality of fresh produce is needed for increasing the demand side so that the stakeholders can opt to go for proper postharvest management to assure safety and quality. Establishment of a toll-free number, direct mail service, or consumer information system are imperatives for consumer sensitization while systemic efforts like consumer education in curricula are also crucial (FAO 2018a, b).

5.4.3 Proactive Government Actions

Being the member of Food and Agriculture Organization (FAO) and World Health Organization (WHO) under United Nations and obligation to abide by the *codex alimentarius* guidelines for assuring basic food safety and guidelines, Nepal is yet to practically implement those available legislative measures in action (FAO 2018a, b). Development of national standards and guidelines for fresh produce handling and storage are few urgent actions. Recently Nepal government-endorsed Nepal Good Agricultural Practices (NepalGAP) certification schemes to ensure the safety and quality of food. However, encouraging and enabling environment could be better created by facilitating the farmers or traders in the business to implement it (DFTQC 2021). Commodity-wise programmes for horticultural research and extension exist under government but specific research and extension activities on postharvest management of all horticultural produce are yet to be observed. Recent government plan for establishment of fresh produce market in all seven provinces with all facilities for modern fresh market is a right move.

5.5 Recommendation for Improved Postharvest Management

5.5.1 Infrastructures and Facilities

Improvement in existing collection centres at small farmers' groups and upgrading of those collection centres as packing houses to facilitate cleaning, washing, sorting, grading and packaging could be instrumental in increasing the scale of production and supply to meet market demand for quality produce (Gautam et al. 2021). Construction of new and improvement of existing storage structures for various fresh produce is needed that not only helps maintain the harvest quality but also assists in regulating the market price through storage of, otherwise, over supplied fresh produce (Bhattarai 2018). Similarly, provision of temperature-regulated transport

facilities for perishables is a basic minimum condition to reduce their normal physiological and biological processes including respiration and other internal metabolisms that lead to faster decay (Acharya 2017). Cold storage at the major production site or market destination is not worthy in the scenario of lack of refrigerated transport to maintain cold supply chain. A modern market centre with adequate facilities should be considered for systematic postharvest management which can provide basic facilities of cold storage, ripening or other postharvest treatments (Kader 2013). Establishment and operation of processing facilities for using the low grade or off-sized fresh produce to make some value-added products is of immense importance. Encouraging private sector through provision of soft loans or subsidized interest is important.

5.6 Regulations and Actions

There are plethora of rules, regulations, policies and standards and authorities to regulate the food safety and quality issues under broad food safety and quality framework in Nepal (Bajagai et al. 2020). Several voluntary and mandatory food standards and guidelines are being practiced in Nepal including HACCP, Good Hygiene Practices (GHP, Good Manufacturing Practices (GMP) depending upon nature of the industry and produce. However, due to lack of government's priority to implement such instruments, food safety issues are not getting enough allocation of resources and investment in development of infrastructures, facilities and skilled technical human resources is inadequate. Recently, Nepal government developed and implemented NepalGAP as a voluntary certification scheme for agriculture produce and provided detailed guidelines for farmers and related institutions to produce safe and quality produce which have several provisions on proper postharvest management of fresh produce (DFTQC 2021). NepalGAP has five different modules namely food safety, environment management, product quality, worker health, safety and welfare and general requirement modules

(DFTQC 2021). General requirement modules' checklists number 10.6 looks at maturity index for harvesting and time of harvesting along with temperature and humidity management of the fresh produce. This is very encouraging sign to learn from and further mainstreaming the concept of safety and quality in fresh produce. Proactive government action and implementation of existing regulations and legislative measures are imperative.

5.7 Improved Postharvest Management in Nepal

Few agribusinesses established with goal of supplying safe and quality produce to consumers are emerging in recent years in Nepal. Those businesses are making a good and systematic investment in fresh produce production, postharvest management and marketing through their own outlets with motto of supplying safe and quality produce. One such agribusiness is MUNAA Krishi Limited (Mutual Undertakings between NRNs and Agricultural Authority, munaa.com.np), which is a public company established in 2018 and operating in Kathmandu with aim of establishing a packing house in the Kathmandu valley and supplying seasonal vegetables and fruit after cleaning, sorting, grading, certification, chemical residue analysis, packaging and branding. The company shared its motto of supplying safe and quality produce and reducing postharvest losses along the supply chain. The company is currently buying fresh agriculture produce directly from individual farmers, farmers groups or their cooperatives, implement recommended postharvest practices for transportation and carrying out packing house operations before selling through their four retail outlets.

Another business striving to supply safe and quality fruit is Agro Manang (agromanang.com.np), which is a private company promoting Nepalese apple through its own production and marketing with special branding system. Production is being done through its own and leased land of around 25 ha in Manang district in

midwestern high hills and producing organic apples with Gala, Golden Delicious, Fuji Mema and Fuji Kiku varieties and investing in apple processing for producing apple juice and chips. The company constructed its cold storage facilities in Manang and Kathmandu along with modern packing facilities for sorting, grading, branding and packaging of apples in Kathmandu. Similarly, the movement of the sweet oranges grown by farmers associated with Chisapani Junar Producers' Agriculture Cooperative in Sindhuli district is being tracked for their origin with growers' details, harvest, processing and packaging dates and food miles using Quick Response (QR) codes in coordination with an emerging organic online retailer business of food product namely Green Growth Ltd.

Increased consumer awareness and responsive government started to regulate and assess imported and local fresh produce for chemical pesticide residues through rapid bioassay methods in Kathmandu and major fruits and vegetables wholesale markets. These sporadic interventions across the country amplified the importance of growing safe and quality fresh produce among farmers and import of only safer produce among fresh produce wholesalers. This is initiating a positive discussion on need for safety and quality fresh produce and major interventions needed to ensure this goal by major stakeholders.

5.8 Fresh Produce Safety Guidelines and Quality Standards for Nepal

Food-borne illnesses are reported in past few years in Nepal and some of them might be linked to fresh agricultural produce. A recent study by Ghimire et al. (2020) conducted in Kathmandu, Nepal reveals all (100%) of raw salad vegetable samples (carrot, cabbage, capsicum, coriander and lettuce) obtained from open markets and retail shops from Kathmandu, Bhaktapur and Lalitpur of Nepal, was infested with *Giardia* cysts while 24% samples were infested with *Entamoeba histolytica*. This infestation might

have emerged from washing of the raw vegetables with infested water or any other stages of supply chain but is due to lack of implementation of safety and quality assurance. Another area of concern in Nepalese context is pesticide residues in the raw vegetables sold in the market. A recent study by Bhandari et al. (2019) depicted that 44% of tomatoes and 19% of chilli exceeded MRLs while 93% of eggplant and 100% of tomato and chilli had higher pesticides than MRLs. The causes for exceeding MRLs are related to not following required waiting period, inadequate understanding of the information on the pesticides label, incorrect dilution involving higher concentrations than recommendation and belief among farmers that higher doses will kill the pests effectively. Microbes present in the fresh produce are major risks, which consumers are not able to notice as they are undetected with naked eyes (Ghimire et al. 2020). Such microbes can come from different sources like water used for irrigation or cleaning processes, which could be contaminated by faeces from humans, pests and animals and human sewage. Use of undecomposed organic manure, farmyard manure or other organic manure contaminated with human or animal faeces, or sewage could also be the cause of contamination. Fresh produce picking and postharvest handling by contaminated workers due to inadequate toilet facilities and poor hand washing practices are other sources of biological risks (Klementina et al. 2013). Moreover, packaging materials or transportation vehicles might be contaminated with faeces. Poor personal hygiene practices due to lack of proper handling guidelines and regulatory mechanism stand as a major cause of contamination of fresh produce in Nepalese context. Transportation of the fresh produce in public transportation combined with negligence of workers involved in handling of fresh produce leaves a lot of risks of biological contamination along the supply chain.

Recently, the GoN promulgated National Food Safety Policy 2019 which focuses on safety of primary agricultural production and is aimed at implementing the GAP. Soon after, Nepal developed NepalGAP quality assurance system for safety and quality of agriculture production.

Food safety module and product quality module of NepalGAP are directly relevant to postharvest management and quality regulations for fresh produce. However, the lack of any significant incentives or premium market for the certified products with premium prices along with the allocation of resources for regulation and strict implementation of food laws and directives remains major bottleneck. Little interest among farmers to implement NepalGAP and other safety and quality assurance schemes like GHP and GMP are challenged to safety, quality and postharvest management of fresh agriculture produce in Nepal. Challenges associated with federal structures and decentralization of food safety and quality monitoring system include establishing the food quality laboratories at provincial level, assigning the technical staff and aligning numerous pieces of legislation affected by the restructuring of the administrative system (FAO 2018a, b). Nevertheless, NepalGAP is a good entry point for Nepalese food sector and fresh produce sector to assure its safety and quality provided its proper field implementation and independent third-party audit and verification (DFTQC 2021). Assessment of harvest quality is a crucial step for any fresh produce as all postharvest operations and handlings aim at keeping the harvest quality as far as possible. As market is a function of quality and price of the produce in general, quality of the produce is an important determinant for the success of any business. Hence, a systematic implementation of quality assurance system is the key to success in the emerging market provided the purchasing capacity of the consumers is sufficient to afford the price increased due to quality assurance system (FAO 2018a, b). Several quality assurance systems have been developed for assuring the fresh fruit and vegetable quality. GlobalGAP, SQF, Freshcare, *codex alimentarius* code are some of them. Nepal being the member state of the international organizations like FAO, WHO and World Trade Organization, codex codes need to be followed to facilitate trade and business and ensure safety and quality of the fresh produce nationally as a minimum safety and quality assurance scheme.

Codex alimentarius is a basic and standard quality assurance system developed jointly by FAO and WHO of the United Nations. Following are the most relevant codex standards for safety and quality of fresh produce (Table 5.1).

Table 5.1 is self-generated table, compiling related codes for fresh fruit and vegetables. Looking at the Nepalese context, two standards namely NepalGAP and *Codex alimentarius* are quite practical safety and quality assurance system where more work on developing guidelines, product specifications and orientation to the farmers and stakeholders is needed.

5.9 Postharvest Management and Quality Imperatives for Nepal

A serious and systematic effort is urged for postharvest management and quality and safety regulations of fresh agricultural produce which starts with acknowledging its contribution to food security, human health and nutrition along with boosting trade, creating job opportunities and strengthening national economy (Gautam et al. 2021; FAO 2018a, b). Basic understanding of nature and perishability of the fresh produce among all stakeholders is needed which paves the path for implementing proper postharvest management. This asks for general consultation workshops and meetings across the local, provincial and central level governments and stakeholders for formulation of implementable plans based on available legislative measures. Gaps in the present policies and regulations need to be identified and adequate resources and skill sets are to be provided and information in this regard needs to be shared among stakeholders. Fresh produce is one component of the wider

food system. So, it needs to be brought under broader food safety and quality network while special consideration is to be given to postharvest management of fresh produce given its perishability and physiology. Inadequate, inefficient and scattered production systems among smallholders should be consolidated for economies of scale which creates space for implementing mechanization, quality assurance schemes like NepalGAP, or other safety and quality guidelines. Cost-effective on-farm and near-farm packing house operations, creating value-chains, maintaining cold chains, ensuring quality and product safety besides prolonged shelf-life technologies are needed (Acharya 2017; Bhattarai 2018). A better information to market system helps reduce the losses in perishables. In open economy and globalized world, greater understanding of market intelligence mechanisms, good trade practices and legal aspects of the multilateral trade regime and agreements are necessary.

5.9.1 Safety and Quality Regulations

National standards for fresh produce and quality and safety guidelines should be developed in line with *codex alimentarius* guidelines and NepalGAP quality assurance schemes. *Codex alimentarius* provides a general guideline for almost every fruit and vegetable crop for quality standardization while NepalGAP, through its five comprehensive modules and its checklists, provides very thorough guide to safety and quality (DFTQC 2021). This assures the consumers' communities and encourages markets for supplying quality produce at premium prices. This should go with increased quarantine regulations to assess and monitor the safety and quality of imported fresh produce in the current scenario of

Table 5.1 Relevant codex codes of practices for fresh produce safety and quality regulations

Reference	Codes of practice and standards
CAC/RCP 53–2003	Codes of hygienic practice for fresh fruit and vegetables
CAC/RCP 44–1995	Code of practice for packaging and transport of fresh fruit and vegetables
Codex STAN	Codex standards for different fruit and vegetables

imports from two big neighbouring countries (India and China) and other countries. Fast, accurate and non-destructive methods of quality and safety assessment and monitoring protocols along the supply chain are urgently needed at those custom entry points and at the national laboratories to be able to increase the sample size and come up with the results quickly. Good technologies, tools, equipment and instruments are already available for the assessment of safety and quality parameters right from farm to the consumer's table (Nicolai et al. 2007). This needs adequate considerations for introducing, validating and contextualizing of those technologies and instruments in close collaboration with research institutions including NARC and Universities (Acharya 2017).

5.9.2 Recommendations for Local Government

Federal Nepal decentralizes its extension and regulatory service systems for food and agriculture to provincial and local authorities. This authority comes with big responsibilities and opportunities that demand legislation and guidelines viz: food standards, food regulations and related guidelines. Implementation of such guidelines asks for the process for its formulation which is democratic, participatory and practical. It needs a participatory consultative process among stakeholders at different stages of formulation. A team of experts and officers including agriculture, food technology, business and legislation could be formed in each local level for facilitating the implementation and execution of the legislative measures in action. Routine review of implementation status and feedback from stakeholders is very important process to strengthen the implementation process along with relevant updates of those measures in legislation. An effective implementation and assurance of proper postharvest management and safety and quality regulations can be expected through the provision of third-party auditing and certification. NepalGAP is a quite comprehensive certification scheme to follow for Nepalese

farmers where DFTQC oversees its compliance and issues NepalGAP certification for the produce or farm as per guidelines. As agriculture and food involve multiple stakeholders, the issues of production, trade or legislative compliance evolve where interdepartmental or relevant ministerial coordination is imperative. A local-level committee to oversee the issues of field implementation of compliance and feedback can be formed under local authority which not only identifies the scope of regulation but also helps in facilitating the smooth implementation of the certification schemes.

Local government has a pivotal role in facilitating the systematic implementation of postharvest management in fresh fruit and vegetables. Those roles include facilitating and encouraging the private sectors in construction of relevant infrastructures (storage, road, etc.) and laboratories (food assessment laboratory) and providing training and skills for their efficient operations. Besides, local authorities can also facilitate lending the soft loan and credits for investment in production through financial institutions, formulation of relevant guidelines and regulations for supply of quality seeds, inputs, tools and equipments, operation of packing houses, cold storage, transportation of the fresh produce and monitoring the quality of goods and services (Gautam et al. 2021). Establishment of resource centres at local government level which can demonstrate all needed operations from production to packing house and storage could be an example in this direction.

5.10 Conclusions

Markets and consumers are the major drivers for quality fresh produce which warrants proper postharvest regulations and quality management. Open market economy of Nepal means that internal production needs to compete with the imported products, mainly from the adjacent large economies of India and China. As large economies like India and China have competitive advantage of 'economy of scale', they can produce food with low cost. The production cost is

high in Nepal. Thus, proper postharvest management of fresh produce needs systematic government support for major fixed assets including storage, market infrastructures and transport facilities. Local and provincial governments need proactive engagement with stakeholders to execute the right to safe and quality food for its people. A facilitative approach is essential to replace current authoritative approach for efficient implementation of legislative measures to assure safety and quality of fresh produce by developing local quality standards and guidelines. At local government level, the establishment and operation of cold storage facilities and support for the establishment of packing houses for farmers' groups or agriculture cooperatives, fitted with small cool chambers, can be a turning point. An analytical and scoping study is needed to assess the need for postharvest management and quality regulations that leads to benefits to national economy, job creation and improve people's health.

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Strengthening National Seed System for Food and Nutrition Security in Nepal

6

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Abstract

Seed is the most important input in crop production, determining yield and affecting food and nutrition security. The ultimate gain of genetics and plant breeding efforts can be realized only when good quality seed is available to farmers for production. This chapter aims to analyze strengths and weaknesses in seed policies, programs, strategies, and their implementation in line with the country's commitment to the United Nations' sustainable development goals. It is also focused on the

production and distribution of crop seeds in Nepal which is vital for agricultural productivity, food self-sufficiency, and nutrition security. Availability of good quality seeds is possible through a robust national seed system where public and private sectors work together. Participation of the private sector in the seed production and distribution system in Nepal is encouraging, but significant contribution from this sector is yet to come. Demand for hybrid seeds is increasing especially in the vegetable sector. Although Nepal has a well-defined system of variety development, release, registration, and notification process, due to the porous border system with India, sometimes unauthorized and unsuitable crop varieties are illegally imported. This often causes big losses to farmers as such varieties might not be suitable to agroecological conditions of Nepal. Since the seed is produced and distributed through a formal and informal system with the participation of both the private and public sectors, a strong coordination is vital among various stakeholders. More focus is needed to safeguard the seed quality, especially during harvesting and storage using dry chain technologies. In general, the seed policies in Nepal are relatively favorable to the seed sector, but it also has many challenges including application of advanced technologies. The policy implications of this review could also be useful in improving the national seed systems of the South Asian countries and beyond.

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Keywords

Seed policy • Seed quality • Plant breeding • Crop productivity • Food security

6.1 Introduction

Seed is an important agricultural input influencing various aspects of producers and consumers. In biological terms, a seed is the repository of the genetic potential of crop species and their varieties resulting from continuous improvement and selection by farmers, agronomists, and plant breeders over time. Good quality seed is a primary input for increasing crop production (SQCC 2013a). The ultimate gain of genetics and plant breeding efforts can be realized only through a robust national seed system. The use of good quality seeds alone can contribute to a 20–30% increase in crop yield (Thompson 1979; Afzal et al. 2019). Availability of good quality seeds affects farming decisions of producers, subsequent quality and quantity of produce, farm profitability and ultimately it plays a key role in food and nutrition security of a country. The World Food Summit in 1996 has stated that food security exists when all people always have access to sufficient, safe, and nutritious food that meets their dietary needs for an active and healthy life. FAO (2009) states four pillars of food security which are—food availability, access, utilization, and stability of the food supply system so that adequately nutritious food can be assured to all sections of society, irrespective of age, income level, and social status. Therefore, food security is not only the availability of enough calories but also meeting the nutritional quality. The choice of strategy on national food security is dependent on production resources and the systemic and institutional strength of the political, economic, and social life of a country. There are mainly three types of agricultural food policy measures aimed at addressing food security—food self-reliance, food self-sufficiency, and food sovereignty (Baer-Nawrocka and

Sadowski 2019). Food security can be achieved by increased crop production using good quality seeds of high-yielding varieties along with improved agronomic practices, which ultimately lead to increased farm income, increased rural employment, and better access to food.

Without the use of quality seeds, there will be little benefit from other essential agricultural inputs such as fertilizers, irrigation, farm machinery, and labor to increase efficiency and crop productivity (Gauchan 2019). A recent study has shown that the introduction of hybrid seeds in major cereals and vegetables has brought major yield gains in agricultural production in Nepal, but at a high environmental cost (Freshley and Delgado-Serrano 2020). However, the adoption of high-yielding open-pollinated (OP) varieties in crops has retained hope for more sustainable production systems (Open-pollinated seed means self-pollinated as well as cross-pollinated crops here). The study recommends that the adoption of different OP varieties can be enhanced if more resources are provided in developing such varieties in partnership with early adopters together with training on sustainable farming techniques and their economic and environmental advantages.

Availability of quality seeds is vital to increase crop production, therefore, the Seeds Act was promulgated in 1988 to increase and regulate the supply of quality-assured seeds. The standards and the process of producing and supplying seed are specified in seed laws (Act, Rules, Directives, and Guidelines). To strengthen the Seeds Act, seed policy documents (National Seed Policy 2000 and National Seed Vision 2013–2025) were introduced with specific targets. At the national level, Nepal was not only food sufficient until 1980s, but also had surplus food and used to export through Paddy and Rice Export Company from the Terai region (FAMSD 1982; Pyakuryal et al. 2010). Change of fortune happened in the last 50 years from a food exporter to a food importer despite agriculture being placed at the high priority sector of economic development by the National Planning Commission.

6.2 Background and Objectives

Seed sector development in Nepal is currently guided by the National Seed Vision (NSV) 2013–2025. A holistic and sustainable seed system development is anticipated in the document through the active participation of all stakeholders. The NSV emphasizes improving the food and nutrition security and livelihoods of small farmers and benefits consumers thereby addressing the United Nations sustainable development goals (SDG), eliminating poverty of all forms (SDG #1) and, ending hunger, achieving food security, and improving nutrition (SDG #2) by 2030. The report on the national review of sustainable development goals of Nepal discusses on national targets, strategies, and achievements together with challenges and opportunities. It mentions that Nepal has been able to gear up a high growth rate, reduce poverty and macroeconomic stability during the NSV period (NPC 2020). However, there are many challenges ahead in the agriculture sector to address two other relevant SDG goals; urgent actions to combat climate change (SDG #13) and protect and restore sustainable ecosystems (SDG #15).

This chapter aims to (1) document the status of seed sub-sector development, analyze the effectiveness of various attempts of seed production and seed self-sufficiency programs of government agencies, non-government organizations, community groups, and farmers' cooperatives; (2) provide a brief review of advancement in biotechnology, mechanization and digital technologies that seed stakeholders in Nepal could adopt in strengthening the national seed systems and; (3) analyze the effectiveness of seed sector policies and laws, identify emerging issues, and outline potential options, obstacles, and opportunities for improvement.

6.3 Seed Systems in Nepal

A well-functioning seed system uses the appropriate combination of formal and informal supply channels, market, and non-market transactions to

stimulate and address the evolving demand of farmers for quality seeds (Maredia et al. 1999). The seed supply system in Nepal has been described briefly in the following subsections.

6.4 Formal Seed System

The formal seed system involves a highly regulated chain of activities leading to seed supply of locally released, registered, or approved varieties either through certification system or through truthful labeling system. The chain usually starts with plant breeding, resulting in different types of varieties, including hybrids, and their maintainer lines. The institutions involved in developing, multiplying, and distributing varieties as certified seeds can be publicly and/or privately funded and organized in various ways. The formal sector of seed production and supply in Nepal was initiated in the early 1980s mainly on wheat by the then Agriculture Inputs Corporation (AIC). Later, the Department of Agriculture introduced District-level Seed Self-Sufficiency Program in 1998 to speed up the process of supplying good quality seeds to farmers. Then, AIC was divided into two companies: Agriculture Inputs Company Limited and National Seed Company Limited for dealing with fertilizers and seeds, respectively. Both companies merged to form Agriculture Inputs Company Limited in 2018. The emergence of private seed companies in Terai in the beginning of 2000 expanded the production of formal seed sectors in Nepal (Gauchan 2019).

In the certification system, quality of breeder seed, parental lines, foundation, certified and improved seed classes is controlled by the Seed Quality Control Centre (SQCC) at the federal level. At province and municipality level, it is done by the Seed Laboratories of those jurisdictions through the inspection of standing crops in the field and testing seed quality in the laboratory. However, in the truthful labeling system, the standard and quality of seed are controlled by the producers and traders during seed production and subsequent post-harvest operations.

Although the formal seed system started decades ago in Nepal, it is limited to a few major crop varieties developed by the National Agriculture Research Council (NARC) and the farmer-preferred varieties were not prioritized to the required scale by the national authority. This situation is gradually improving with the involvement of private sector.

Formal system requires replacement of old seeds by new seeds on a regular basis. Seed replacement rate (SRR) is the replacement of old seeds by fresh and good quality seeds obtained through the formal seed system. The old seeds should be replaced with a new seeds every two to three years for OP varieties and every year for hybrids. This is designed to ensure the availability of quality seeds. However, the extremely low SRR remains one of the hindrances in introducing modern varieties (Singh et al. 2017). It was due to breakage of seed production chain, unavailability of high yielding or farmers' preferred varieties, lack of information about new varieties, and awareness of quality seed with farmers.

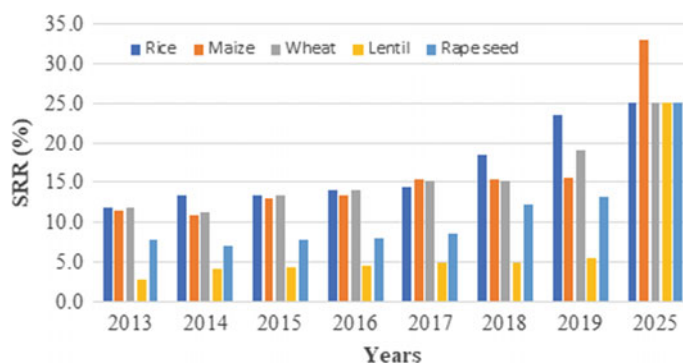
In 2013, the baseline year of the NSV, the SRR of rice, maize, wheat, lentil, and rape seed was 11.9, 11.4, 11.9, 2.8, and 7.7%, respectively (Fig. 6.1) indicating that nearly 90% of the seed requirement was fulfilled through informal systems (SQCC reports 1012/2013 ~ 2018/2019). The SRR target itself is low in comparison to India's 33% for self-pollinated crops and 50% for cross-pollinated crops (Prasad et al. 2017). The NSV has a target of achieving the SRR of about 25% for self-pollinated crops and 33% for

cross-pollinated crops by the end of 2025. Similarly, the SRR of vegetables is expected to reach 90%. The SRR for all types of hybrids is forecasted to be 100% by the same time (SQCC 2013a). The SRR of rice, maize, wheat, lentil, and rapeseed reached 23.4, 15.6, 19, 5.4, and 13.2%, respectively in 2019. The SRR achievement for rice and wheat is achievable by the end of the NSV period, but several more years will be required for the rest of the crops at the current growth rate (Fig. 6.1).

6.5 Informal Seed System

The informal seed supply system refers to the traditional arrangements adopted by farmers or farmers' groups to supply seeds. The informal seed supply system is also known as farmer-managed seed system, traditional seed system, or simply farmers' seed system. In this system, activities tend to be integrated and locally organized which embrace various ways to produce, process, maintain, disseminate, and access seed directly from their own harvest, through exchange among friends, neighbors, relatives, or through local markets (Bishaw et al. 2008). Improving informal seed supply is crucial for locally available crops and their varieties for the development of the national seed sector as it contributes more than 80% of the total seed supply (SQCC 2021). In addition, supporting the informal seed sector will help to conserve genetic resources thereby improving genetic diversity, crop productivity, farmers' livelihood, and

Fig. 6.1 Target of SRR of major crops in Nepal (Source SQCC 2012/13–2018/2019)



ultimately food security (Singh et al. 2013). Gautam et al. (2020) state that a community-based maize seed production program in 20 hill districts of Nepal has demonstrated strong influence on improved seed adoption, crop yield, and household food self-sufficiency providing positive socio-economic impact on socially marginalized small-scale farms. This finding justifies why the informal system has remained the dominant seed supplier of improved and local varieties for many crops. However, supplying and monitoring of seed quality in the informal seed system have remained a major challenge in Nepal. These problems can be addressed to a great extent by a wide-scale adoption of dry chain technology which involves storing of commodities in moisture-proof containers after drying to safe moisture contents (Bradford et al. 2018). A recent study in Guatemala conducted by Guzzon et al. (2020) suggests that conserving local cultivars and landraces at community levels can be effectively achieved by using dry chain practices without the need of extensive storage infrastructure with dehumidifier or refrigeration facilities. Nepal is known for its different agroecological terrains and rich agrobiodiversity, where the farmers have used an informal seed system to maintain and manage biodiversity. Therefore, this system focuses on farmer management of local varieties which have been selected over time and seed is produced under local production practices (Bishaw et al. 2008). So, seed is circulated in a short and simple way without adopting any regulations (Jones et al. 2001; Bishaw et al. 2008).

Besides two major seed systems, there is a third category called integrated seed system which is not a uniquely different seed system but a combination of some features of both systems in one setting, or a holistic approach (ISSD 2014). It also recognizes the co-existence, evolution, and importance of the formal and informal systems and looks for opportunities and options to improve them both by recognizing and supporting integrations. In Nepal, community-based seed system is an example of such system that supports integration of these two systems for the development of holistic and dynamic seed

system to meet the needs of diverse groups of farmers and stakeholders for the increased farm productivity, income, and increased resilience of the farming systems in the face of changing climate and market requirements (Louwaars and de Boef 2012; Sperling et al. 2013; Gauchan and Shrestha 2020). Maintenance of seed quality and improvement in biodiversity at farms and community groups would be possible using dry chain practices (Bradford et al. 2018).

6.6 Advances in Plant Breeding and Applied Biotechnology

Plant breeding basically exploits existing genetic variations or creates new variations and selects superior plant types to improve crop plants for quality and yield. Breeding methods can be simplified into two broad categories: plant breeding based on (i) morphological variations in the existing population and subsequent selection of desirable traits (ii) controlled mating of desirable parents and subsequent selection of recombinant offspring based on either morphological traits or in combination of morphology and DNA markers. The traditional plant breeding remained dominant since the domestication of crop plants and currently, it has been strengthened by the development of molecular markers. The continuous selection based on desirable traits can lead to narrowing of genetic diversity making crops vulnerable to biotic and abiotic stresses. However, this can be overcome by introducing a new pool of genes from landraces and wild ancestors. Several methods can be used for introducing exotic variations into elite germplasm without undesirable effects (Bresgheello and Coelho 2013; Cobb et al. 2019). Controlled mating and spontaneous mutations have been the source of introducing various traits into elite recipient lines. Mutation caused by physical or chemical agents induces genome-wide random mutations which can greatly expand genetic variation and has been able to develop >3000 crop varieties (Foster and Shu 2011; Oladosu et al. 2016). Similarly, hybrid variety development technologies have

significantly accelerated breeding efforts, especially in clonally propagated crops, such as potato and banana, and fully cross-pollinated crops, such as maize.

Over the last decades, genetic engineering has offered another tool to conventional plant breeding for selecting desirable traits using DNA molecular markers. The identification of DNA markers linked to the traits of interest let the breeders select plants without the need for growing them in the field. This is an efficient method of discarding undesirable plants early in the generations allowing more desirable plants for testing in the next phase. However, this is not an alternative to field testing which must be done to validate the laboratory results at a later stage. The DNA technology also allows introducing genes or traits from another unrelated organism where the foreign DNA is randomly integrated into the genome of desirable plants (Anwar and Kim 2020) which is not possible through conventional breeding. This transgenic approach is widely used for improving biotic and abiotic stress tolerance and increasing productivity in many crops, such as soybean and cotton. However, the commercialization of transgenic crops is subject to a long and costly regulatory evaluation process with a potential opposition from anti-GM campaigns. As a result, only a handful of countries in selected crops have allowed adoption of such technology.

To overcome the problem of transgenic approach, genome editing technologies such as clustered regularly interspaced short palindromic repeats (CRISPR)-Cas9, CRISPR-Cas12a, and base editors more recently are being used to efficiently modify plant genomes in crops to improve traits without integrating foreign DNA into the genome (Gaj et al. 2016; Zafar et al. 2020). These precise techniques are coming to define next-generation plant breeding. This technology allows specific manipulation of crop genes and creates novel variations through deletion or silencing of undesirable genes or activation of favorable genes to develop desirable crop plants. Some of the examples of this technology are increased seed size and shape in tomatoes, increased seed size in rice, and increased seed

size and seed number/silique in canola (Haque et al. 2018). Undoubtedly, this is the most recent advance in genome editing with precise target as it is not dependent on random integration of foreign genes with potentially deleterious effects as in the case of transgenics which was confronted by some on the grounds of human health and ecological safety concerns. In Nepal, state agencies such as NARC and its subsidiary research farms mostly focus on breeding methods of introduction, domestication, selection, and hybridization for the development of OP varieties. The application of tissue culture techniques in crops like potato and banana, and hybrid development in rice, maize, and tomato are also being practiced by the state agencies and private companies in the country, but there is a long journey ahead to catch up with advances in cross-cutting science such as genome editing to enable practical seed production.

6.7 Mechanization in Seed Production and Processing

A recent study by Takeshima and Bhattarai (2019) reports that tractors, threshers, and irrigation pumps are the main machineries used by Nepalese farms. These machines are increasing efficiency and profitability of seed production business by allowing the producers to perform farm operations in a timely manner so that seed production and quality are least affected by adverse weather conditions such as excessive rainfall, wind, and hailstorm during seed harvest. In the meantime, the application of farm machinery increases farm and labor productivity. Takeshima and Bhattarai (2019) further state that the number of tractors and threshers is increasing within the rural locations because the equipment is being hired by small-scale farmers in the foothills and valleys of mountainous regions, suggesting that even small-scale farms can run seed production enterprises efficiently using such machinery. However, the cost of hiring machinery puts extra pressure on small farmers who use their own labor for farming operations. In the plain Terai region, such a practice is already common.

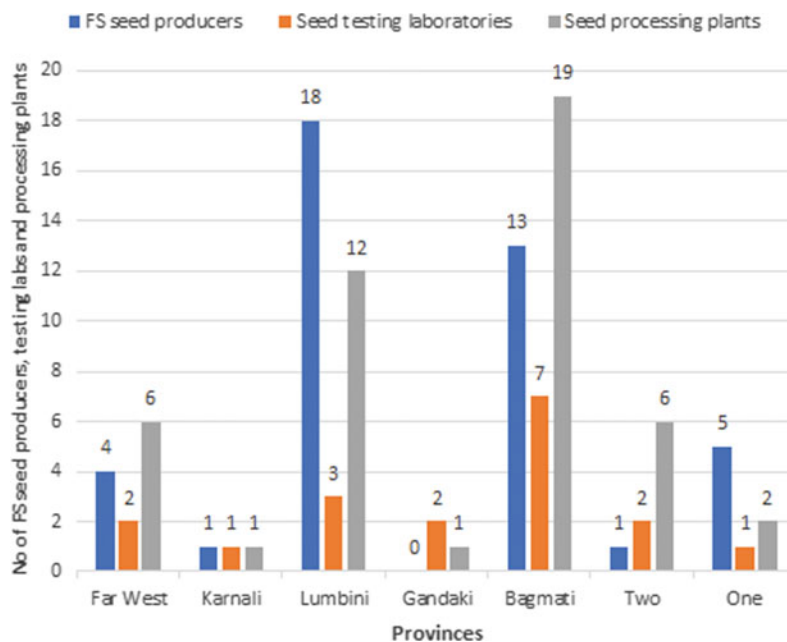
Important post-harvest operations of the seed are threshing, drying, grading, and storage. Threshing, drying of seed to a proper moisture content, and appropriate packaging of seed are vital operations in the value chain as it determines seed viability and vigor and guard against insect and disease attack until the seed is planted or sold. A recent study in the mid-western Nepal estimated that about 10–20% losses were observed in vegetable seeds from farms to the wholesale market due to poor drying and storage practices (Timsina and Shivakoti 2018). The unfavorable humid weather conditions immediately after harvest and poor storage facility at the seed grower's disposal were major problems of small-scale vegetable seed growers. The study recommended that promotion of post-harvest technologies to maintain a dry chain throughout the vegetable seed system would provide higher returns to the seed producers. The number of seed processing plants is limited throughout the country and especially so in four provinces—Karnali, Gandaki, Province number two and one (Fig. 6.2) indicating more investment is needed to establish and sustainably operate such infrastructure to boost the seed industry in the country.

6.8 Need for Application of Digital Technology in Seed Systems

In Nepal, SQCC has been using a paper-based system to record and plan seed production every year, but it is a time-consuming process and cannot provide accurate information when needed. A new digital seed information system, which enables all the value chain stakeholders to access the seed information in real-time, is needed to replace the existing system. During the time of restricted movement and social distancing due to the COVID-19 pandemic, importance of the live information system has been vividly realized.

The introduction of a digital technology to seed information systems will reduce the workload of SQCC as the demand and supply data will be entered by seed companies, traders, and research organizations. The system will link seed value chain actors to each other and provide vital information for seed users and suppliers for proper planning and management of good quality seed. In one exemplary initiative, the Nepal Seed and Fertilizer Project is deploying digital technologies to create an efficient, integrated, and

Fig. 6.2 The number of foundation seed (FS) producers, seed testing laboratories, and seed processing plants in Nepal by province (Source Drawn using data from SQCC 2019)



dynamic digitally-enabled seed information system in Nepal. The platform is expected to be useful in managing supply and demand for breeder seed, foundation/source seed, as well as certified/labeled seed for all crops on a real-time basis. Moreover, this system also has the capability to help policy makers to plan and monitor seed production and distribution over a time (Pradhan et. al. 2020).

6.9 Variety Development and Release or Registration in Nepal

In Nepal, the agricultural research and development program was initiated in 1950 and the plant breeding program began in 1951 (Joshi 2017). Since then, NARC, a public sector organization, has been developing new varieties of various crops and recommending technologies for production, processing, and post-harvest management of seeds. Although the variety development and submission for release or registration are open to both the public and private sectors after the initiation of “Directives for Variety Approval, Release, and Registration, 2016”, there is still dominance of NARC in developing new crop varieties.

Once the varieties are developed, they are submitted for release or registration in the National Seed Board (NSB). The national varieties are either released or registered and made available for the commercial production and transaction after their notification in the Nepal Gazette. NSB releases a variety if it is developed domestically and passes through all the steps of research protocol for development and recommendation for cultivation. Any varieties not meeting the above criteria can be registered under one of the three categories: (a) developed in Nepal, not yet passed through all the steps of research protocol but found appropriate for cultivation in at least two seasons’ multi-location yield trials, and showed superior performance in researchers’ observation; (b) developed abroad but found appropriate for cultivation in Nepal from at least two seasons’ multi-location yield

trials; and (c) local landrace. When the variety is released or registered, the name of that variety is required to be published in Nepal Gazette for notification purposes without which a variety has no legal entity. All varieties notified through this process are protected by the Plant Breeders’ Right (PBR). However, due to subsistence level of farming practices where farmers produce predominantly for their own consumption, only a small amount, if any, of the produce is sold and the chances of getting data on these sales are minimal. Therefore, the prospect of obtaining any end point royalties on PBR varieties is negligible until the farming is fully commercialized.

In the past, there was dominance of domestically developed varieties in the notification list. However, the situation has changed in recent years. Since 1960, the NSB has notified 698 varieties of crops of which 45% are nationally developed and 55% are introduced from abroad. Among the total notified varieties, 286 (41%) are notified through release and 412 (59%) are through registration processes. Out of them, 356 (51%) varieties are OP, 336 (48%) are hybrids and 6 (1%) are parental lines (Table 6.1 and SQCC 2021). Variety development in Nepal is constrained due to lack of trained manpower and appropriate infrastructures with both the public and private sectors. Due to this reason, there is a dominance of registered exotic varieties in the notification list.

6.10 Breeding for Biofortified Crops

Along with food sufficiency, undernutrition due to inadequate minerals and vitamins in the diet is a major problem in developing countries including Nepal. Nearly 41% of under five-year-old were stunted (low height-for-age), 29% were underweight and 11% were wasted (low weight-for-height) in 2011 in Nepal (MoHP et al. 2012). The sustainable development goal aims to reduce stunting below 15%, underweight 9%, and wasting 4% for the five-year-old population in Nepal by the end of 2030

Table 6.1 The number of open-pollinated, hybrid varieties and parental lines notified by the National Seed Board (NSB)/Seed Quality Control Centre (SQCC) in Nepal from 1960 to 2020

SN	Crops	Release			Registered			Total			Grand total	Denotified/ Deregistered
		OP	HB	PL	OP	HB	PL	OP	HB	PL		
1	Rice	67	2	–	17	48	–	84	50	–	134	23
2	Maize	22	5	6	1	59	–	23	64	6	93	14
3	Wheat	32	–	–	–	–	–	32	–	–	32	13
4	Finger millets	5	–	–	–	–	–	5	–	–	5	–
5	Barley	6	–	–	–	–	–	6	–	–	6	–
6	Buckwheat	1	–	–	–	–	–	1	–	–	1	–
7	Legumes	41	–	–	2	–	–	43	–	–	43	3
8	Oil seed	19	–	–	1	1	–	20	1	–	21	1
9	Industrial crops	12	–	–	–	–	–	12	–	–	12	–
10	Potato	11	–	–	5	–	–	16	–	–	16	–
11	Vegetables	49	–	–	56	220	–	105	220	–	325	58
12	Forage crops	15	–	–	2	–	–	17	–	–	17	–
13	Fruits	3	–	–	3	1	–	6	1	–	7	–
14	Sweet potato	2	–	–	–	–	–	2	–	–	2	–
	Total	273	7	6	83	329	0	356	336	6	698	110

Note OP = open pollinated, HB = Hybrid, and PL = parental lines. Source SQCC (2021)

(NPC 2017). The progress made on stunting, wasting, and underweight was found to be 36, 10, and 27 percentages, respectively in 2016 (MoH et al. 2017). The Multi-sectoral Nutrition Plan II puts major focus on the adequate nutrition of mothers and children in the first 1000 days from conception to avoid irreversible consequences and reduce undernutrition among women from 15 to 49 years of age by 15% (NPC 2017). In a similar note, about 95% of pregnant women have had food-derived-mycotoxin markers in the bloodstream in Terai region of Nepal, which has drawn public notice for intervention strategies to minimize food toxins and malnutrition of children and mothers (Andrews-Trevino et al. 2020). Malnutrition and food insecurity are likely being exacerbated due to the COVID-19 pandemic relegating millions of people to poverty and challenging the well-being of resource-poor communities due to economic, food, and health systems disruptions (Headey et al. 2020). Therefore, the development of biofortified varieties on major

crops can play a sustainable solution for addressing the malnutrition issues in Nepal. Until now, NARC has developed biofortified varieties from three crops: two in maize for quality protein (QP); five in wheat for zinc, iron, and/or protein, and four in lentils for zinc, iron, and/or protein (Table 6.2). To address the malnutrition problem, NARC is collaborating with different international research organizations and/or private seed companies to develop more nutrient-enriched varieties.

6.11 Seed Without Borders Initiative

Developing a crop variety is an expensive and time-consuming process requiring at least eight to ten years of research. To expedite the variety release, a concept of “Seeds without Borders” was initiated to facilitate exchange and use of crop varieties across countries. The initiative facilitates inter-regional sharing and transfer of

Table 6.2 Biofortified varieties of maize, wheat, and lentil crops developed by NARC in Nepal from 2008–2021

Crops	Varieties	Bio-fortification and concentrations	Released year	Production domains
Maize	Posilo-1	Protein	2008	Mid-hills from East to West Nepal below 1600 m
	Posilo-2	Protein	2018	Terai and inner up to 800 m altitude (summer and winter), Mid-hills: from 800 to 1800 m (summer)
Wheat	Zinc Gahun-1 (Zinc wheat-1)	Zinc (Zn) in grain: 34.5–45 ppm, Iron (Fe) in grain: 39–41 ppm and Protein (%): whole grain: 9.3–10.4 and flour: 9.2–10.0	2021*	Terai and inner-terai
	Zinc Gahun-2 (Zinc wheat-2)	Zinc in grain: 39.9 ppm, Iron in grain: 39.05 ppm, and protein in flour: 11.39%	2021*	Terai and inner-terai
	Khumal Shakti	Zinc and Iron	2021*	Mid-hills: 1000 to 1700 m altitude
	Himganga	Zinc and Iron	2021*	Mid-hills and high hills: 1000 to 2290 m altitude
	Bheriganga	Zinc and Iron	2021*	High hills: 1700 to 2290 m altitude
Lentil	Khajura Musuro-3	Fe: 81.475 mg per kg seed and Zn: 65.2 mg per kg seed	2017	Terai to mid-hills (180–1700 m)
	Khajura Musuro-4	Fe: 79 mg per kg seed, Zn: 45.19 mg per kg seed, and protein (%): 27	2019	Mid-Far Western Terai
	Shraddha Kalo Masuro	Fe: 75 mg per kg seed, Zn: 42 mg per kg seed) and protein (%): 25	2020	Terai-Inner Terai-Mid Hills

Note * = Approved by National Seed Board in March 2021 for the notification. *Source* SQCC (2021)

plant material beyond the border in similar agroecology to promote crop production (Jhomai 2020). The other initiative is the Siem Reap Agreement which was originally made among India, Bangladesh, and Nepal for rice in 2014. Later, the Dhaka and Kathmandu Agreements were extended to include all cereals, pulses, oil seeds, vegetables, sugarcane, and fiber crops.

Some progress has already been made in the last eight years with the start of the Protocol of Discussion, namely Dhaka Agreement 2013, followed by Kathmandu Agreement in 2014, and Siem Reap Agreement in 2017 (Jhomai 2020; Gauchan and Joshi 2019; MAFF and IRRI 2017). For example, India notified six rice varieties from Bangladesh and Nepal released two rice varieties, Ciherang sub-1 (submergence tolerant) and Hardinath-3 (drought tolerant) from

India, (MAFF and IRRI 2017). In addition, the process for the establishment of SAARC Seed Bank (2010) and other regional collaborations have been initiated.

6.12 Seed Storage and Buffer Stock

The seed buffer stock is a system where source seed and improved seed reserves are maintained for future uncertainties just like in the recent COVID-19 pandemic of 2020 when the seed demand can become unexpectedly high. The government should come up with a special program at strategic locations and seasons to mitigate the future unforeseen events. It was initiated by the then National Seed Company Limited (NSCL) to some extent, but maintenance and

management of seed buffer stocks for emergency needs have not been handled properly despite the National Seed Vision's recommendation of 10–20% of seed quantity to be stored as buffer stock by 2025 (SQCC 2013a).

A big investment is required to establish traditional seed storage structures in Nepal. However, new dry chain technology would enable storage of recalcitrant seeds without using the traditional cold infrastructures (Bradford et al. 2018). A recent study by Bhaktavar et al. (2019) has reported that maintaining dry chain during storage of maize seeds in hermetically sealed bags was the most effective option for maintenance of seed quality by minimizing insect pest incidence. Currently, federal and provincial governments, development partners, and financial institutions have offered subsidies and or loans to seed companies, cooperatives, or farmers' groups to establish and refurbish seed storage facilities in each province. Moreover, some established seed companies and cooperatives and farmers' groups have been receiving enough support from different development partners. So, the wider adoption of dry chain practices along with use of existing unused storage infrastructure after minimum refurbishment would be the most cost-effective and practical option for strengthening seed supply chain.

6.13 Seed Demand and Supply

In Nepal, seed supply is met through the domestic production of OP varieties and import of mostly hybrid seeds. The domestic seed is mostly produced by seed companies, cooperatives, farmers' groups, and individual farmers and sold to growers through agrovets (60%), cooperatives (15%), local governments (15%), and development projects (10%), where more than 60% seed is subsidized by the local governments and the development projects (Ghimire et al. 2020). More interestingly, most of the hybrid seeds are sold through agribusiness shops, including the hybrids produced domestically.

Farmers prefer to grow hybrids due to high yield potential over the OP seeds and easy availability of notified hybrid seeds in the agribusiness shops. Majority of such seeds are imported into Nepal from India. Importers must obtain a license from the NSB Secretariat. However, due to the open border between India and Nepal, seeds of notified varieties are also brought to Nepal illegally without obtaining a license. In addition to the seeds of notified varieties, some traders, agrovets, and farmers bring spurious seeds on the name of hybrids (SEAN 2012) which are often not true hybrids and farmers bear significant losses every year.

In 2019, 45 licensed firms imported seeds from 30 international seed companies and sold through seed dealers, wholesalers, agrovets, cooperatives, and farmers' groups. The total seed import of maize, rice, and vegetables seed increased over 12-fold from around 255 tons in 2010/11 to 3,200 tons in 2018/19 (SQCC, 2020 unpublished data). The demand for major OP seeds is increasing consistently, but the supply is not keeping pace with increasing demand (Table 6.3). The total value of all seeds sold in Nepal was US\$27.6 million from 32,360.0 tons in 2018/19, whereas the value of domestic seeds was US\$14.9 million from 28,110.0 tons. The value of imported seed was US\$12.7 million only from 4,250.0 tons (Ghimire et al. 2020). Because of this big and ever-widening gap of seed demand and supply situation in the country (Table 6.3), Nepalese farmers often source seeds, especially hybrid seeds of vegetable and rice, from other countries via informal channels. As a result, quality and genetic purity of those seeds are not properly tested and assured by the national seed authority. In recent years, there have been frequent reports of crop failures and a big economic loss to growers. To address those issues, measures including strengthening informal seed supply with wider adoption of dry chain storage practices, awareness education to innovative growers, and access to technical support for hybrid seed procurement are recommended.

Table 6.3 Seed demand and supply (tons) of different crops during 2013 to 2019

Year		Rice	Maize	Wheat	Lentil	Rape seed
2013	Demand	76,576	21,785	91,833	6829	1985
	Supply	9135	2492	10,958	190	154
2014	Demand	71,009	21,241	90,509	6829	1985
	Supply	9537	2330	10,216	280	140
2015	Demand	71,237	17,648	91,285	8179	2162
	Supply	9621	2294	12,259	352	166
2016	Demand	68,145	17,832	89,499	8179	2162
	Supply	9472	2407	12,530	368	173
2017	Demand	71,195	19,552	92,703	8226	2133
	Supply	10,297	2989	13,983	397	183
2018	Demand	73,477	23,854	84,821	7906	2246
	Supply	13,533	3683	12,910	388	274
2019	Demand	70,252	23,911	84,479	8351	2603
	Supply	16,453	3721	16,068	449	344

Source (SQCC 2010/11 to 2018/2019)

6.14 Seed Policies and Regulations

There are two streams of policies and laws providing guidance for seed sector development in Nepal. The policy consists of National Seed Policy 2000 (NSP), NSV, and Agriculture Development Strategy (ADS). Similarly, the current legal stream consists of Seeds Act 1988 (amended in 2008), Seeds Rules 2013, 11 directives, and two guidelines approved between 2016 to 2018 to facilitate the implementation of Seeds Rules, 2013. In this section, we will briefly discuss those policies and laws and how these legal documents are contributing to the implementation of policy provisions for the development of a robust seed system in Nepal. To improve the seed system, the need to update these policies and laws are reviewed in line with the advancement in the seed value chain at the national and international levels.

6.15 National Seed Policy 2000

Seeds Act 1988 and Seeds Rules 1997 were in operation before the approval of national seed policy (NSP) in April 2000 in line with the Act

and Rules. Seeds Act 1988 and Seeds Rules 1997 are supportive to achieve the NSP goal, which provides a broad framework for the contribution of transactions and use of good quality seeds to increase crop yield (MoAD 2013a). The NSP aims to increase the availability of quality seeds, promote seed exports by increasing the effectiveness of seed business, and coordinate with relevant agencies for conservation and rights protection over the indigenous genetic resources. To achieve these objectives, policy measures are suggested in variety development and maintenance, seed multiplication, quality control, increased involvement of the private sector in seed business, distribution mechanism, institutional strengthening, and the use of modern technology including the dry chain.

The NSP contributed increasing involvement of the private sector in seed production, processing and distribution, seed testing, seed analysis, seed sampling, and seed crop inspection. Similarly, the use of modern technologies in seed production and quality assurance and the establishment of Seed Quality Control Centre as a regulatory body to monitor the seed quality during the flow from producers to end-users are other strengths of this policy. Besides these strengths, there are some weaknesses in the

NSP. Farmer's preference is largely increasing toward hybrids, but the focus of this policy is on open-pollinated seeds, and it is silent on the development and use of hybrid seeds. Similarly, there is a big role of seed processing, storage and handling, and seed marketing in maintaining the seed quality that is inadequately dealt with in the NSP (Khanal 2017).

6.16 National Seed Vision 2013–2025

The national seed vision (NSV) was approved and implemented by the Government of Nepal in April 2013 (SQCC 2013a). Implementation of NSV is based on the five value chain stages: viz varietal development and maintenance, seed multiplication, seed processing, and conditioning, seed marketing, and seed use. The overall goal of this vision is to increase farm income by increasing crop yield and create employment opportunities through increased business activities in the seed value chain for self-sufficiency, import-substitution, and export promotion. The NSV aims to increase the SRR of cereals from 11% in 2010 to 23.8% in 2025 and vegetables from 68 to 90% in the same duration. Other aims are increasing the cumulative number of OP varieties from 232 in 2010 to 423 in 2025 and hybrid varieties from 2 in 2010 to 60 in 2025 through joint efforts of public and private sectors, reaching rice and vegetable yields to 3.8 t/ha and 19 t/ha, respectively. The establishment of four big seed industries with research and development capacity by the private sector is another major target of this vision.

The NSV was reviewed twice in 2017 and 2020 after its approval. The first review showed that the SRR of cereals seems achievable but the stagnant status of SRR in vegetables from 2015 to 2019 indicates that the SRR target of vegetable seeds is difficult to achieve (SQCC 2018; Ghimire et al. 2020). The variety development target of NSV is also lagging. Only 47 OP and seven hybrid crop varieties were developed and released within the last six years of the NSV commencement, and 144 OP and 51 hybrid

varieties must be developed and released in the remaining six years of NSV to meet the target which seems to be difficult to achieve (Table 6.1). The necessary Directives and Guidelines have been prepared, but they are still to be approved by the Council of Ministers and notified in the Gazette for formal legality. Although the foundation work has been completed, the establishment of large seed industries by the private sector is yet to be achieved. The NSV proposed to increase the budget, trained manpower, infrastructure facilities, and institutional arrangements to achieve the seed production targets. Alternative measures were proposed to increase scientific manpower by mobilizing university students and academics and the scientists working outside the public sector. However, these matters are still under consideration which is a concern for achieving the NSV goal (SQCC 2018).

6.17 Agricultural Development Strategy

The agriculture development strategy (ADS) is a visionary document for 20 years (2015 to 2035) prepared concurrently with the NSV. The vision states that a self-reliant, sustainable, competitive, and inclusive agriculture sector drives economic growth and contributes to improved livelihoods and food and nutrition security leading to food sovereignty (GoN 2016). The ADS has not dealt with the seed sub-sector separately but mentioned it in guiding principles to keep linkages between the ADS and NSV (SQCC 2018). There are commitments in the ADS to support capacity building and mobilizing resources as per the provisions of existing seed policies and the NSV. The ADS emphasizes on community-based seed production, an initiative adopted to produce and manage the seeds of specific crop varieties following standard procedures for the fulfillment of community needs and supply the excess amount outside. In addition, the ADS highlighted the development of competent hybrid varieties and producing their seeds to fulfill domestic demand, establishment of a seed information system, and

protecting seed sovereignty of the people. Adoption of dry chain technology in the seed production and supply system can greatly help to meet these demands.

6.18 Evolutions of National Seed Laws

Seeds Act 1988 was promulgated to provide a legal framework for the supply of good quality seeds to farmers. There is a provision by the NSB to look after the policy and variety notification and other provisions to provide a legal base for the transaction of good quality seeds in the market. The Act was amended for the first time in 2008 (SQCC 2014) to address the issues observed in the seed sector in the last 20 years and further strengthen this sector in changing global and national context.

The promulgation of the Constitution of Nepal in 2015 transformed the country from the unitary system to a federal structure of governance with the formation of federal, provincial, and municipal governments. The Seeds Act was amended together with other Acts in March 2019 to harmonize them with the new constitution. The federal and provincial governments have the regulatory power for seed quality control after this amendment (GON 2019). For full amendment of this Act in line with the Constitution of Nepal, a bill was registered in the Federal Parliament in May 2019 (MoALD 2020a), but it is yet to be approved. This delay further delays the amendments of rules, directives, and guidelines, which are attached to the Seeds Act. This will be detrimental to keep the seed business on the right track.

The first amendment of the Seeds Act 1988 created the need for amending the existing Seeds Rules. The amendment of Seeds Rules 1997 was started immediately after the amendment of Seeds Act 1988 in 2008. To align the rules with the amended Act, most of the rules were either changed or new ones added. The rules that were changed or added outweighed the rules that got

continuity. Hence, the government decided to replace Seeds Rules 1997 with Seeds Rules 2013 (SQCC 2014).

Seeds Rules 2013 describes the composition as well as the roles and responsibilities of the three sub-committees: Variety Approval, Release and Registration; Planning and Monitoring; and Quality Standard Setting and Management specified in the Seeds Act 1988. Similarly, the rules explain the variety approval, release, and registration process. In comparison to the previous rules, the process of obtaining a license for undertaking seed business has been simplified in Seeds Rules 2013. Provisions of seed certification and truthful labeling system parallelly from breeders to improved seeds, allowing the private sector to establish seed testing laboratories, monitoring seed quality from field to markets by the individuals having specific qualifications, making seed sellers liable if producers bear the loss from the use of seeds sold with a false declaration are other additional features in the Seeds Rules 2013. Thus, the Seeds Rules 2013 provide more freedom to work and place responsibility to the private sector than the replaced Seeds Rules 1997.

There are two groups of directives and guidelines. The directives and guidelines prepared before the approval of Seeds Rules 2013 and NSV are categorized in the first group. The second category of directives was prepared after the approval of Seeds Rules 2013 and NSV to facilitate proper implementation of their provisions. This category is approved and implemented mainly to enhance the role of the private sector in the seed business and make seed entrepreneurs responsible for the quality of seeds they produce and supply. All these directives and guidelines are expected to help increase the role of the private sector and decrease the role of the public sector in seed business as envisaged in the NSV (SQCC 2013a).

In summary, the Nepalese seed sector is working under the broad framework of NSV, which was prepared to overcome the shortcomings observed in the NSP. To support the

implementation of policy provisions in the NSV and NSP, except the latest proposed amendment of Seeds Act, other legal documents (rules, directives, and guidelines) were amended or formulated timely and brought under implementation. If we compare the policy and legal environment of Nepal with her nearest neighbors, they are more favorable for the growth and development of the seed industry (Khanal 2017).

6.19 Challenges and Opportunities of Seed Industry in Nepal

Nepalese seed sector is experiencing challenges on numerous fronts such as delay in amending Act, inadequate human resources, inadequate infrastructure and facilities, low quality of informally supplied seeds, and limited application of advanced technologies. The amendment of the Seeds Act, which facilitates the amendments of other legal instruments, is pending in the Parliament. This will have an impact on maintaining the quality of seeds in the seed value chain. Similarly, the draft of the Plant Variety Protection and Farmers' Rights Bill, which would be instrumental in protecting the breeders' rights over the varieties they developed and farmers' rights over the indigenous varieties they protected is yet to be passed by the Parliament. The development of new competitive varieties and their adoption by farmers is lagging due to inadequate human resources, infrastructure facilities, and capital investment. Quality improvement of informally supplied seeds is neither in the priority of government nor users although the share of such seeds is around 80%. All these factors have compounding effects on agricultural production and profitability, national-level food and nutrition security, and achievement of national commitments to sustainable development goals, namely 1, 2, 13, and 15.

Despite these challenges, the vegetable seed industry is growing fast in Nepal. The industry has a high comparative advantage because of varied agroclimatic conditions and rich biodiversity in the country and favorable government

policies and priorities. There is huge potential of producing high-value low-volume vegetable seeds in the high hills and mountainous regions and exporting them to the international market. The increasing awareness of farmers on quality seeds has created demand for domestically produced seeds which is ultimately good for the growth of the domestic seed industry. A recent study in rice seeds revealed that about 70% of seeds produced and supplied in the market were truthfully labeled, while certification accounts for only one-third of the marketed seeds (Gauchan et al. 2014). Because of favorable policies and laws and the commitment of the private sector, the opportunities to grow the industry are plenty. The technical capacity of the private sector has also been developed tremendously in the past few years through the implementation of different projects. Proper utilization of seed production potential, improvement in the quality of informally produced seeds, increased farmer level awareness on seed quality, and enhanced participation of private sector in breeding and seed quality control could boost the national seed system.

6.20 Contribution of Seed Sector to Sustainable Development Goals

Regarding Nepal's progress in SDG (1) of ending poverty in all forms everywhere, the percentage of people living below the national poverty line significantly dropped from 38% in 2000 to 21.6% in 2015 and further to 16.7% in 2019/20 (NPC 2020). However, Nepal faces challenges in achieving SDG (2) of achieving zero hunger, food, and nutrition security. The current rate of progress needs to be accelerated to meet these goals. These are not standalone goals but interlinked with various other goals (NPC 2020). Disasters like floods, drought, and current COVID-19 pandemic have given an important lesson to the policy makers that preparedness to address unexpected events of public importance is critical, especially in keeping pace with domestic food production and assurance of

national food stock. The immediate response of the GoN was the directive to focus on supporting its citizens and increasing food production in the next cropping season. However, this comes with the challenge of meeting unexpected high demand for quality seeds. Although the NSV envisaged buffer seed stock up to 20% of the total seed for uncertain times, it was not achieved when COVID-19 hit. The Right to Food and Food Sovereignty Acts 2018 recently introduced by the GoN to address zero hunger provided strong support for the achievement of SDGs (1) and (2), but seriously lacked concrete action plans to improve food availability, and strategies to deal with crises (Adhikari et al. 2020). The two other relevant SDGs for the agricultural sector that have strong influence in the robust seed systems are urgent actions to combat climate change (13), thereby minimizing effects of flooding during rainy season to seed and to protect and restore sustainable ecosystems (15).

6.21 Conclusion and Policy Recommendations

Favorable policies to create a working environment for seed value chain stakeholders, trained human resources in the public and private sectors and capital investments are prerequisites for seed industry development in Nepal. There should be a balanced development of the aforesaid areas for sustainable growth in the seed sector. Several policies and laws were developed in the seed sector. However, the recent restructuring of governance after the promulgation of the constitution in 2015, created confusion on the smooth implementation of these laws and policies. The amendment of the Seeds Act, which facilitates the implementation of rules, directives, and guidelines is yet to be completed. Besides the lack of progress in formulation of laws and policies, not much progress has been achieved in the capacity building of human resources in the seed sector. Seed quality control mechanisms could not become fully functional unless simultaneous progress is made in all these areas.

Significant progress has been made on the enabling of the private sector in the seed industry in Nepal. Private sector, which has a significant contribution in the functioning of the seed value chain, is onboard now. The private sector-friendly policies and laws have revitalized and made them committed in the seed business. Current research activities are focused in developing open-pollinated varieties and producing their seeds, on the contrary farmers' preference is on hybrid seeds showing a gap in the demand-driven research. Based on the review of the Nepalese seed sector, following policy recommendations are made:

1. Seed vision needs to embrace new quality-centric technology like dry chain method that can be upscaled to improve food and nutrition security, biodiversity, and disaster resiliency.
2. The NSV has provided a broad framework to develop hybrid varieties to meet its increasing demand. Research is also directed in public and private sectors to increase the number of hybrid varieties in rice, maize, and vegetables. However, clear guidelines to produce hybrid seeds and maintain their standards are lacking.
3. Seed sector policies and laws implemented after 2013 made the role of the public sector as a facilitating body and kept the private sector at forefront. Implementation of those policies is essential to improve the capacity of private sector stakeholders and speed up seed industry development. The private sector in Nepal is becoming ready to perform unconventional roles, such as variety development, maintenance, producing breeder seeds, maintaining seed quality through its own mechanism, and seed quality testing which are mostly done by the public sector. It will be better for the public sector to work jointly with the private sector for the next few years to develop the capacity of the private sector to perform these roles independently.
4. Private sector needs to communicate more frequently with public institutions;

- establishment of a private sector coordination cell in the NARC would be an appropriate measure to bring the public and private sectors close to each other.
5. The Nepalese landraces and their genetic enhancement should be strengthened by using both conventional and molecular techniques focusing on regional and location-specific or niche-based varietal improvement. The application of tissue culture techniques in crops like potato and banana, and hybrid development in rice, maize, tomato, and other crops are very important. Embracing new tools such as marker-assisted selection will enhance breeding process. Genome editing technologies such as clustered regularly interspaced short palindromic repeats (CRISPR)- Cas9, CRISPR-Cas12a, and base editors are the new generation tools for efficiently modifying the plant genomes in crops to improve traits without integrating foreign DNA into the genome. However, it is urgently necessary to strengthen the organizational and human resources capacity to embrace this technology in Nepal.
 6. To fulfill the gap between seed demand and supply, the capacity of private sector needs to be strengthened in seed production, processing, quality maintenance, storage, and distribution. Public sector needs to be supportive to the private sector by increasing the supply of breeder/nucleus seeds/inbred lines, investment in advanced technologies, use of modern technologies in information collection and dissemination, as well as the frequency of monitoring and guidance of scientists and seed specialists.
 7. In the seed industry, data is collected and processed manually until now, but the work has begun to digitize the seed information systems for efficient information management and data sharing. This needs to be implemented as soon as possible to make the seed system more effective.
 8. The implementation of directives, namely “producing seeds of pre-release varieties for quick dissemination and adoption, 2016” facilitates the participation of the private sector in the variety dissemination process and quick adoption of newly released varieties. The provisions of such directives must be followed sincerely to reap the benefits of newly released varieties by farmers and end-users.
 9. Trained human resource is always a major constraint in the seed sector of Nepal. An institutional mechanism needs to be established to source diaspora expertise and attract university academics and students in the seed business. The uniform variety registration process for all crops is found unsuitable for vegetable crops in Nepal. The vegetable sector includes several crops and there are several varieties in each crop. Private sector is hesitant to go through a long registration process to import small quantity of seeds of a particular variety as the variety-wise seed use is low. Therefore, it is recommended to simplify the vegetable variety testing and registration process. This will help to increase the use of formally supplied seeds and ultimately the SRR.
 10. Extension programs need to be developed to improve the quality and supply of farm-saved or seeds acquired by farmers through other means such as through commodity exchange or received in kind, which are other seeds produced informally at the community level. This will help increasing the production and yield as well as conserve indigenous crop varieties.

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Agrobiodiversity, and Neglected and Underutilized Species for Food, Nutrition, Livelihood, and Environmental Security in Nepal

7

Bal Krishna Joshi and Devendra Gauchan

Abstract

Agrobiodiversity is one of the important components of biodiversity that is important for food and nutrition security. This chapter aims to highlight the importance, conservation, and sustainable use of agrobiodiversity with special emphasis on native, neglected, and underutilized species (NUS) and future smart crop species for ensuring food and nutrition security in Nepal. The paper is derived from a literature review and the authors' experiences of implementing some relevant project activities and initiatives in Nepal for the last two decades. Nepal has initiated conservation and sustainable use of agrobiodiversity employing four strategies namely ex-situ, on-farm, in-situ, and breeding. About 85% of the cultivated crop species in Nepal are NUS. The use of NUS and landraces in research and breeding is very limited. Recently some good initiatives and practices have been developed and piloted for

the conservation and use of agrobiodiversity. These NUS can directly contribute to achieving the UN's Sustainable Development Goals (particularly Goals 1, 2, 3, 8, 12, 13) and fulfilling national goals of reducing poverty and ensuring food and nutrition security. Poor investment in research, education, and development, and weak seed regulatory framework is the key "policy" constraint for the promotion of NUS. Developing site-specific staple, nutritious, and climate-resilient varieties and diversified products utilizing rich agrobiodiversity of diverse NUS crops for the promotion of sustainable agriculture systems is the best strategy for long-term food, nutrition, environment and livelihood security in the country.

Keywords

Agrobiodiversity • Good practices • Neglected and underutilized species • Food and nutrition security • The site-specific staple crop

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7.1 Introduction

Food, nutrition, and livelihood security are the prime concern of each person, household, community, region, and country. From the beginning of human civilization, agrobiodiversity—a subset of biodiversity is the key and the simplest means for food, nutrition, and health security of human

beings. With the increase of population pressure, ensuring food and nutrition security is becoming a global challenge. Economic development and cultural change can reduce the value of maintaining crop diversity on-farm due to the availability of scientifically bred varieties and complementary external inputs which may foster specialization into a few varieties (Bellon et al. 2015). As a result, multiple negative consequences are observed in terms of loss of agrobiodiversity, crop failure, and increased vulnerability due to stresses, poor adaptation, and changing climate (Mizatovi et al. 2012; Chaudhary et al. 2020; Joshi et al. 2020a).

Nepal's total estimated population in 2019 was 28.34 million with a growth rate of 0.61% per year within the last eight years (Fig. 7.1; MoALD 2020). Growth rates of livestock and agricultural production are higher than population growth rates (Joshi 2017a). These populations need to feed on total cultivated land areas of 3.09 million ha (21% of total land). Currently, 60% of the total population is involved in agriculture (MoALD 2020). Agrobiodiversity is directly related to total agricultural land and farming communities for higher production. Growing evidence exists that agrobiodiversity can support resilient livelihoods, healthy diets, and nutrition and promote sustainable land use and ecosystem services and contribute to adaptation to changing climate (Bioversity International 2017; Gauchan 2019; Maraseni et al. 2021). It is commonly observed in Nepal that an average number of items in a regular food dish (either morning or evening meal) constitutes about 17 species—rice (or maize or finger millet), grain legume (*daal*), main vegetable (*tarkaari*), green leafy vegetable (*saag*), pickle (*achar*), milk (or curd), turmeric (*besaar*), ginger (*adhuwa*), cumin (*jiraa*), chili (*khursaani*), tomato, garlic, onion, coriander, fenugreek (*methi*), lemon (*amilo*) and oil. This also indicates how much diversity is used in food culture for our survival. These diversities are needed for longer-term food and nutrition security along with to achieve UN's Sustainable Development Goals (SDGs) (particularly Goal 2: zero hunger; Goal 12: responsible consumption and

production; Goal 13: climate action; Goal 14: life below water, and Goal 15: life on land).

Nepal is rich in agrobiodiversity due to diverse climatic variations, agroecology, and socioeconomic settings (Upadhyay and Joshi 2003) that have created and maintained many variants within different species of crops, forage, livestock, insects, micro-organisms and aquatic plants, and animals (Joshi et al. 2020a). Each agricultural genetic resource (AGR) has an important role in food, nutrition, environment and health security. However, research, development, and education have not given due consideration to these native agricultural genetic resources particularly those of neglected and underutilized species (NUS) for their use in food and nutrition security (DFQTC 2012; Joshi et al. 2019a, 2020b). Exotic agricultural genetic resources have dominated everywhere for example in farmer's fields, markets, education, kitchen, etc. Recently, many stakeholders have started giving priority to native and localized AGRs. National Agriculture Genetic Resources Center (NAGRC), Local Initiatives for Biodiversity, Research and Development (LI-BIRD), Ministry of Agriculture and Livestock Development (MoALD), and Biodiversity International have jointly implemented more than 25 agrobiodiversity conservation (ABC) and related projects across the country since 1997. This chapter aims to highlight the importance, conservation, and sustainable uses of agrobiodiversity with special emphasis on native AGRs and those of NUS and future smart crop species for ensuring food, nutrition, and livelihood security in Nepal, mainly based on the experiences, outcomes, and good practices of these projects and the authors' experiences of working in this field for the last more than two decades.

7.2 Need of Conservation and Sustainable Use of Agrobiodiversity

Conservation and sustainable use of agrobiodiversity is vital for ensuring food and nutrition security, supporting livelihoods, and improving

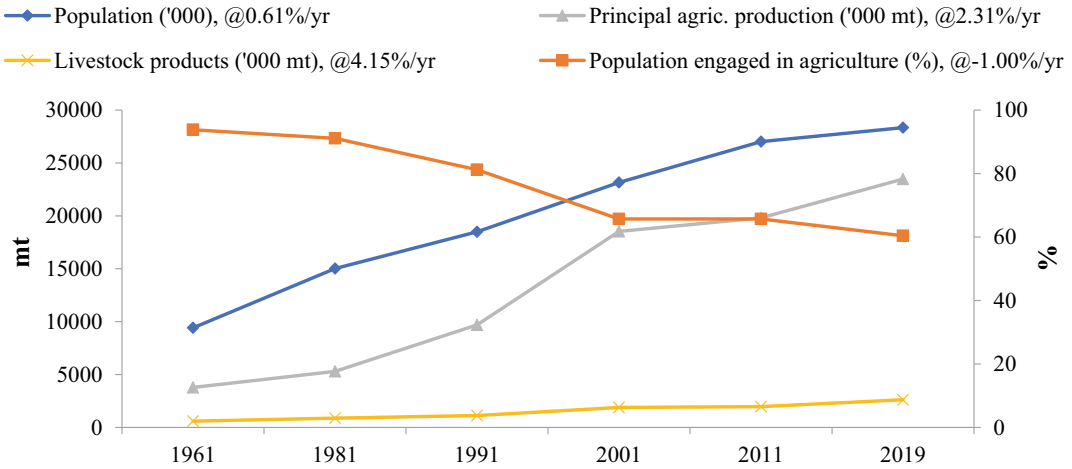


Fig. 7.1 Total population, agriculture production, and growth rate over years (growth rates in percentage are for from 2012 to 2019). *Source* Drawn from Joshi (2017a); MoALD (2020)

ecosystem services. Agrobiodiversity exists at all levels (ecosystem, species, genetics) in different locations (Pudasaini et al. 2016; Shrestha 2013; Upadhyay and Joshi 2003; Gauchan et al. 2003). In the past until the early nineteenth century, when the population was low, native and original (*Maulik*) technologies including native landraces were enough to secure food and nutrition. Major principles and practices should therefore be focused on *Maulik* technologies including native agrobiodiversity and marketing them globally for food, nutrition, and livelihood security. Working and developing site-specific staple cereals, vegetables, pulses, fruits, livestock, and aquatic species should be the main strategy for sustainable use and conservation of agrobiodiversity.

Agricultural Genetic Resources (AGRs) are mainly for food and nutrition security. The food security situation is deteriorating in Nepal and major factors for this situation are poor agricultural growth, genetic loss, declined national agricultural priority, global climate change, global food crisis, and political instability (Bista et al. 2013). About 71,400 tons of food was deficit in FY 2017/18 (MoALD 2020), and 35 districts are food deficit (Pokhrel et al. 2017). The status of food security and nutrition of the people in Nepal is extremely low as the country in 2018 ranked 73rd position in Global Hunger

Index (GHI) out of 135 countries (von Grebmer et al. 2020).

In the total of cereal grains, production is higher than the requirement, but large amounts of agricultural produces are imported every year. Therefore, research and development need to focus on market and consumer demands. The best strategy for increased food production is a vertical expansion for which genetic enhancement is most to all AGRs.

7.3 Agrobiodiversity in Achieving National and UN Sustainable Development Goals

Agrobiodiversity is vital to meet the national development goals and targets related to agriculture including food, nutrition, and health security envisioned in Agriculture Development Strategy (MoAD 2015), National Seed Vision 2013–2025, new Constitution of Nepal (2015), NBSAP (MoFSC 2014), Zero Hunger Challenge (MoAD 2016) and 15th plan (NPC 2019).

Agrobiodiversity is directly or indirectly related to meeting most of the Sustainable Development Goals (SDGs), mainly SDG (1) No Poverty, (2) Zero Hunger, (3) Good Health and Well-being, (8) Decent Work and Economic

Growth, (12) Responsible Consumption and Production, and (13) Climate Action. Goal 2 (zero hunger) seeks sustainable solutions to end hunger in all its forms by 2030 and to achieve food security. The aim is to ensure that everyone everywhere has enough good-quality food to lead a healthy life. Moreover, Nepal made its commitment to undertake Zero Hunger Challenge (ZHC) declared by the Rio+20 Conference on Sustainable Development held in Brazil in 2012. To make Nepal free from hunger and malnutrition by 2025, the Ministry of Agriculture and Livestock Development (MoAD) launched the ZHC Initiative on 19 December 2014 (MoAD 2016) with the development of five strategic pillars. To achieve the targets of ZHC, every component of agrobiodiversity should be managed, utilized, explored, and improved across the country.

7.4 Components and Sub-Components of Agrobiodiversity

Three main sources of AGRs in farming communities are from own production, exchange from neighbors/relatives, and purchase from market. These AGRs are scientifically categorized and outlined in terms of components and sub-components based on nature and uses. Agrobiodiversity has been grouped under six components namely crops, forages, livestock, aquatic, insects, and micro-organisms (Fig. 7.2). Each component is further divided into four sub-components, i.e., domesticated, semi-domesticated, wild relatives, and wild edible in Nepal (Joshi et al. 2020a). Agrobiodiversity on each component and sub-component exists at five levels (agroecosystem, species, variety/breed/biotype/race/strain, genotype, and allele levels).

Status and Distribution: Nepal ranks 49th in the world for biodiversity with a total of 24,300 species in the country (MoFSC 2014; Joshi et al. 2020a). Among them, 28% are AGRs. Climatic variations are the major determinant factors to maintain and create huge diversity in agriculture. Economically valued such AGRs have been

reported within an altitude range from 60 to 5000 msl in Nepal (Joshi et al. 2020a). The total number of species both native and exotic under different components and sub-components are listed in Table 7.1. Insect and microorganism genetic resources cover only economical (food value and direct use) and beneficial species. Insect species are higher in number followed by crop species. Though insects have not commonly been focused on food and direct use. Under crop and forage species, a total of 1506 species have been reported (Fig. 7.3) (Joshi et al. 2017a, 2020a; Upadhyay and Joshi 2003). Among them, 93 species are introduced, 670 species are wild edible, 224 are crop wild relatives, 35 are semi-domesticated and 484 are cultivated crop species. Among 484 cultivated species, 64 are agronomic, 145 are horticultural and 275 are forages species. However, due to the focus on exotic materials and other factors (Chaudhary et al. 2020), about 40% of the native agrobiodiversity has been lost and farmers in many locations have reported up to 100% loss of a particular species (Joshi et al. 2020a).

Importance: Agrobiodiversity has a greater role in the provision of regulating and supporting ecosystem services, in particular regulating pests and diseases, increasing levels of pollination, carbon sequestration, and improving water quality and soil-forming processes (Hajjar et al. 2008; Acharya et al. 2019). Agrobiodiversity can also improve the resilience of climate change at the landscape, farming system, and farm level with a diverse use of resilient species, varieties, and breeds (Mijatovi et al. 2012). It can fulfill the diverse requirements of humans and supply the thousands of different kinds of genotypes to grow in diverse agro-climatic conditions.

Among the many basic practices, the major determining factors for the continued maintenance of agrobiodiversity are diversified stresses, diversified production, diversified growers and consumers, diversified seasons for achieving diversified products, and diversified nutrient contents and environmentally balanced products (Fig. 7.4). Diverse forms of many businesses also depend on sustainable use of agrobiodiversity. Settlement of human being in a wide altitude

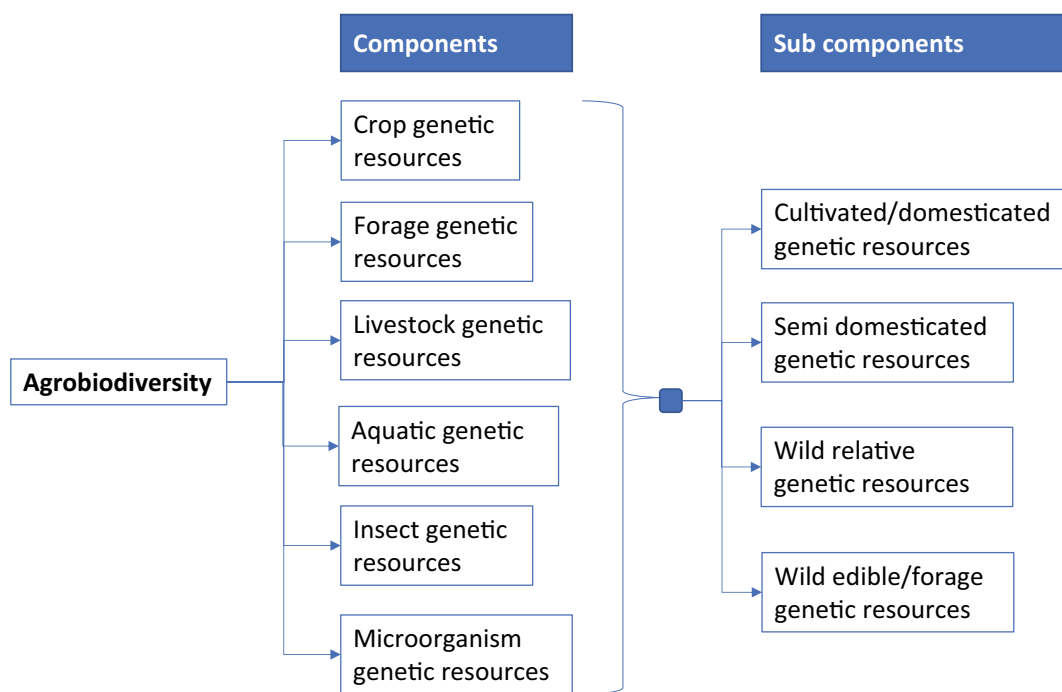


Fig. 7.2 Coverage and components of agrobiodiversity (Adapted from Joshi et al. 2019a)

Table 7.1 Number of species and estimated loss percentage (in parenthesis) of agricultural genetic resources in Nepal

Agrobiodiversity component	Sub-component				Total (Average)
	Domesticated	Semi domesticated	Wild relatives	Wild edible	
1. Crop genetic resources	295(60)	30(45)	214(45)	500(50)	996(50)
2. Forage genetic resources	375(40)	5(35)	10(40)	170(45)	510(40)
3. Livestock genetic resources	21(45)	3(35)	4(30)	11(50)	35(40)
4. Aquatic genetic resources	46(40)	7(30)	NK	230(35)	267(30)
5. Insect genetic resources	29(15)	5(10)	10(10)	3467(45)	3500(20)
6. Microbial genetic resources	32(15)	10(10)	6(20)	760(35)	800(20)
Total	782(36)	60(28)	244(30)	5146(45)	6108(35)

NK, Not known. Domesticated species include both native and exotic species. Adapted from Joshi et al. (2020a)

range in the country is only possible because of the successful production of agrobiodiversity. Even one can produce a variety or breed of the same species with different nutrient contents by growing in a different environment. People can get balanced and better nutrients by consuming food items that are produced in the same locality. Long-term growing of the same genotypes in the same locality can produce more nutrient-dense

products that most suit the local demand. These general statements should always be considered for a healthy environment. Native AGRs are considered tastier and costly than others because of their local preferences and therefore getting higher benefits from their sales by some farmers and businesspersons. The study showed that modern varieties of rice, wheat, and maize crops have higher carbohydrates and less

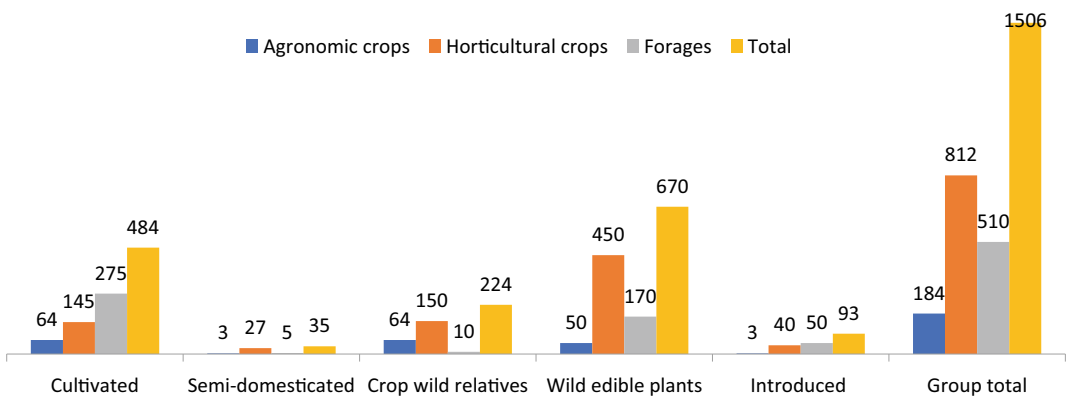


Fig. 7.3 Total species of agricultural plant genetic resources in Nepal. The bar within the category corresponds bottom to top for the legend sequence. Adapted from Joshi et al. (2017a)

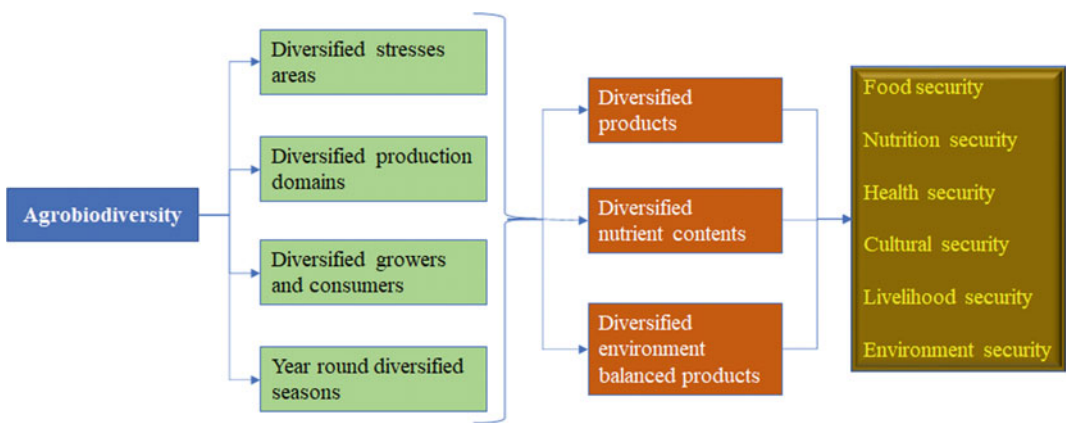


Fig. 7.4 Scope and basic practices of agrobiodiversity for food, nutrition, and livelihood security (Source Authors’ own conceptualization)

micronutrients than their native landraces and other minor cereals (Joshi et al. 2020b). Many other nutrients are better in minor cereals and native landraces compared to improved major staple crop varieties (Joshi et al. 2020b).

7.5 Agrobiodiversity for Sustainable Farming System

A sustainable and profitable farming system is the most demanded and expected system in the production sector. Almost every earth point and time differs and keeps changing; therefore,

agriculture practices should accord with this that help to develop better and competent genotypes continuously. But modern agriculture ignores the site-specific evolutionary process and stops using the genetic entity grown from within the same crop production domains or sites/land. Large area with a single genotype also triggers unsustainable production. High adaptation with the greater degree of occurrence of evolution and maximum heterogeneous genotype populations are the principles for sustainable farming systems and for which agrobiodiversity is key to practice this principle. Agrobiodiversity conserved in-situ and on-farm also adjusts and evolves themselves in

the changing context of climates and different stresses (both biotic and abiotic). Intra and inter varietal and species diversity play a significant role to address environmental and other types of stresses and agricultural problems. Besides, both natural and artificial breeding is only possible in the presence of genetic diversity. All the resources available in certain areas can be effectively and efficiently utilized through agrobiodiversity. There are many successful cases of mixtures at species and genotype levels that make the production system more sustainable and dynamic (Joshi et al. 2020c; Zhu et al. 2000).

Integration of science with tradition makes technology more sustainable and profitable. Traditional farming systems with rich indigenous knowledge, genetic diversity, and culture are the key to food and nutritional security (Gauchan 2008). Major concern should therefore focus on how one can maximize the diversity in the production system for developing self-reliance and a self-dependent agriculture system. Many kinds of factors are involved to increase the diversity at species, varietal, genotype, and allelic levels. Farm maintenance of crop diversity is related to the household food sufficiency level of traditional crops. Factors influencing on-farm crop diversity and household food security varied with the crops and were mainly related to farmers' age, family size, farm size, agroecosystem, and market factor (Gauchan et al. 2020). Recently some good practices have been developed and piloted in Nepal for conservation, marketing, and value chain development and sustainable utilization of agricultural genetic resources focusing on traditional crops. These include sourcing and deploying diversity to farmers' fields from national Genebank and other research centers, mobilization and strengthening of farmers' groups and cooperatives for community seed banks establishment, participatory crop improvement, participatory four-cell analysis, simplification and design of electric processing equipment, adoption of diversity-based farmers' field schools, agrobiodiversity fairs linking with food fairs and market and value chain development of local diverse crop products (Sthapit et al. 2012; Joshi et al. 2019a; Gauchan 2019).

7.6 Neglected and Underutilized Agrobiodiversity

Each agricultural genetic resource has some role in food and nutrition security in Nepal. Many of them perform poorly though the risk of complete failure is minimal. Improvement either on genetic performance, agronomical or processing, or product diversification is needed to continue their cultivation. However, due to different factors, very few genetic resources have been studied, improved, and developed. Such improvement is generally related to commercial farming. Most of AGRs have the potential to commercialize. Based on literature review and discussion among the scientific team, the criteria were developed to define the neglected and underutilized agrobiodiversity (NUA) (Joshi et al. 2019b) and future smart food (FSF) (Li and Siddique 2018; Joshi and Shrestha 2018). NUA are currently underutilized in research and development, though they have high potential to meet food and nutrition security of growing population. NUA is any species or any varieties/ breeds that have been under-researched and not been so far released and registered or commercialized or not included in formal education, research, and development program, if included, only for a short period and could not contribute significantly to improvement and utilization of these crops.

Based on the components of agrobiodiversity and current knowledge, NUA is divided into nine categories (Fig. 7.5) (Joshi et al. 2019a). These are NUCS (crop species), NUFS (forage species) NULS (livestock species), NUAS (aquatic species, NUIS (insect species), and NUMS (microbial species based on components of agrobiodiversity, and Future Smart Food (FSF), Data Deficit Species (DDS) and Unknown Species (UKS) based on current knowledge. Among NUA, FSF has four criteria: nutrient-dense, climate-resilient, economically viable, and local available or adaptive (Li and Siddique 2018). Further, there are many different types of neglected and underutilized landraces, breeds, strains, and genotypes. Besides, there are many

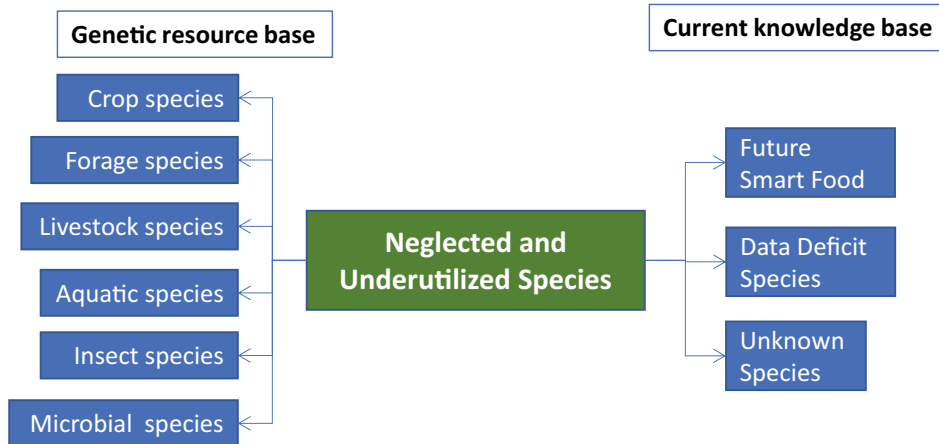


Fig. 7.5 Grouping of neglected and underutilized species (NUS) of agriculture in Nepal. NUS here covers only cultivated and domesticated species. Adapted from Joshi et al. (2019a)

semi-domesticated, wild relatives and wild edible species in Nepal (Dangol et al. 2018; Kc et al. 2017; Singh et al. 2017) and these all are neglected and underutilized.

Any NUS may be excluded from the NUS category after the priority given by research and development institutes over time (Joshi et al. 2019a; Padulosi et al. 2013). For example, earlier, finger millet was NUS but lately, this crop is not NUS, mainly because some varieties of these crops have already been released and or registered, and recently increased research and development emphasis have been given for this crop. Future smart crops (FSCs) are NUS that are known for their high potential for food and nutrition security, and high adaptability to changing climates (Joshi and Shrestha 2018; Joshi et al. 2019a, b). FSCs have tremendous potential to contribute to food security, nutrition, dietary and culinary diversification, health, and income generation, and are well adapted to marginal soil and harsh climatic conditions (Li and Siddiqui 2018).

Neglected and Underutilized Crop Biodiversity: Neglected and underutilized crop biodiversity (NUCB) are sub-components of NUA that involve neglected and underutilized crop species (NUCS). There are a larger number of crop species and landraces that are associated with food and nutrition security of many farming

households across the country, but investment in terms of technical and financial is almost zero on these crops. There are several minor crops and species which are highly valuable but presently undervalued, which should be an essential element of any model for sustainable smallholder-focused agricultural development (Kahane et al. 2013). Varieties of very few crop species have been improved (Joshi et al. 2017b). About 85% of the total 577 cultivated crop species are neglected and underutilized (Joshi et al. 2020a). At the landrace level, there are almost more than 95% neglected and underutilized in Nepal. These are also called minor crop species, orphan crop species, or secondary crop species and landraces (Padulosi et al. 2013). Even in rice, there are many neglected and underutilized landraces. For example, Shali Dhan is very good in terms of drought tolerance and quality grain, however, it has not been utilized in research for the development of high-yielding quality rice (Joshi et al. 2013).

Many crop landraces have a greater role in the food, nutrition, and livelihoods security of many farmers however, they are of secondary priority in terms of research, education, study, and development. Comparative analysis has shown that their features, nutritional composition, adaptation capacity, tolerance ability to stresses, social value, cultural value, and ecological value

are better than introduced varieties (Joshi et al. 2019a). Researchers, extension and development organizations, academicians, policy, and decision-makers have rarely considered this crop biodiversity in their works (Joshi and Shrestha 2018). Shrestha (2013) has listed many indigenous vegetables and most of them are NUCS. Such crop species and landraces are important for the subsistence of the local community however they were poorly documented, studied, and neglected by the mainstream research and development activities. Simple intervention on these NUCB can greatly help to support the livelihoods of the farming community as well as for long-term conservation through use. For example, product diversification of proso millet which was a neglected and undervalued species in high mountains of north-western Nepal such as Humla simply enhanced the values of this crop and farmers have increased the areas under this

crop (Joshi et al. 2019b). In addition to the traditional system of preparing food items, 12 new food items were able to prepare from the flour of this crop (Fig. 7.6). This also helped to create marketing at local and regional levels. Product diversification of native landraces is one of the best practices for making food and nutrition security in a particular area.

There are many species of aquatic plant genetic resources, which are neglected and underutilized. Dangol et al. (2014) have reported 14 species as vegetables, three species as edible grains, one as edible nut, one as pickle, one as a condiment, and two species used as the fermenting substrate for making alcoholic beverages.

With liberalization, commercialization, and inadequate priority are given in agrobiodiversity, the trend of growing single-type crop variety is rapidly increasing, and same types of products

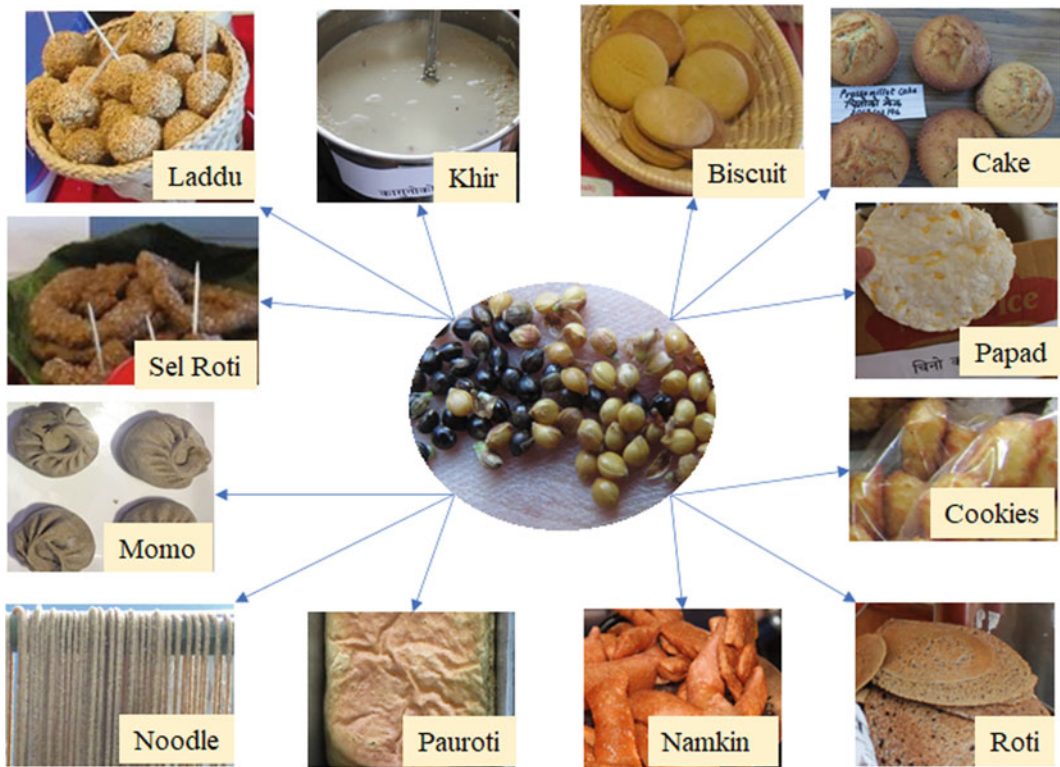


Fig. 7.6 Diversifying the use forms through adding values for making competent commodities. Twelve different foods can be prepared from proso millet along

with other mixes in addition to the traditional system of consumption (Source Authors' own work)

are found in three sources, i.e., own production, neighbor and relative production, and market, which resulted in same types of taste across the country. Much of the agrobiodiversity is neglected and underutilized, but many species could be alternatives to different products of main crops. Examples of potential alternatives of potato and tomato are given in Fig. 7.7. However, further research is necessary to assure the alternatives.

Neglected and Underutilized Livestock and Fishery Biodiversity: Livestock and fishery play a key role in nutrition security and generating income, but many of the local livestock and fishery species are currently underutilized. Besides, livestock supports enhancing production and sustainable farming. Relatively diversity at both species and genotype levels is less in livestock and fisheries in comparison with agricultural plant genetic resources. There are 35

agricultural animal species in Nepal, among which, 17 are domesticated which consists of 13 native and four exotic livestock species (Abington 1992; Joshi et al. 2020a). Similarly, among the total 232 edible finfish species, 16 are exotic and 216 indigenous including 15 ornamentals (Gurung 2017; Husen 2019; Joshi et al. 2020a). 28 species (16 exotic and 12 natives) are under cultivation. Like in crop species, current government priority has been given to exotic animal and fish species. Farmers and consumers in Nepal perceive that native species and breeds are tastier and better adapted to diverse environments and management systems but relatively costlier for consumers because of their greater demand and limited availability in the market. However, research, extension, and education system continue to promote introduced breeds resulting in the genetic erosion of native animal and fish diversity. The traditional system of livestock

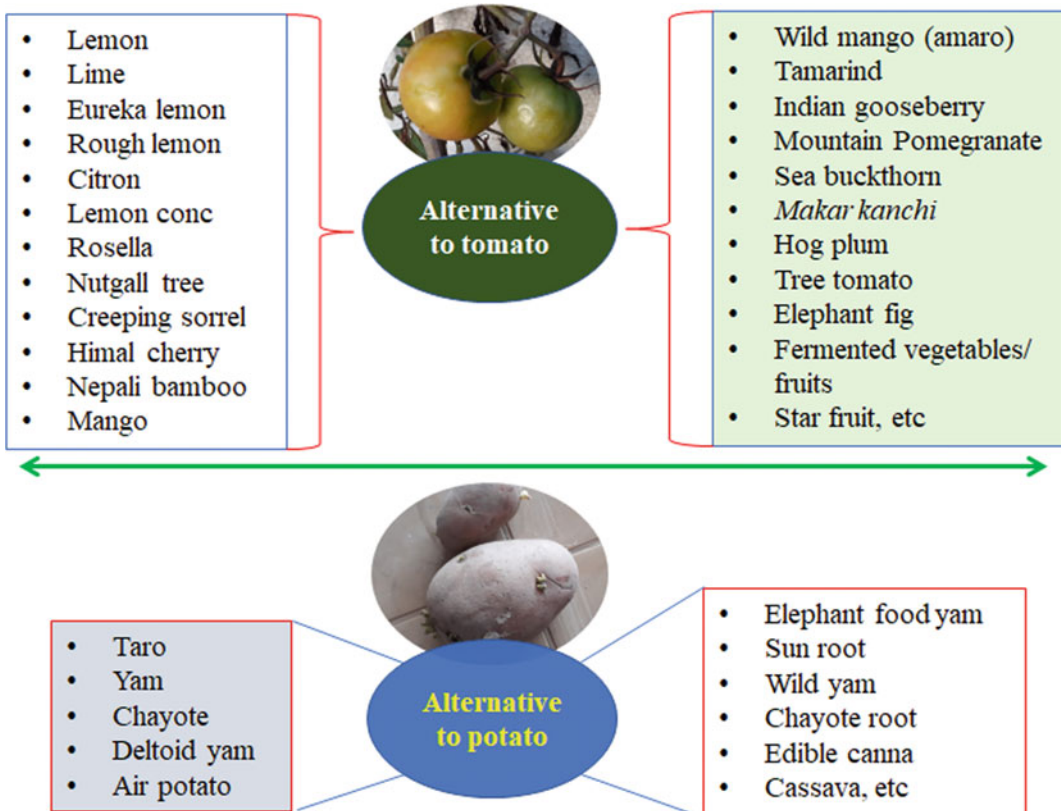


Fig. 7.7 Alternatives to tomato and potato for making vegetables, pickles, and boil recipe (Source Authors' own work)

rearing with local fodder, grasses, *khole*, feed, additives produce quality organic products, i.e., tasty milk and meat. Animal dung with this system also smells less and non-bad, and compost is also high quality which also helps to produce quality grains, vegetables, and fruits. In contrast, improved breeds with improved feed and improved grass in the modern animal system produce more milk and meat with less tasty, poor quality along with lower quality bad-smelling dung. The current scenario has shown that many farming households have been leaving animal farming, mainly because of the necessity of day-to-day care to animals and labor scarcity at the farm and community level.

7.7 Reasons and Factors Making Agrobiodiversity Neglected and Underutilized

Presently agriculture development in Nepal is dominated by the ad hoc promotion and commercialization of exotic technologies and practices. The focus is on the production of a few major crops and modern varieties in favorable pockets with intensive input use and pocket package approach without considering their inadvertent effect on agrobiodiversity conservation (Gauchan et al. 2017). Major reasons behind these focuses are because of economic scale of production and marketing on few major food staples, easy access to new technologies and support services from international and national sources and greater availability of policy support, provision of incentives, funding priority, consumer preference and market demand for few major crops and modern varieties.

In the past five decades of agricultural development, native species and varieties were never promoted rather they have been replaced by introduced technologies such as many exotic varieties and breeds associated with the use of external inputs mainly agrochemicals. Most Nepalese people presently give value to exotic sources other than existing native germplasm and technologies. Promoting and marketing exotic

technologies and so the preference of these are the main factors on making native agrobiodiversity neglected and underutilized. The agriculture research-extension-education model always focuses on exotic genetic resources. Reasons behind this system are many. For example, due to liberal economic policies, education system is oriented toward the foreign information and technologies (Gauchan et al. 2005). Growers, consumers, and businesspersons always prefer and expect to have foreign technologies due to high respect that comes from foreign sources. Researchers also found easy and fast to get results from foreign germplasm. Research protocols and funding mechanisms are well established for such genetic resources. Understanding of native agrobiodiversity is very much limited and investment is almost neglected (Gauchan 2019; Gauchan et al. 2020). It is generally perceived that the performance of native crop landraces and breeds is very low. Many native genotypes are undervalued without researching on potentialities of such landraces and breeds.

7.8 Agrobiodiversity Conservation Strategies

Conservation of agrobiodiversity has been initiated since 1986 in Nepal. The earlier focus was given to the ex-situ strategy. After 2010, four strategies namely ex-situ, on-farm, in-situ, and breeding have been adopted for conservation, marketing, and sustainable utilization of AGRs (Joshi 2017b). Agrobiodiversity includes the diverse nature of genetic resources, therefore needs varied actions and multidisciplinary approaches for conservation. Conservation actions in Nepal can broadly be grouped under five components, namely sensitization, strategies/methods/approaches, accelerators, enabling environment, and conservation values (Joshi et al. 2020a). Within each component, there are several good practices, processes, methods, and actions (Joshi et al. 2020a) that support conservation, marketing, and sustainable use of agrobiodiversity.

Conservation Approaches and Methods:

Under the four strategies mentioned above, 80 good practices including processes, methods, and actions have been developed, applied, and adopted across the country for accelerating conservation and use of total agrobiodiversity. Some practices are suitable to a particular site and a particular genetic resource. These practices are not only for assuring the availability of AGRs in the future but also for accelerating the evolutionary process and advancing the agricultural research system.

Conservation Status: Within the country, 18,765 accessions of AGRs have been conserved in the National Genebank and other different kinds of banks in Nepal. A total of 24,683 accessions of Nepalese crops, forages, and microbes have been conserved in different international and foreign gene banks (Joshi et al. 2020a).

7.9 Constraints and Issues in Conserving and Mainstreaming NUA

- The current agricultural policies of Nepal are focusing on the production of a few major crops and well-researched uniform modern varieties of crops in favorable pockets with intensive input use and package approach without analyzing their consequences on management of on-farm crop genetic diversity (Gauchan et al. 2003, 2017). The area covered by improved varieties and focus on short-term profitability of agricultural production are major indicators of the current development programs. Presently, priority has not been given to NUA in education, research, and extension. Potentialities of NUA are not being explored widely but with the limited knowledge, it is miscommunicated widely that native genetic resources perform poorly.
- Financial and qualified human resources are the major constraints in the conservation and sustainable use of agrobiodiversity. The agrobiodiversity sectors are always neglected and undervalued, therefore funded less in the

country. Human resources in the past were also oriented toward the introduction and promotion of foreign technologies.

- Single site-based conservation and focusing only on few crops as staple ones could not be an effective strategy and means for better managing and utilizing agrobiodiversity considering the diversity of agroecological and farming systems and socioeconomic settings.
- Presently, consumers, growers, and experts always think that new technologies are better than existing native ones, which have replaced many technologies in the last few decades of agricultural development, consequently, it has resulted in increased dependency on foreign genetic resources. Moreover, due to lack of focus on R&D of local genetic resources, technologies for improving NUA is limited.
- Until recently agrobiodiversity conservation focus has been given only to orthodox crops but there are other many AGRs associated that are important to be emphasized for food, nutrition, health, and environmental security.

7.10 Mainstreaming and Strengthening NUA

The process of mainstreaming very few technologies and genotypes undermines and ignores the values of genetic diversity. There is a general understating that, as the genetic and species diversity increased, there is a high chance of food, nutrition, and livelihood security. It is almost impossible to get food and nutrition security across the country without giving due priority to neglected and underutilized agrobiodiversity. Mainstreaming and strengthening of native technologies are therefore location-specific. Some of the notable native technologies that need to strengthen, and mainstream are traditions of seed systems, household-specific and site-specific technologies, dynamic population, small but heterogeneous population, diversity rich solutions, landraces enhancement, product diversification, value addition (both breeding and nonbreeding), marketing,

integration in education, research and development, diversity and food fairs, etc.

Not losing the unique genetic diversity, red zoning, red listing, gap analysis, and germplasm rescue missions is the immediate action that needs to take at a national level. Factors along with landraces status are widely assessed through the techniques called red zoning and red listing in Nepal (Sthapit et al. 2012; Joshi 2019), which have significantly contributed to minimizing the loss of genetic diversity. Good practices of agrobiodiversity management should be included in the education system, research, and development systems by all relevant stakeholders. Many landrace possess very specific traits which are required to fulfill the requirement of specific household and caste. The total edible food production, availability, and requirement are sufficient to meet food requirements at the national level, however, there is a wide disparity in availability and access of food and level of food security across agro-ecological regions, locations, and intra-household levels (MoH 2017). For this reason, food baskets should differ from one area to others to promote the *Maulik* technology and to balance the production distribution. Access to information on native technologies are very limited to all users, therefore, a web-based information hub is necessary to accelerate the advantages of native genotypes and technologies. In addition, harmonization of agrobiodiversity and seed policy, legislation, and certification procedure of the country is essential to facilitate inter-regional sharing, exchange, and trade of products of common crop varieties important for food and nutrition security (Gauchan 2019). This is also essential to provide incentives to plant breeders and researchers for the promotion and exchange of germplasms and products to promote innovation in agriculture and promote national and regional food security.

There are some successful cases of NUA that have contributed significantly to food and nutrition security (Joshi et al. 2019a; Ojha et al. 2020; Shrestha and Joshi 2018) through the intervention of some practices of agrobiodiversity

conservation. High hills of Nepal are food deficit areas and most of the native crops of these areas are neglected and underutilized, e.g., proso millet, foxtail millet, amaranth, etc. Rice is transported by airplane and becomes very costly. The government of Nepal has subsidized rice transportation to remote areas. Rice production in the country is not enough and needs to import from other countries. One of the strategies to end hunger is making at least one native crop as the staple food for a particular site (i.e., site-specific staple crop). To make local native crops a major staple crop in a particular site, some initiatives were undertaken on some future smart food crops, i.e., proso millet, amaranth, and foxtail millet.

Six different techniques and approaches (namely diversity fair, community seed bank, participatory plant breeding, diversity field school, product diversification, and mechanization for processing) were started for proso millet. One of the major problems in this crop is dehusking which takes a lot of time and very tedious. Mainly women involve in dehusking with a traditional technique called *Khal ma chutney*. Due to this problem, many farmers were not interested to grow this crop, even though they are climatically smart in this area. Therefore electric-run machine (*chino Kutak*) for dehusking proso millet has been developed and demonstrated to farmers. Farmers are now interested to grow this crop and male farmers also started involving in dehusking. Similarly, the other five interventions had made proso millet more competent and helped to grow and use proso millet continuously. Therefore, location-specific stable crops should be identified rather than making only a few crops stable across the country. Farmer and consumers can now prepare 12 different kinds of foods from cereals and pseudo-cereals in addition to traditional food items. These created the consumer prefer nutritious items. Farmers, researchers, and consumers have now given due emphasis to this crop and its products. It is expected that this will contribute to ending hunger in addition to conservation of native diversity on-farm.

7.11 Globally Significant Nepalese Agricultural Genetic Resources

Experiences have shown that there are many AGRs that are produced in Nepal which have global potential to market and the global community got attracted and enjoyed having them (Joshi and Shrestha 2018; Joshi et al. 2019a, 2020b). Many such native species and genotypes which have tremendous potential to contribute to food security, nutrition, dietary and culinary diversification, health, and income generation, and also considered to be adapted to marginal soil and harsh climatic conditions, need to be explored and given priority. Himalayan agricultural products are also valued highly globally in terms of purity, quality, tasty, healthy, and nutritive (PQTHN), therefore, possess the quality of monopolizing the global markets at least for some products, e.g., products of Nepalese hog plum (*lapsi*), honey, amaranth, sheep, fish, bean, etc. Another example is buckwheat which is well known for its genetic diversity as well as high quality and healthy food due to its high rutin content in the world (Joshi 2008). To be healthy over a long time, lectin-free and polyphenol-rich foods are very important. Many NUS is low or free in lectin but rich in polyphenol. Following AGRs (species and landraces) (Box 7.1) have

greater sale potential globally and need to advance them for the global market.

7.12 Conclusions

Agrobiodiversity resources including neglected and underutilized species have relatively higher potential to perform better even in poor management and stressful environments in the country. Despite Nepal being rich in agrobiodiversity, the diversity of native agricultural genetic resources is not fully exploited and utilized for ensuring food, nutrition, environment and livelihood security for the increasing population. This study highlighted that the native agrobiodiversity in Nepal needs to be improved, and its market and value chains need to be upgraded through research and development. Future research is needed to understand the differentiation between NUS processing and product technologies. Most farming communities and development organizations currently have given due priority to exotic technologies; therefore, there is an urgent need to change the perceptions over native AGRs so that potentialities of native AGRs could fully be exploited. Institutional and personal capacity should be enhanced on making location-specific AGRs as a staple and commercial.

Box 7.1. Global potential genetic resources

• Buckwheat (<i>Fagopyrum esculentum</i>, <i>F. tataricum</i>): Mithe and Tite Paper • Rice (<i>Oryza sativa</i>): Jumli Maarshi, Kaalanamak, Samundraphij, Anadi, Jorayal Baasmati • Wheat (<i>Triticum aestivum</i>): Mudule Gau • Foxtail millet (<i>Setaria italica</i>): Dude Kaaguno • Amaranth (<i>Amaranthus</i> spp): Leafy and Grain Amaranth • Bean (<i>Phaseolus</i> spp): Jumli Bean, Baakhra marne simi • Lentil (<i>Lens esculenta</i>): Kaalo Musuro • Black gram (<i>Vigna mungo</i>): Kaalo Maas • Horse gram (<i>Macrotyloma uniflorum</i>) • Alas, flax (<i>Linum usitatissimum</i>) • Chili pepper (<i>Capsicum annum</i>): Akbare Khursaani • Ginger (<i>Zingiber officinale</i>) and turmeric (<i>Curcuma longa</i>) • Leafy vegetable: Jaringo, Ghujmuje Raayo, Simpligaan • Moringa (<i>Moringa oleifera</i>)	• Cucumber (<i>Cucumis sativus</i>): Bhaktapure Local, Maadale Kaakro • Potato (<i>Solanum tuberosum</i>): Mudeko Aalu, Jumli Aalu, Thaar local Aalu • Mandarin orange (<i>Citrus reticulata</i>): Mankaamanako Suntalaa, Khokuko Suntalaa • Banana (<i>Musa</i> spp): Maalbhog, Ghiu kera • Fruit: Chiuri, Imli, Drumstick, Kaagati, Jyamir, Jaamun, Timur, Lapsi • Mushroom: Patke chya, kalo dunghe chayu • Herbal tea: Ilam ko Chiya, jadibudi chiya • Honey: Birt mauri, putka ko honey • Fish: Baarako Pangaas Maachha, Trisuliko Sahar Maachha • Buffalo (<i>Bubalus bubalis</i>) and chauri (Bos grunniens) • Goat (<i>Capra aegagrus hircus</i>): Chyangra and Khari

Recently some good initiatives and good practices have been developed and piloted in Nepal for conservation, marketing, and utilization of agricultural genetic resources. These include mobilization and strengthening of cooperatives and farmers' groups for participatory crop improvement, community seed/genebanks establishment, adoption of diversity-based farmers' field schools, and agrobiodiversity fairs linking with food fairs and market chains. Some achievements are made in mainstreaming them in recent policies and programs. However, still, current policies and programs do not favor the use of intra-level landrace and varietal diversity as well as native traditional AGRs. There is low awareness of the value and poor market development which are the key constraints in the conservation, use, and promotion systems of native AGRs and NUS crops. Poor investment in research and institutions and weak seed regulatory framework are the key "policy" constraints for the promotion of native AGRs and NUS and future smart food crop species.

Recently, global movement on diversifying the agriculture produces has created scope on utilization of NUS for food and nutrition security. Global marketing of some native AGRs is necessary for sustaining agriculture and attracting young generations as well as conserving them through use. Developing site-specific staples, more nutritious, diversified products, and climate-resilient varieties, as well as long-term conservation and sustainable agriculture system, are the best strategies for long-term food and nutrition security in the country. For the promotion of sustainable food systems and nutrition-sensitive agriculture, it is suggested research and development including *niche* value chain development of NUS crops through organic and eco-friendly production and certification system linking with geographic indication. These strategies can greatly contribute to achieving at least six SDGs (1) No Poverty, (2) Zero Hunger, (3) Good Health and Well-being, (8) Decent

Work and Economic Growth, (12) Responsible Consumption and Production, and (13) Climate Action.

7.13 Policy Implications

Very few genetic resources across the country will never be able to secure food and nutrition in Nepal. Looking only widely adopted few genetic resources has many limitations in the country where agroclimatic conditions and topography differ widely. Inclusive agriculture (i.e., giving due attention to all AGRs) is good and simple strategy to grant livelihood security to small-holder farmers and rural poor. Policies and program developing mapping agro-eco-zones considering micro-environment is needed to develop site-specific staple species or landraces, at least one of each cereal, grain legume, vegetable, spices, fruit, livestock, and fish. Policies and programs for the utilization of other components of associated agrobiodiversity such as food insects and micro-organisms need to be developed that may also have significant role in some areas to enhance the livelihoods of farming communities. Policy formulation is necessary for enhancing and supporting household-specific to village specific to province-specific products focusing on neglected, underutilized, understudied, and unexploited crops and other neglected plant and animal species that may have greater potential to boom the overall economy of the county.

A self-dependent agriculture system, at least for major agriculture inputs should be the guiding principles and practices for a sustainable farming system. There is a big gap in the quality and price of agriculture products between primary producers and consumers and therefore, a coherent environment needs to be created and flourished to establish a direct linkage between primary producers and consumers to minimize these gaps and to make both producers and

consumers satisfied. In addition to these, most people live in the city and urban areas. This demands the research and development on urban agriculture for waste management, better environment, proper resource utilization, fresh harvest, etc. that could minimize the havoc in urban areas. This will require promotion of good practices of agrobiodiversity management to be included in the education, research, and development systems.

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Improving Soil Health and Soil Security for Food and Nutrition Security in Nepal

8

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Abstract

Soil health and soil security are intrinsically interconnected with food and nutrition security. Hence, their improvement is necessary for a normal functioning of terrestrial ecosystems, including but not limited to increasing biodiversity and crop productivity and

improving people's livelihoods. This chapter reviews the soil fertility status across various agro-ecological or geographic regions of Nepal, soil-related constraints to crop production, factors affecting soil fertility decline, improved soil management practices, soil-related policies and strategies, and contribution of soil to food and nutrition security in the country. Comparisons with south Asian literature are also made wherever relevant. Soils show spatial variability across agro-ecological or geographic regions. Soils across hills and mountains are light-textured, shallow, and susceptible to erosion while low-lying areas including Terai have heavy textured soils with greater depth, and prone to flooding. Majority of the soils in the country are acidic, low in organic carbon and total nitrogen, and deficient in zinc, boron, and molybdenum. Soil fertility is in declining trend mainly due to soil nutrient mining, depletion of soil organic matter, soil erosion in hills and mountains, and inappropriate use of chemical fertilizers in Terai region. Long-term cropping systems experiments conducted across research centers and farmers' fields have indicated that integrated nutrient management with organic inputs and inorganic fertilizers is necessary for maintaining soil nutrient balance and enhancing productivity, profitability, and sustainability of cropping systems. The contribution of soil to food and nutrition security is discussed in relation to the importance of

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improved soil management practices including the use of organic inputs (manures, compost, residues), inorganic fertilizers, legumes in crop rotation, green manures, cover crops, and mulching, in-situ manuring, strip cropping, hedgerow/alley cropping, and practicing reduced or minimum tillage within the framework of integrated plant nutrient management. Improving soil information systems and site-specific nutrient management using digital technologies such as digital soil maps, mobile soil testing labs, and Nutrient Expert-based site-specific nutrient recommendations are also discussed. The chapter also highlights policy implications and recommendations for increasing food security through maintaining soil health and soil security and achieving various SDGs, in particular SDG #2 (end hunger, achieve food security and improve nutrition), #6 (water quality), #13 (climate action), and #15 (life on land) in Nepal.

Keywords

Digital soil map • Fertilizer recommendation • Food security • Nutrient management • Soil management practices

8.1 Introduction

Globally, soils provide food for close to eight billion people today. To achieve global food security for 9–10 billion people by 2050, food production through agriculture must be increased by 70% (ELD 2015). Achieving global food security and reducing hunger is a challenging task, particularly in the context of declining soil fertility due to land and soil degradation. Thus, improving soil fertility can play an important part of the solution (Usman et al. 2018). Healthy soils are pivotal for food security as food production depends on well-functioning soils. This requires better understanding of the properties and processes of soils at national and international scales.

It is estimated that 33% of soils globally and 52% in tropics are moderately or severely affected by soil degradation including erosion, acidification, salinization, contamination, chemical pollution, and compaction (ELD 2015; Hossain et al. 2020). The land degradation could potentially reduce global food productivity by 12% and increasing food prices by 30% over the next 25 years (ELD 2015). Therefore, the quality and fertility of agricultural lands have to be improved to feed the growing population. Sustainable management of soil health and maintenance of soil security are important to achieve several Sustainable Development Goals (SDGs) of the United Nations, in particular SDG 2 (end hunger, achieve food security and improve nutrition), SDG 6 (water quality), SDG 13 (climate action), and SDG 15 (life on land) (Bouman 2020). Soils directly relate to seven of the SDGs (Bouman 2020), with the reminder indirectly related through the contribution of soil ecosystem services (Keesstra et al. 2016).

Soils of south Asia provide food for almost 1.8 billion people, but are prone to degradation due to, but not limited to, increased erosion, soil acidity and alkalinity, drought, and submergence posing a threat to future food security. Nepal, a landlocked country in south Asia, has fragile ecosystems with about 83% of the area occupied by hills and mountains and the remaining by leveled or undulating lands in Terai (plain) and Inner Terai regions (Krupnik et al. 2021). Accordingly, soil fertility status vary across agroecologies, land types, and cropping systems. This paper discusses the importance of soil in achieving food and nutritional security in Nepal including (i) soil security and its relationship with food and nutrition security, (ii) soil fertility status and factors affecting soil fertility decline, and soil and nutrient management practices, and (iii) research and policy implications for augmenting the role of soil in achieving the food and nutrition security. The chapter is based on the review of the published literatures, web-based references, and a long practical experience of the authors in Nepal.

8.2 Soil Security and Its Relationship with Food and Nutrition Security

Soil security is concerned with maintaining and improving soil resources to produce food, fiber, and freshwater, maintaining the biodiversity and ecosystem services and contributing to energy and climate sustainability and human health (McBratney et al. 2014; Gomiero 2016). Addressing soil security through enhanced soil care and best management practices sustainably improves food, fiber, and water quality (Kopittke et al. 2019; Pozza and Field 2020). Soil degradation can have the substantial impact on food security as it reduces crop productivity and nutritional quality of food, and adversely affecting human health (Bindraban et al. 2012; Jones et al. 2013). It is evident that achieving food security is impossible without healthy soils.

Soil security has five dimensions—capability, condition, capital, connectivity, and codification (5Cs) (Pozza and Field 2020; Fig. 8.1). For each dimension there is the common question of how they contribute to the measurement, analysis, and/or management to the six global challenges of food, water, and energy security, maintaining biodiversity and human health, and adapting to or mitigating climate change. Ball et al. (2018) considered three types of connections (direct, indirect, and temporal) within a framework of soil connectivity to facilitate delivery of soil-related messages to three distinct target audiences (Table 8.1). They showed the importance of transferring agriculture by sensible soil management for food security, prevention of soil degradation, and soil restoration. Pozza and Field (2020) mapped the relationship between food and nutrition security and soil security in line with a subset of the SDGs (Fig. 8.1). They described that the natural factors such as climate and environmental systems, and anthropogenic factors such as socioeconomic and political systems affect the interactions between food and nutrition security and soil security. “Condition” aspect of soil security has strong interaction with “availability” and “codification” with both

“availability” and “stability” while “capital” has no or weak interaction with “access” and “codification” with “utilization” aspects of food and nutrition security. Bouman (2020) applied 5Cs for the understanding of the relation between soil security with food and nutrition security which can make future soil research much for effective.

8.3 Soil Fertility Status in Nepal

Soil fertility status varies across agro-ecological zones of Nepal (Fig. 8.2). In general, soils across hills and mountains are more fertile, i.e., higher in organic matter, total nitrogen (N), available phosphorus (P), and potassium (K) compared to soils across Terai region. However, soil fertility is in declining trend across the country due to various natural and anthropogenic factors, such as losses of organic matter and nutrients through erosion; low use of organic inputs such as farmyard manure (FYM), compost, green manuring; increasing cropping intensity and residue removal; no or imbalanced application of inorganic fertilizers; low or no use of secondary and micronutrients; and nutrient mining (Tripathi 1997). Soils of hills and mountains are prone to erosion because of steep slopes and geologically active and fragile ecosystems. Soil erosion and runoff are however highly variable due to diverse land use, soil types and slopes, and climatic characteristics. Bajracharya et al. (2007) reported that annual soil loss from agricultural lands in Nepal ranged 0–105 t/ha depending on soil surface conditions and cover, slope, and rainfall characteristics. Using remote sensing data and GIS tool, Dahal (2020) classified soil loss through erosion based on its severity into six categories—low, moderate, high, very high, severe, and very severe—for the Kathmandu district. It is reported that approximately 80% of soils had low to moderate (0–10 t/ha/yr), while 20% had high to severe (>10 to 80 t/ha/yr or more) soil erosion potential.

The content of soil organic matter (SOM) also shows wide variability across agro-ecological regions of Nepal. Its content is lower in the

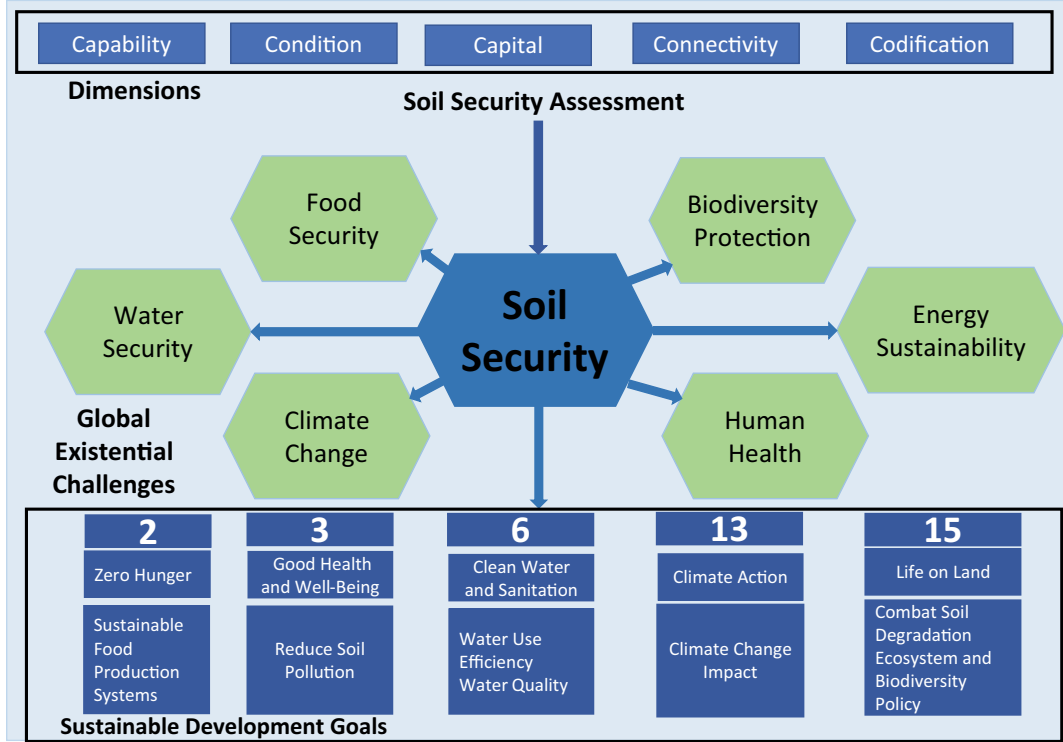


Fig. 8.1 Soil security and the nexus between global existential challenges and sustainable development goals (Adapted from Pozza and Field 2020)

Table 8.1 The framework of three types of connection between soil and people

	Type of connection		
	Direct	Indirect	Temporal
Main examples of creating connection	Hands-on teaching of visual soil evaluation or description	Information on soil and food production	Information on changes to environment due to soil degradation
Message	Good soil quality is important for production	Soil is important for food production, food quality, and human health	Degraded soil can reduce food security and increase environmental degradation
Target group	Farmers, land managers	Public (e.g., gardeners, cooks, school children)	Policy makers, eco groups
Example intended outcome	Improved soil management	Increase in local food production and of environmental awareness	Adoption of a more sustainable farming system

The three types of connections are not mutually exclusive (Adapted from Ball et al. 2018)

majority of Terai soils while medium in the mid-hills (Fig. 8.2). Similarly, there is the substantial effect of altitude on soil nutrients and pH (Table 8.2). Organic carbon (OC), total N, available P and exchangeable K and micronutrients

(Zn, Fe, Mn, Cu, and B) are higher at higher altitude compared to that in the lower altitude and Terai regions. Higher nutrients and OC content in hills and mountains could be associated with lower temperature and lower mineralization rates.

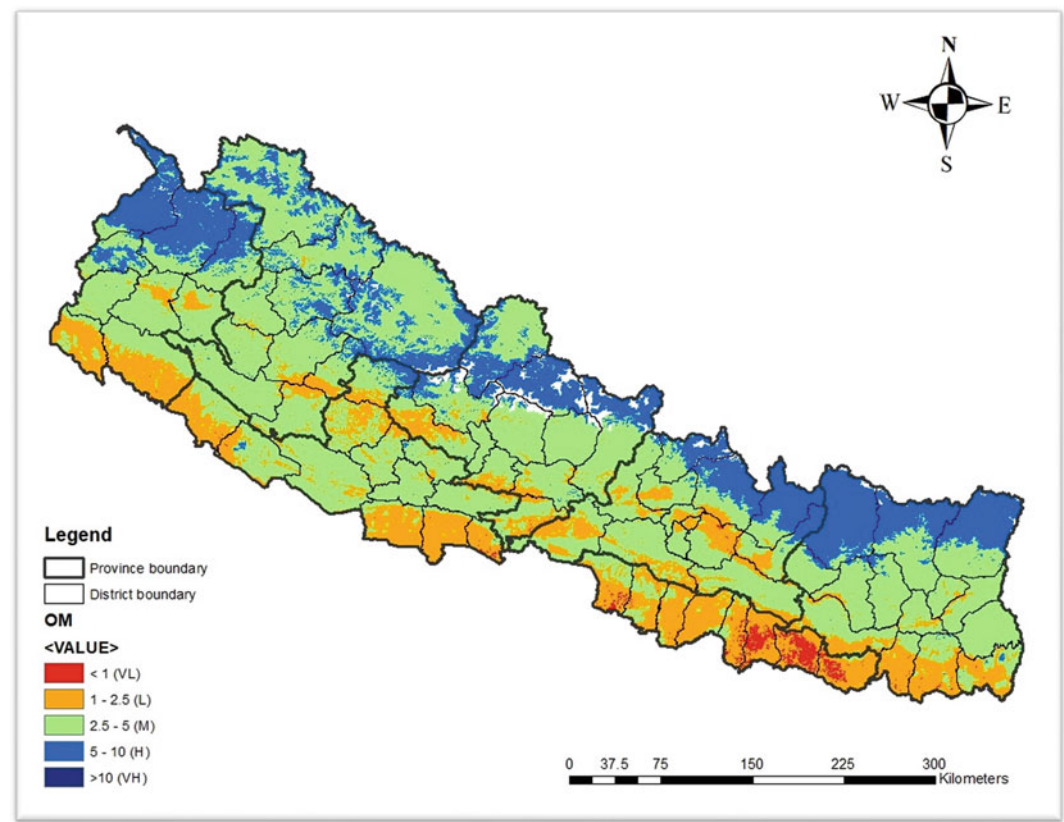


Fig. 8.2 Soil organic matter content across districts in three ecological regions of Nepal (Source <https://soil.narc.gov.np/>)

Table 8.2 Effect of altitude on plant nutrients in the western hills of Nepal (Adapted from Tripathi 1999)

Altitude (m)	pH	OC (%)	Total N (%)	Avail. P (mg/kg)	Exchan. K (cmol/kg)	Avail. Zn (mg/kg)	Avail. Fe (mg/kg)	Avail. Mn (mg/kg)	Avail. Cu (mg/kg)	Avail. B (mg/kg)
<600	6.05	1.07	0.15	30.2	0.40	0.91	174.0	46.3	1.29	0.50
600–1000	5.80	1.59	0.17	43.8	0.32	1.05	179.4	55.9	1.42	0.55
1000–1600	5.64	2.24	0.22	98.1	0.42	0.87	194.6	61.5	1.59	0.65
1600–2200	5.66	2.90	0.27	202.2	0.45	0.85	174.2	68.4	1.68	0.66
Mean	5.79	1.95	0.20	93.6	0.40	0.92	180.6	58.0	1.50	0.59
SE	0.11	0.13	0.01	18.1	0.06	0.16	10.5	10.5	0.29	0.07
P value	0.001	<0.001	<0.001	<0.00	0.10	0.56	0.10	0.30	0.56	<0.05

In addition, soils are shallow in higher altitudes. Hence, together with low soil pH, shallow soils, and soil’s proneness to erosion, crop yields are low in higher altitudes. In general, soils across eastern hills and mountains are more acidic than western hills.

Soil physiochemical properties also vary with land-use systems. Ghimire et al. (2018) reported higher total N in forest soils (0.27%) than in agricultural soils (0.07%) (Table 8.3). Available P in all land-use types was low, with the highest amount in *Bari* (upland) soil (24.2 kg/ha)

Table 8.3 Chemical properties of soil (average $\pm$ standard deviation) for each land-use type (Adapted from Ghimire et al. 2018)

Land type	pH	OM (%)	TN (%)	AP (kg/ha)	AK (kg/ha)	Textural class
Forest	7.25 $\pm$ 0.19	2.56 $\pm$ 0.34	0.27 $\pm$ 0.07	9.77 $\pm$ 0.64	155.0 $\pm$ 33.2	SL
Degraded land	5.81 $\pm$ 0.37	0.86 $\pm$ 0.12	0.07 $\pm$ 0.01	1.22 $\pm$ 0.03	98.2 $\pm$ 12.6	LS
Khet (low land rice)	5.47 $\pm$ 0.31	1.40 $\pm$ 0.08	0.12 $\pm$ 0.04	15.97 $\pm$ 2.03	184.7 $\pm$ 35.5	SL
Bari (upland sloping terrace)	5.95 $\pm$ 0.55	1.56 $\pm$ 0.15	0.15 $\pm$ 0.03	24.16 $\pm$ 3.33	245.6 $\pm$ 23.7	SL

OM organic matter, TN total nitrogen, AP available phosphorus, AK available potassium, SL sandy loam, LS loamy sand

and lowest in degraded soil (1.2 kg/ha). Available K was medium for all land-use types except for the degraded soil.

8.4 Factors Affecting Soil Fertility Decline in Nepal

Depletion of plant nutrients and soil organic matter and increasing soil acidity or alkalinity adversely affect soil fertility and soil quality and reduce crop yields. These ultimately threaten the global food security. Some of the important factors affecting soil fertility decline in Nepal and generally in south Asia are discussed below.

8.4.1 Soil Nutrient Mining

Soil nutrient mining happens when the quantity of nutrients removed by a crop exceeds the quantity that is recycled back and/or replenished in the field. Nutrient mining causes a decline in the native soil fertility and may jeopardize future food security. Soil nutrient mining poses a huge challenge for practicing sustainable agriculture in general and achieving food security in particular (Selim 2020). One of the main reasons for soil nutrient mining is continuous cropping and harvesting (with nutrient removal from soil) without addition of nutrients through organic inputs and fertilizers. Mining can also be associated with other reasons including erosion, imbalanced fertilization, increased nutrient losses through leaching and volatilization, depleting SOM, and

inappropriate cultivation practices (Mamathashree et al. 2017). Farmers in mid-hills and Terai of Nepal have been intensively using their land, i.e., growing double or triple crops in a year using high-yielding varieties. In these intensive cropping systems, nutrient removal generally exceeds the amount recycled or replenished resulting in negative nutrient balances.

Rice–wheat (R–W) is an important cropping system in the Indo-Gangetic Plains (IGPs) of south Asia (Timsina and Connor 2001). Long-term experiments (LTEs) and simulation modeling under R–W systems have demonstrated mining of major plant nutrients, leading to nutrient imbalances and deterioration of soil quality (Timsina et al. 1995; Timsina and Connor 2001). Such LTEs, however, confirmed that application of organic amendments can significantly increase soil OC and total N compared to no application (Tiro-Padre et al. 2007). In addition, the application of inorganic fertilizers in combination with organic amendments under R–W system in eastern and western Nepal improved soil fertility and increased crop productivity and economic benefits compared to the application of either one only (Pilbeam et al. 1999). Similarly, in the central Terai (Parwanipur), Gami et al. (2001) reported that both rice and wheat responded to N, but not to P, K, Zn, and S application, indicating that N is the most limiting factor but not K and secondary and micronutrients for cereal crop yields. However, with increasing cropping intensity coupled with low or no addition of K and other secondary and micronutrients including S, Zn, B, or Mo

Table 8.4 Effect of chemical fertilizers and FYM on the twenty-year mean grain yield in a long-term experiment on rice–rice–wheat rotation experiment, Bhairahawa, Nepal (Adapted from Regmi et al. 2002a)

First rice (kg/ha)				Second rice (kg/ha)			Wheat (kg/ha)			Yield (t/ha)		
Treatment	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	N	P ₂ O ₅	K ₂ O	First rice	Second rice	Wheat
Control	0	0	0	0	0	0	0	0	0	0.339	1.066	0.532
N	100	0	0	100	0	0	100	0	0	0.719	1.330	0.581
NP	100	13	0	100	13	0	100	18	0	2.577	2.465	1.200
NK	100	0	25	100	0	25	100	0	25	0.630	1.300	0.611
NPK	100	13	25	100	13	25	100	18	25	2.760	3.082	2.301
FYM ^a	80	18	40	80	18	40	80	18	40	2.797	3.138	2.202

^a FYM applied at the rate of 4 t/ha (dry weight basis) to each crop. Total N, P, and K content in FYM are averaged values

resulting in soil nutrient mining, particularly across the Terai districts. A Terai site in western Nepal (Bhairahawa) has already shown negative K balance, K deficiency, and net K depletion in an R-R-W system, even though recommended levels of fertilizers were added to the system (Regmi et al. 2002a, b; Table 8.4). Thus, application of K fertilizers should be encouraged to improve soil fertility and increase crop productivity (Ojha et al. 2021).

8.4.2 Depletion of Soil Organic Matter (SOM)

SOM plays a critical role in improving soil's physical, chemical, and biological properties. It helps to improve water infiltration and water holding capacity and serves as a slow-release reservoir of nutrients (especially for N, P, and S) and increases microbial activities (Timsina 2018; Maraseni et al. 2008). Declining SOM is a global problem. In Nepal, depleting SOM is associated with increased cropping intensity, low use of organic inputs such as FYM, compost, and crop residues. Also, burning of rice and wheat residues and use of animal dung as fuel, particularly in the Terai region of Nepal, have contributed to decline in SOM. Prior to the introduction of chemical fertilizer in 1952, organic amendments, particularly manures were the major sources of nutrients in Nepalese agriculture (Pandey and Joshy 2000). Most farming across mid- and high

mountains still use organic inputs for maintaining soil fertility and increasing crop productivity (Acharya et al. 2007). The magnitude of organic inputs used however varies across agro-ecologies, farm size, and cropping systems. A study conducted in Banke district in Western Terai has shown that small and medium-sized farmers use relatively higher amounts of organic inputs compared to large farmers (Baral et al. 2019). However, evidence indicates that the use of organic inputs is in declining trend in Nepal (Bajracharya et al. 2007). As crop residues are extensively used for animal feed, and little or no residues are returned to the soil (Khadka et al. 2019), it is one of the greatest challenges for improving soil fertility.

Hill farming systems of Nepal have traditionally strong links between three main components of agroforestry systems: forest, livestock, and crop. In this system, livestock gets feed from the forest, and manure from livestock is used for crop production. The hill farmers use tree cuttings and forage from forests and grasses from terrace bunds for cattle feed and for mixing with livestock manure and urine to prepare compost. Therefore, the forest is an important source of nutrient flow to cultivated land (Maraseni and Pandey 2014; Pilbeam et al. 2000). In recent decades, the agricultural labors and livestock number per household in both hills and Terai have reduced substantially because of schooling of children, labor outmigration, and younger generation being less attracted to

agriculture (Tripathi and Ellis-Jones 2005; Acharya et al. 2007). Such social changes have been attributed to the reduction in the amount of manure produced and net organic inputs addition to the soil (Subedi et al. 2015).

8.4.3 Imbalanced Application of Fertilizers

Application of inorganic fertilizers is increasing globally as they have higher nutrient contents, are easy in handling, and are less labor-intensive for transportation and application in fields as compared to organic amendments (Timsina 2018). More importantly, increased cropping intensity and introduction of high-yielding crop varieties demand for more nutrients (Timsina and Connor 2001; Timsina 2018). Smallholder farmers in Nepal and in all other south Asian countries use inorganic fertilizers without taking into consideration of right sources, right rates, and right application timing (Timsina et al. 2021, 2022). Majority of the farmers in Nepal have low technical know-how and apply excessive or imbalanced amounts of fertilizers without soil tests or without considering crop nutrient demand (Subedi et al. 2015; Krupnik et al. 2021; Timsina et al. 2021, 2022). These authors reported that the continuous and imbalanced application of inorganic fertilizers can result in soil degradation such as reduced SOM, increase soil hardness, acidification, micronutrient deficiencies, deterioration of soil and water qualities, and loss of agro-biodiversity. Amgain and Timsina (2004) and Timsina et al. (2021, 2022) concluded that cereal yields in farmers' fields are decreased due to decrease in soil fertility, negative nutrient balances, and imbalanced or sub-optimal use of fertilizers. As a thumb rule, nutrients removed by crops at harvest should be replaced into the soil either through organic inputs or inorganic fertilizers. However, Nepalese farmers apply a higher amount of N fertilizer compared to K or other secondary nutrients and most farmers don't apply micronutrients as there is no government recommendation for micronutrients for most crops. Higher use of N is

associated with its cheaper price and quick plant response. Andersen (2007) reviewed micronutrient problems in the cultivated soil of Nepal and reported that out of eight micronutrients (B, Zn, Fe, Cu, Cl, Mo, Ni, Mn), B and Zn are the most limited in the Nepalese soils followed by Mo, which limit agriculture production and directly or indirectly affects human nutrition. Therefore, future studies should focus on recommending balanced plant nutrition across different soil types and cropping systems and raising farmers' awareness to adopt balanced fertilization including micronutrients.

8.4.4 Environmental Factors

Environmental factors such as rainfall and temperature determine soil fertility and the supply of plant nutrients. In high rainfall areas, such as eastern hills and mountains, basic cations such as Ca, Mg, and K can be lost by leaching and hence soils are more acidic compared to soils of western hills where average annual rainfall is low. Similarly, soils of hills and mountains where temperature is low have higher SOM and total N due to slow decomposition and mineralization rates compared to warm and tropical Terai regions. In addition, soil parent materials also determine soil fertility. For example, pedologically most of the sandy soils across the hills and mountains are derived from phyllite and schist or sandstones, quartzite, and granite leading to infertile soils (Carson 1992).

8.5 Soil and Nutrient Management Practices

Countries across the world have been adopting different soil and nutrient management practices including different combinations of organic inputs and inorganic fertilizers to improve soil fertility and crop productivity. The ratio of organic inputs and inorganic fertilizers depends on their availability and objectives of the farming. In this section, we review the existing practices followed by farmers and prioritized practices promoted by the

government and non-governmental organizations and then suggest some sustainable soil management strategies for Nepal. These practices are grouped into three categories: nutrient management, soil management, and integrated plant nutrient management practices.

8.5.1 Nutrient Management Practices

Farmers have been applying different organic inputs available on their farms and inorganic fertilizers to fulfill plant nutrient demands. In general, farming across hills and mountains is organic-based where inorganic fertilizers are used as a supplement, while farming across the Terai region is based on inorganic fertilizers and organic inputs used as a supplement. In Nepal, the main approach of nutrient management is the integrated use of organic inputs and inorganic fertilizers (see Sect. 5.3 for detail). Previous studies on inorganic fertilizers are limited to determine optimum rate of major nutrients (NPK) and less importance is given to secondary and micronutrients, use of enhanced-efficiency fertilizers, and improved application methods.

8.5.1.1 Application of Organic Inputs and Incorporation of Rice and Wheat Straw

Increase in SOM content is necessary for sustainable improvement of soil fertility and crop productivity. Commonly used organic inputs, particularly by smallholder farmers in Asia are FYM, compost, and poultry manure. Although these inputs have low nutrient content, they can improve soil's physical, chemical, and biological properties such as increasing water infiltration and water holding capacity and increasing nutrient holding capacity through increased cation exchange capacity, soil buffering capacity, and microbial activity and biomass (Buresh and Dobermann 2009; Timsina 2018). In general, management practices that increase SOM can substantially increase crop yields (Lal 2006; Mekonnen and Hoekstra 2011). In addition to application of organic inputs, organic matter in soils can also be increased by adopting crop

rotations, crop diversification, mulching, and maintaining soil cover in the cultivated lands (Kharal et al. 2018).

8.5.1.2 Increased and Balanced Application of Inorganic Fertilizers

Inorganic fertilizers play a critical role to achieve global food security. Fertilizers can increase crop yield by at least 30–50% (Stewart et al. 2005; Roberts 2009). The use of inorganic fertilizers in Nepal has been increasing over the years with the growing popularity of modern agriculture (Shrestha 2010; Takeshima et al. 2016). Their use has grown steadily in the past two decades in the Terai region, while it has stagnated in the hills and mountainous regions (MoAD 2018; Devkota et al. 2018, 2019; CSISA 2019; Krupnik et al. 2021). However, average (national) fertilizer application rates are very low ($\text{N:P}_2\text{O}_5\text{:K}_2\text{O}$ is 41:18:18 kg/ha) compared to other south Asian countries (Takeshima et al. 2016). The lower use of inorganic fertilizers is mainly due to its unavailability at the time of application, lack of cash for purchase by resource-poor farmers, frequent changes in government policy on subsidies, and difficulties in transporting to hills and mountains (Subedi et al. 2015). Despite the government recommendations on rates and timing of fertilizer application, Nepalese farmers do not use recommended rates, particularly in hills and mountains due to inaccessibility or timely unavailability due to remoteness and non-affordability due to high prices. Also, the fertilizer recommended rates are old, outdated, and blanket type. They need to be recommended by adopting 4Rs (right source, right rate, right time, and right place) of nutrient stewardship approach to increase their use efficiency and crop productivity. To achieve this, farmers' technical skills on 4Rs need to be improved which could help ensure balanced fertilization and increase fertilizer-use efficiency. Also, the magnitude of fertilizer uses in Nepal, particularly in cereals, needs to be increased to increase productivity and achieve food security target set by the government, but should be used efficiently and effectively (Timsina 2018).

Low fertilizer-use efficiency due to increased losses through various processes is the major problem for increasing crop yields and farm profits and reducing the adverse effects of fertilizers on agricultural and aquatic ecosystems. Losses are more from N fertilizers. Past studies have focused on finding alternative strategies to increase N-use efficiency. Some commonly used strategies are the application of various types of decision support systems (DSS) tools including green seeker optical sensor, soil–plant analysis development (SPAD) meter, and leaf color chart (LCC). Similarly, the use of different enhanced-efficiency fertilizers such as slow-and controlled-release urea, improved application methods such as deep placement of urea, localized placement of boron-, sulfur- or zinc-coated urea, and blended fertilizers are in practice globally for increasing N-recovery efficiency and fertilizer-use efficiency. Few studies conducted in Nepal showed that DSS tools such as green seeker optical sensor and LCC can be alternatives to current practices to improve N-use efficiency of lowland rice (Marahatta et al. 2017; Baral et al. 2021). Baral et al. (2021) found a significant increase in grain yield with urea deep placement over conventional fertilizer application in rice, and N application using green seeker saved significant amount of N and increased N-use efficiency. Similarly, Dhakal et al. (2020) reported 25% N saving with the deep placement of urea briquettes on hybrid maize (Khumal Hybrid-2) in Western Nepal compared to the recommended fertilizer practice.

8.5.1.3 In-Situ Manuring

In-situ manuring is the practice of fertilizing the field by keeping and rearing the animals in the field itself. Generally, cattle and buffalo are kept in the open terraces in hills and mountains of Nepal for a week or so and transferred to other terraces. Such system is continued in winter for 4 to 6 months for making the field fertile. In-situ manuring is also carried out using the migratory flocks of animals (sheep and goats) kept in the transhumance system in Nepal (Aryal et al. 2022). In winter (October/November–April/May), these flocks are brought down from the

alpine pasture to feed on crop residues and wild grasses and manure the fields (Subedi et al. 1989). According to Dhital et al. (1990), two nights of in-situ manuring by sheep produced the highest maize yield (2.74 t/ha) followed by cattle manure applied equivalent to two nights of manure (2.41 t/ha). In-situ manuring by sheep for three nights produced significantly higher maize grain (5.49 t/ha) and biomass yield (27.66 t/ha) over the direct application of equivalent amount of sheep manure (Sthapit et al. 1988).

8.5.1.4 Management of Acid Soils

Soil acidity is one of the main factors for declining soil fertility in Nepal (Turton et al. 1996; Khadka et al. 2019). Soils vary in acidity across the agro-ecological regions, with approximately 50% being acidic and needing amendments with appropriate measures to improve soil fertility and crop productivity (Tripathi 1999). Acid soils are caused by five main factors: presence of acid-forming parent materials, leaching of Ca and Mg, continuous use of acid-forming urea fertilizer, removal of Ca and Mg by crop uptake or by leaching, and plantation of pine trees and use of tree litters in degraded hill slopes.

Nepalese farmers correct soil acidity by adopting different strategies including appropriate use of organic inputs and lime (CaCO_3). Tripathi (2001) reported a positive response of agricultural lime, FYM, and P fertilizers for maize, wheat, upland rice, and soybean in the acidic soils of eastern, western and central Nepal. Previous studies have suggested that the applications of lime at 2–3 t/ha, manure at 10 t/ha, and P_2O_5 at 60 kg/ha could be the practical solutions for maintaining soil fertility of the acidic soils (Tripathi 1999, 2001). The author also reported that only 40–45% of applied lime was utilized by the first crop with the remaining 55–60% by the succeeding crops. These results suggest that lime should be applied at every 3 to 4 years intervals. Correcting soil acidity with the application of lime could also increase N fixation by legume crops. Schreier et al. (1995) reported significant improvement in biomass production of N-fixing trees and native grasses with the use of

agricultural lime and manure in highly degraded acid soil of Jhikhu Khola watershed in Kavre district in mid-hills in central Nepal.

8.5.2 Soil Management Practices

Improvement of soil fertility and soil health is important for improving crop productivity. It requires healthy soils to supply indigenous nutrients or release of nutrients added through organic inputs or inorganic fertilizers. Therefore, it is important to improve soil health by adopting sustainable soil management practices. Nepalese farmers have been using different soil management practices for a long time. Some of the most important practices are discussed below.

8.5.2.1 Legumes in Crop Rotation

Grain legumes can fix a significant amount of atmospheric N, which not only meets its own N demand but also supplies N to soils thereby increasing soil fertility and productivity of the succeeding crops. Plant roots and stubble contain a substantial amount of N which can be utilized by the succeeding crops. After the grain or pods of pulse crops are harvested, the straw can be incorporated into the soil, which not only provides nutrients but also improves the soil's physical and biological properties. In Nepal, traditionally legumes are integrated into crop rotations in many ways such as intercropping, mixed cropping, etc. Inclusion of mungbean after harvesting wheat and before planting rice has shown enormous beneficial effects. In-situ growth of mungbean and incorporation of its residues (after picking of the pods) before rice transplanting supplied 60–85 kg N/ha to rice in Punjab, India (Rekhi and Meelu 1983; Antil et al. 1989). In another study, mungbean N benefit to maize in the summer mungbean-maize was about 40 kg N/ha also in India (Ali and Mishra 2000).

8.5.2.2 Bio-Fertilizer Use

Bio-fertilizers are substances produced through biological processes with significant nutrient value that can be used as an effective source of nutrients. These contain living organisms that

when applied to soil, seed, or plant surfaces colonize in the rhizosphere or the interior of the plant and promote growth by increasing the availability of nutrients to the host plant (Brevik 2012). The micro-organisms in bio-fertilizers restore the natural nutrient cycle and build SOM. There are several sources of bio-fertilizers including bacteria, fungi, and algae. Common sources of bio-fertilizers in Nepal's cereal-based cropping systems include *Rhizobium* spp. and *Azolla* associated with blue-green algae (*Anabaena azollae*) primarily in rice fields (Subedi et al. 2015). *Azolla* is a free-floating water fern commonly found in south Asia. When associated with blue-green algae, *Azolla* spp. can fix around 40–60 kg N/ha from atmospheric N. Under optimal conditions, soil incorporated *Azolla* spp. can release as high as 70% of fixed N to rice, providing a slow-release N source in lowland rice fields (Kannaiyan 1982).

Free-living N-fixing bacteria such as *Azotobacter*, *Azospirillum*, and *clostridium* spp. also fix N in the non-legume crops such as rice, wheat, barley, millet, and cotton. These are not as common as *Rhizobium* but they have a potential for N fixing in non-legume crops. In recent years, some private suppliers in Nepal are supplying different forms of micro-organisms in liquid formulations such as Effective Micro-organisms (EM), Jeevatu, Jibamrit, etc. and farmers are using them on a limited scale. However, there is no effective quality control mechanism of such liquid micro-organisms, which come from India and are formulated in Nepal.

8.5.2.3 Green Manuring

Green manuring (GM) is practice of growing range of species, particularly legumes together or in sequence with crops and incorporating the biomass in soil during vegetative to flowering stages (Timsina 2018). With the similar efficiency like that of inorganic fertilizers, GM crops release nutrients during decomposition and can improve soil quality and fertility (Becker et al. 1995b; Selvi and Kalpana 2009) by improving soil's physical, chemical, and biological properties, stabilize the soil structure, increase the soil water holding capacity, and enhance soil micro-

biological diversity (Kumar et al. 2014; Bista and Dahal 2018). Green manures, especially the deep-rooted ones, can absorb the nutrients from deep in the profile and make them available to plants after decomposition. The practice of in-situ manuring of *Sesbania* before transplanting rice is increasing in irrigated rice lands in the Terai region of Nepal, which can potentially substitute about 50% fertilizer N to rice crop (Personal communication with Rice Scientist late Bhola Man Singh Basnet, April 2021).

8.5.2.4 Cover Crops and Mulching

Cover crops are grown *in-situ* in the field while mulches (e.g., leaf, straw, dead leaves, and compost) are either *in-situ* or brought from outside and applied in the field. There are mainly three mulching systems in Nepal: In-situ mulching (plant residues left on the soil after harvest), cut/collect and carry mulching (dried or green plant residues brought from elsewhere and used as mulch), and plastic mulching. Plastic mulches are now getting popular in the mid-hills, particularly in commercial vegetables and fruit orchards. The purpose of growing cover crops or mulching is same: to cover the soil surface and protect soil against wind, reduce soil and water erosion, trap nutrients that may be lost by leaching and build and improve soil fertility, suppress weeds, control diseases, and pests, conserve soil moisture, and promote biodiversity (Van Derwerken and Welcox 1988). Atreya et al. (2008) reported that rice straw mulch is effective in conserving soil and nutrients in mid-hills of Nepal. Best adapted grass or some cultivars of legumes can also be grown as cover crops to improve soil health and protect soil from erosion, provide forage for livestock, or develop wildlife habitats (King et al. 2019). Keatinge et al. (1999) used models to determine the feasibility of six legume cover crops to reach maturity prior to the sowing of the different monsoon season crops in Nepal. Model outputs indicated substantial variability in legume maturity date due to genotype, site, elevation, and sowing date effects. They concluded that cover crops could potentially be grown in autumn prior to sowing of the monsoon

crops across most of the mid-hills. Subedi et al. (2015) reported that relay planting of soybeans, cowpeas (*Vigna unguiculata*), velvet beans (*Mucuna pruriens*), and finger-millet (*Eleusine coracana*) into maize crops are traditional practices in the hills of Nepal, which help conserve soil and trap N losses.

Mulches can improve soil properties such as maintaining soil temperature, conserving soil moisture (reduced soil evaporation), improving bulk density, aggregate stability, and nutrient availability, and retarding germination and growth of weeds. Farmers use mulches mainly in ginger, colocasia, sweet potatoes, vegetables, and fruits (Subedi et al. 2015). Mulching can have huge benefits for soil management, especially in the sloping lands in the hills and mountains, which are prone to losses of soil nutrients. Atreya et al. (2008) reported reductions in the annual loss of SOM, total N, available P_2O_5 , and exchangeable K_2O by 52%, 46%, 32%, and 53%, respectively by using mulches in a maize-mustard (*Brassica campestris*) cropping system in the mid-hills. The major limitation of using mulches however is the greater labor demand, especially for cut or collect and carry systems.

8.5.2.5 Strip Cropping

Strip cropping is the practice of growing crops in strips or bands arranged against the slope of the land. The crop strips in slope serve as barriers for erosion in sloping lands (Subedi et al. 2015). Acharya et al. (2008) reported that the low-input strip cropping is effective in conserving soil and water through the sieve-barrier effect and could maintain the overall sustainability of the land-use practices in sloping lands of Nepal. They also reported that farm income can be increased by incorporating strips of ginger (*Zingibre officinale*) in maize-based systems in the sloping terraces.

8.5.2.6 Agroforestry Systems

Agroforestry system is practice of growing crops, trees, and livestock together to improve soil fertility, conserve soil and water, and meet food, fiber, and fuelwood requirements. Agroforestry

systems are practiced in various forms from time immemorial in hills and Terai of Nepal (Dhakal et al. 2022). Hedgerow intercropping or alley cropping, a form of agroforestry system, is growing mainly leguminous crops or N-fixing plants as hedges between the main crop rows and incorporation of pruned biomass into the soil (Subedi et al. 2015). The benefits of hedgerow system are soil conservation by minimizing erosion, reducing nutrient losses from runoff, addition of SOM and plant nutrients, and nutrients lifting from deep soil into the surface. This system is also known as Sloping Agricultural Land Technology (SALT), or contour hedgerow intercropping system (Subedi et al. 2015). Adoption of this practice in Nepal is however low, mainly because of high labor requirements and the lopped biomass used as fodder for cattle. Chapagain and Gurung (2010) reported that hedgerow systems with Napier (*Pennisetum purpureum*), sun-hemp (*Crotalaria juncea*), and pigeon pea (*Cajanus cajan*) on the terrace edges and risers are proven practices for soil conservation and supplying forages for livestock. Schwab et al. (2015) compared soil quality in three different agroforestry systems: a fully developed agroforestry (AF), a predominant conventional system (CS) characterized by mono-cropping, and a system transiting to AF for two years (TS) in a typical mid-hills region of Nepal. Considering soil pH, SOM, soil total N and Al contents, base-saturation, and electric conductivity, they found higher quality and more fertile soil under AF than under other systems. They concluded that AF systems have the potential to significantly enhance long-term soil quality and productivity as compared to CS or TS.

8.5.2.7 Reduced Tillage

Reduced or no-tillage could be a potential option to reduce soil and nutrient losses (especially from erosion), particularly from the terraced lands and sequester carbon and nutrients in hills and mountains and to increase crop productivity and profitability by increasing nutrient, water, and energy-use efficiencies in the Terai of Nepal (Krupnik et al. 2021; Amgain et al. 2022; Magar

et al., 2022a, b). Tiwari et al. (2009) reported that reduced tillage with some residue retention in maize-cowpea system was more effective in maintaining soil fertility and increasing farm income compared to conventional maize-millet system. Similarly, Atreya et al. (2008) reported that reduced tillage can reduce soil erosion and increase soil nutrients, both studies suggesting reduced tillage as a viable option for minimizing soil and nutrient losses without sacrificing crop yields in the mid-hills. Ghimire et al. (2011) reported that soils under an R-W system in Terai sequestered significantly higher amounts of organic carbon in 0–15 cm soil depth under no-tillage as compared to that under conventional tillage.

8.5.3 Integrated Plant Nutrient Management (IPNM) Practices

IPNM is a practice of supplying plant nutrients through the integrated use of organic inputs and inorganic fertilizers together with other soil amendments. Potential sources of organic inputs in Nepalese farming systems are FYM, crop residues, and farm waste, green manures, compost. (Timsina 2018; Selim 2020). Adoption of IPNM improves fertilizer-use efficiency, soil's physicochemical, biological and hydrological properties, and profitability of farming systems. Emphasis on the importance and use of IPNM practices for sustainable agriculture has been given in many studies in south Asia: for example, in India (Bhandari et al. 2002; Yadav et al. 2002; Kabba and Aulakh 2004), Bangladesh (Islam and Sah 1998; Panaullah et al. 2001), Pakistan (Zia et al. 1992; Ahmad and Muhammad 1998), Nepal (Brown and Schreier 2000; Regmi et al. 2002a, b), and Sri Lanka (De et al. 1993). In Nepal, particularly in hills and mountains, farmers adopt IPNM practices, which include the integrated use of FYM/compost, inorganic fertilizers, agricultural lime, crop residues/farm waste recycling, inclusion of green manuring and grain legumes, and catch crops in rotations,

and agroforestry practices for improving SOM, protect soil biodiversity, and increase crop yields and income (Vista et al. 2020).

Organic inputs or inorganic fertilizers alone cannot sustain the long-term soil fertility and hence their integrated use is recommended for sustainability of cropping systems (Timsina 2018). Particularly in the shallow soils of mid-hills regions, combined application of organic and inorganic fertilizers is necessary for maintaining soil health and obtaining high yields. Chapagain and Gurung (2010) reported from a three-year study that maize with IPNM practice increased grain yield by 64% and increased yield of the subsequent millet compared to farmer's practice in a maize-millet cropping system. Some past studies have also suggested combined application of organic inputs and inorganic fertilizers for the traditional cropping systems in eastern and western mid-hills and mountains under maize/millet, maize/soybean, and rice-blackgram to increase yields and incomes (Tripathi et al. 1998; Pilbeam et al. 2002).

In addition, integrated use of organic inputs and inorganic fertilizers could help maintain soil biodiversity. Soil microbial communities play essential roles in soil processes such as carbon and nutrient cycling, nutrient uptake by plants, and SOM formation (Kibblewhite et al. 2008; Orgiazzi et al. 2016). Therefore, Mujtar et al. (2019) proposed a holistic approach to soil biodiversity management that strengthens multiple ecosystem functions and provides ecological resilience. Soil biodiversity can have direct and indirect effects on agricultural productivity and food security. Direct impacts occur through plant-soil interactions where specific soil biota impact plant growth and/or plant health, while indirect impacts occur via soil processes in which soil biota are involved, e.g., SOM dynamics, carbon and nutrient cycling, improving soil structure, etc.

We present an integrated nutrient model which should be popularized among the farmers in Nepal but could also be used in other countries of south Asia (Fig. 8.3).

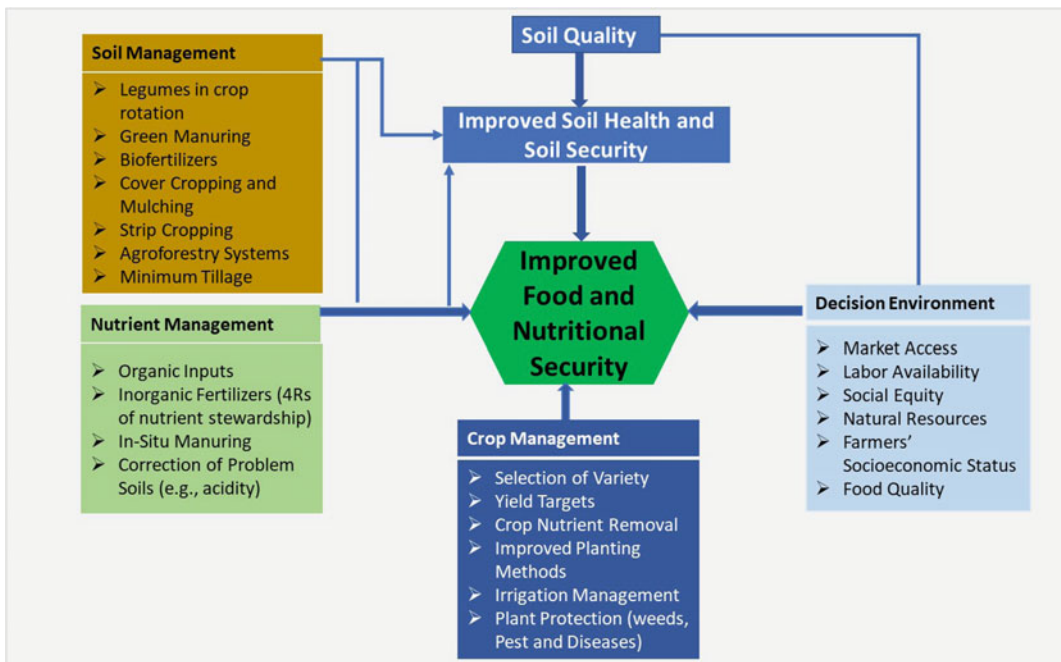


Fig. 8.3 Improving food and nutritional security through improved soil health in Nepal (modified from Sherchan and Karki 2006)

8.6 Improving Soil Information System and Updating Fertilizer Recommendations

In Nepal, access to soil testing facilities is scarce thereby making it difficult for farmers to know the fertility status of their field. On one hand, the country lacks reliable historical data on fertilizer use by crops, seasons, years, and districts. On the other hand, the government fertilizer recommendations are outdated, but yet not been adopted by most farmers. Farmers apply fertilizers based on their own experience rather than following soil-test-based results or government recommendations. This has posed a challenge for farmers and extension workers to determine the right amount of fertilizers for particular crops and sites. The lack of a well-developed soil information system and soil fertility maps makes it difficult for the government and other stakeholders to develop strategies for soil fertility management and fertilizer recommendations for crops. To address this gap, NARC's National Soil Science Research Center in partnership with the "Feed the Future Nepal Seed and Fertilizer project" has recently developed a digital soil map (DSM), which gives output at 250×250 -m resolution (Hengl et al. 2017). The DSM predicts location-specific soil properties including OM, total N, available P_2O_5 , and K_2O , soil acidity, and micronutrients Zn and B across the country. Maps could be used by farmers, policy makers, extension workers, and agro-input retailers as an evidence-based DSS tool to receive location-specific information for making localized management decisions such as for identifying soil problems and applying correct types and rates of fertilizer. (Vista et al. 2021). Prior to the development of the above national-scale DSM, Pandey et al. (2018) had also demonstrated the potential use of DSM to determine the spatial distribution of soil chemical properties of the Bara district in central Terai using the geostatistical interpolation.

Soil mapping can aid in decision-making by planners and efficient fertilizer management by farmers. Pandey et al. (2019) mapped the spatial

distribution of three different land-use types (agriculture, agroforestry, and grassland) in Dang district in mid-western region, and reported that SOM and total N contents were in medium-range in all land-use types, with highest in grassland, followed by agricultural and agroforestry lands. Soil available P_2O_5 showed a significant variation between agroforestry and grassland while soil K content was highest in grassland and lowest in agricultural land. Boron was low while Zn was very low in all systems. Such maps can assist farmers in identifying the expected nutrient levels in their fields and allow them to make easier and efficient fertilizer management decisions to increase crop productivity and farm income sustainably.

In addition to above, there are few newer studies on the development and use of the DSM in Nepal. Campolo et al. (2021) used high-resolution remote sensing data and DSMs, as a low-cost and scalable alternative to estimate soil and fertilizer effects on irrigated wheat yield. They demonstrated the potential of crop cuts and satellite data and crop simulation and machine learning to examine the influence of soil on wheat yield, guide precision fertilizer management, and adopt site-specific soil management practices. Likewise, Lamichhane et al. (2021) sourced environmental covariates from remote sensing and used digital elevation models and climatic and national databases for predictive mapping of soil. The predicted maps were found to show more detailed soil information in comparison to the original soil map and could be used for research, planning, and management of land resources.

Interactive IT-based DSS tools and mobile technologies can aid in providing rapid fertilizer recommendations, improve soil fertility, and achieve food and nutrition security. One such development is the use of mobile lab van technique to provide soil chemical analysis service and fertilizer recommendations based on the nutrient status of the farmer's fields. Pandey et al. (2018) used the mobile soil testing lab van to provide soil testing in farmer's fields itself in eight districts in the mid-hills and Terai regions

of Nepal. The mobile lab van technique can serve as a model to successfully transfer technology for improving soil health and providing fertilizer recommendations.

The other is the Nutrient Expert (NE) DSS to provide site-specific nutrient recommendations for farmers for their specific fields. Nutrient Expert (NE) for rice, wheat, and maize, developed by the International Plant Nutrition Institute together with national collaborators and based on the principles of site-specific nutrient management (SSNM), has been validated and applied in many countries of Asia and Africa. Amgain et al. (2021) used NE-Rice as a nutrient management protocol in several farmers' fields across Terai and mid-hill districts. They found that the nutrient management had a significant effect ($p < 0.05$) on grain yield and gross margins of rice, with the highest gross margins for NE-based recommendation followed by government fertilizer recommendation (GR) and farmer's fertilizer practice (FFP) for several districts in both mid-hills and Terai regions (Table 8.5). The gross margin and benefit–cost ratio were highest for hybrid rice with NE recommendation followed by improved rice with NE, and lowest for improved rice with GR and FFP in the eastern Terai and mid-hills districts. Dahal et al. (2018) used NE-based recommendations and FFP for maize and wheat at two sites (Morang and Jhapa) in Eastern Nepal and found significantly higher productivity and profitability of both crops from the NE-based recommendation in both sites. Therefore, NE for rice, maize, and wheat can be used as an effective and efficient tool for site-specific nutrient or fertilizer recommendations in Nepal and other countries of south Asia.

8.7 Conclusions, Policy Implications, and Recommendations

Healthy soils play a critical role in improving crop productivity and meet food and nutrition security of the growing population. Therefore, priority should be given to maintain soil security through improving soil health. Healthy soils can

maintain balance in ecosystem services including maintaining soil biodiversity, reducing atmospheric pollution, and increasing crop productivity. The study shows that the soil fertility in Nepal is in declining trend due to various reasons including but not limited to less use of organic inputs, continuous nutrients removal from soils without proper replacements resulting in nutrient mining, improper and imbalanced use of inorganic fertilizers, increased cropping intensity, soil erosion, and soil acidity, among others. Declining soil fertility has posed several challenges to increase crop productivity and achieve food and nutrition security.

The Government of Nepal has issued several policies to improve agricultural productivity in general and crop productivity in particular through land or soil management. Some policies directly or indirectly related to soil, land, and fertilizer management are National Fertilizer Policy (NFP) (2003), National Agricultural Policy (2004), National Land Use Policy (2012), National Range Land Policy (2012), Agriculture Perspective Plan (APP) (1995), and Agriculture Development Strategy (ADS) (2015). A twenty-year APP (1995–2015) has identified chemical fertilizer as the engine of agricultural growth and emphasized increased fertilizer use to attain planned agricultural growth. It is apparent from various policies that the Nepal government has given a priority in mitigating land degradation caused by several reasons including inappropriate land use, soil erosion, etc. However, these policies have been generally ineffective in reducing soil erosion, landslides, and floods in relation to set targets (Chalise et al. 2019).

The reasons for ineffectiveness of various policies include i. Implementation of land management-related policies remains weak. As there are no separate laws to address agricultural land degradation, many sectoral laws and program policies provide the legal context relating to sustainable land development through soil conservation, fertility management, and conservation agriculture, ii. Land (Measurement) Act 2019 B.S. and Rules B.S. 2058 consider classification of land in terms of use such as agricultural, commercial, and residential. Implementation of the

Table 8.5 Grain yield and gross margins from rice under farmers' fertilizer practice (FFP), government fertilizer recommendation (GR), and nutrient expert (NE) recommendation across Terai and mid-hills of Nepal from 2015 to 2018 (Adapted from Angain et al. 2021)

Grain yield (t/ha)										
Treatments	Dang	Rupandehi	Lamjung (1)	Lamjung (2)	Kavre	Chitwan	Morang	Jhapa	Lamjung (3)	Bhairahawa
FFP	4.9	4.6	4.0	4.9	5.2	3.9	4.4	4.3	4.2	6.2
GR	5.8	5.0	4.2	5.5	5.1	4.3	4.8	3.7	4.7	6.3
NE	6.5	5.4	5.1	7.4	5.8	4.7	5.5	5.1	5.8	6.4
% Increase in										
NE over FFP	32.7	17.4	27.5	51.0	11.5	20.5	25.0	18.6	38.1	3.2
LSD (0.05)	1.02	1.65	0.80	0.55	1.05	0.74				0.34
Gross margins ($\times 1000$ NRs/ha) ^a										
FFP	63.8	66.7	19.7	10.5	40.4	48.2	12.5	10.3	57.7	16.9
GR	77.6	77.2	27.7	15.1	32.4	57.7	13.1	9.38	71.5	18.7
NE	86.3	99.1	64.3	21.1	64.5	68.9	15.0	12.5	122	20.0
% Increase in										
NE over FFP	35.3	48.6	231	101	59.7	42.9	20.0	21.4	111.4	18.3
LSD (0.05)	11.5	4.78	2.83	2.02	11.48	22.28				1.1

^a 1 US\$ = NRs 115

above Act is often ignored by the government and rather authorizes the private sector to get involved in transforming agricultural lands into towns and built-up areas, iii. Information on soil quality is hardly available for all agro zones. There is no sincere thrust of the government to change the behaviors of people by encouraging them for increasing soil fertility or harness the optimal benefit from raising livestock that can provide sufficient urine and dung to supplement soil nutrients, iv. There are overlapping roles and responsibilities of institutions and lack of coordination among government agencies, v. Government of Nepal has already amended the Land Act 2021 B.S. twice and each amendment has targeted something other than ceiling. Amendments in regulation and devising other sectoral policies has not adequately discussed nor have encouraged sustainable land management, vi. While the soil erosion and fertility-related problems occur in agricultural lands, the Department of Soil and Water Conservation comes under the Ministry of Forestry and Environment which often ignores the Ministry of Agriculture and Livestock Development, and vii. There doesn't seem to be adequate political commitment on addressing soil conservation, fertility, and land management issues. We suggest that the agricultural and land-use policies give priority to soil conservation and management of agricultural lands to produce more food to feed the growing population.

This review has identified several soil and nutrient management-related challenges specific to agro-climatic zones, cropping systems, and management practices suggesting the need for site-specific solutions rather than a blanket approach applicable to the whole country. Most farmers do not know fertility status of their land and farmers' access to soil testing facilities is limited. Fertilizer recommendations for most crops were developed almost four decades ago and most farmers are not aware of even those recommendations. There are no reliable data on fertilizer use by crops, seasons, years, and districts. National research institutes including Nepal Agricultural Research Council (NARC) and Agricultural Universities are conducting

research to address those challenges, but their efforts are not sufficient. An immediate priority should be to collect data on fertilizer use by crops, seasons, and districts and update government fertilizer recommendations for various crops. This would help extension workers to advise approximate fertilizer recommendations to farmers. To provide accurate rates, site-specific nutrient management (SSNM) practices need to be adopted. To understand the farmers' fertility status of their land and develop SSNM practices, recently developed digital soil maps could be an effective guide or tool. Similarly, on-farm trials and demonstrations of improved SSNM technologies such as NE for rice and other cereals in multiple locations across Terai and mid-hills districts could help demonstrate its potential to the farmers, researchers, district- and local-level government agricultural extension officials, and teaching faculties of agricultural universities.

For the sustainable improvement of soil fertility and soil health, NARC has developed a model of integrated plant nutrient system which integrates soil and crop management, the use of organic inputs that are available locally at farm with the combination of inorganic fertilizer. Farmer's awareness should be increased in this approach. In addition, problem soils such as acidity should be corrected by application of agricultural lime. Due to remoteness and rugged landscapes of hills and mountains, farmers' access to agricultural lime however remains a challenge. For this, farmers' access to agricultural lime needs to be increased by Agriculture Inputs Company Limited in partnership with Lime Industry and local-level government and private sector organizations. Supportive policy and markets should be developed for effective and efficient distribution, availability, and affordability of agricultural lime by the local government.

To increase soil fertility and adoption of improved agricultural practices, Government should motivate farmers to adopt efficient soil and fertilizer management practices, which can improve SOM and protect soil biodiversity. Out-scaling of the improved practices should be done in close coordination with field-based extension

workers and staff from different projects and development partners. Yield and economic benefits of any technology should be demonstrated to farmers to increase its adoption. There should be a strong awareness and capacity-building program for technical staff at all levels of the Ministry of Agriculture and Livestock Development to improve understanding and use of improved soil management practices for increasing soil health and soil security and crop productivity and make the country self-sufficient in food production. There is a need to include soil security in policy planning and link it to achieve food and nutrition security and various SDGs, particularly SDG #2 (end hunger, achieve food security and improve nutrition), #6 (water quality), #13 (climate action), and #15 (life on land).

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Plant Clinics for Crop Health and Food Security: Experiences from Nepal

9

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Abstract

Despite public and private extension services and advice of input suppliers (agro vets) for plant protection, crop health problems have remained a major constraint for farmers to achieve potential crop yield in developing countries including Nepal. These agencies provide services based on farmers' verbal sharing of symptoms of sick plants. This practice increases the cost of production and leads to the use of extra chemicals in environment with a possibility of wrong diagnosis of the plant health problems ultimately impacting environment, human and animal health, food safety, and costs of

production. To avoid such problems, the Centre for Agriculture and Bioscience International introduced a novel concept in plant health service called "Plant Clinic" in 2005, which has now expanded to 3700 clinics in 34 countries including Nepal. Plant clinics are meeting venues where the agricultural extension people trained as "plant doctor" diagnose the crop health problems and provide management advice on crop health by also considering the human and ecological health. This chapter outlines the history, need, and operation procedures of plant clinics in Nepal and recommends way forward for effective implementation of this tool in future.

Keywords

Advisory service · Extension · Plant health · Plant protection

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9.1 Introduction

Agriculture has played a vital role in Nepal's economy, employment and livelihoods by contributing 27% to its Gross Domestic Product (GDP) and providing employment for 57% of its working-age population (NPC 2020a). According to Nepal Labor Force Survey (NLFS) 2018, agriculture sector contributes highest share (20%) in formal employment while substantially

huge share for partial employment opportunities (CBS and ILO 2019). Since the start of the implementation of first five-year plan in mid-1950s, Nepal's each government's priority has been toward the improvement of the agriculture sector (NPC 2020a). This has been reflected through the implementation of different extension approaches, methods, and supporting projects for increased productivity, food and nutrition security, commercialization, and agriculture-based economic growth, yet the growth of the agriculture sector has remained below 3% since last three decades (Chaudhary 2018). This has resulted in 52% of the population food insecure (NPC 2020b) and 8.7% of the population receiving food below the minimum calorie requirement (FAO 2019).

Undoubtedly, growth in agriculture sector is primarily concerned with sustainable development and poverty reduction in developing countries like Nepal (World Bank 2010). But increasing land fragmentation, poor economies of scale, lack of proper land use planning, limited access to and adoption of improved farm inputs and technologies, inadequate and weak inputs and service delivery mechanisms (NPC 2020a), and limited access to demand-driven and suitable technologies and extension services (Babu and Sah 2019) are key determinants for lower productivity and sluggish growth of the sector. On the other hand, crop loss from pests and disease during pre-and post-harvest is a critical factor for lower productivity (Oerke 2006) but is often undermined in the agriculture sector development. Farmers in many developing countries like Nepal are primarily dependent on public extension for agro-advisory services including plant health care but the weaker extension systems limit their access and compel them to rely on their own or peers or local agro-input dealers for such services. This has further contributed to higher pre- and post-harvest losses, increased cost of production, and lower competitiveness of Nepalese agricultural industry. To address such problems, CABI invented an innovative extension tool called "plant clinic" to provide better plant health care services to underserved small-holders in an affordable and accessible way

which was replicated rapidly across Africa, Asia and Americas. This approach was introduced in Nepal in 2008 and mainstreamed in public extension system since 2011. With the promulgation of the Constitution of Nepal and new Federal governance system, commercialization of local agriculture sector and food self-sufficiency has become the common goal for all three tier governments. Given the limited human resources at local governments and primary role of agriculture extension, there is huge scope for setting up the plant clinics to achieve the stated goals. But there is very limited information and knowledge products about the plant clinics and their potential role and significance for better food security. Therefore, this chapter aims to portrait the plant clinic as an extension method in Nepalese context to reach the underserved farming communities.

This chapter was prepared through the extensive review of available knowledge documents both in published and unpublished forms, consultations with key stakeholders from government and non-government organizations, private sector service providers, and academia and farming communities. Authors' experience on agriculture research-education-extension systems including the operation of plant clinics in Nepal were extensively capitalized to prepare this chapter and correlate the evidence presented in different forms. This chapter will be a valuable knowledge product for the concerned stakeholders and service providers, particularly in the post-federalization context, to scale up this concept thereby reaching to underserved farming communities. The outcome of this concept has direct contribution to two Sustainable Development Goals (SDGs), namely zero hunger (#2), responsible consumption and production (#12), life below water (#14), and life on land (#15).

9.2 Agriculture Extension Service System in Nepal

Agriculture extension system in Nepal is very generic in nature where single extension technician has to deal with different disciplines like

extension services for production, plant protection, storage, and post-harvest management. Nevertheless, over time, the agriculture extension approaches have been changing to meet the goal set by various economic and agriculture plans of the country (Dhital 2017). Training and Visit System (Thapa 2005), Integrated Rural Development (Sharma 2011), Tuki (Dangol 2004), Farming System Research and Extension, and Block Production Program were some of the extension approaches adopted in Nepal (Dhital 2017). These approaches focused more on extension of agriculture technologies and their testing and validation at farmers' fields to help them for easy adoption. Attention on the specific areas like eco-friendly plant protection was seldom considered. With the outbreak of brown plant hopper (*Nilaparvata lugens* Stal) of rice in central part of Nepal in 1997, Nepal became a member country for Community Integrated Pest Management (CIPM) program with the high consideration of promoting and adopting Farmer's Field School (FFS) (Kafle et al. 2014). CIPM, an important technology transfer tool, was well recognized and emphasized in the Agriculture Perspective Plan (APP) (1995–2015) and the Agriculture Development Strategy (ADS) (2015–2035) along with transfer of improved technologies, commercialization of crops, introduction, and testing of new improved varieties and better crop protection. In the meantime, the country has entered a new governance system of federalism and has restructured its existing agriculture extension system accordingly. The changed structure attempted to revert the existing funnel system of extension service into a cone system; however, the farmers and clients have realized the greater level of disconnection among the three tiers of government system, i.e., federal, provincial, and local governments. In the new structure, the then district-based agriculture development offices (now converted as Agriculture Knowledge Center, AKC) are placed under the provincial government while overall responsibility of extension and services is given to local government. Though the agriculture section in the local government bodies is frontline entities, primarily

responsible to provide agricultural extension services including plant health services, these are not getting adequate technical staff, laboratory facilities, and proper technical guidance. Also, in most of the cases, the agriculture sector has not been the priority of the local governments. At the same time, the ratio of the service providers and service recipients is 1:164 (Adhikari et al. 2013) which is fairly low to cater the demand of the farmers. This called for a rethinking of the current extension system so that farmers can have access to the novel and innovative technologies and be able to adopt improved crop health management practices.

9.3 Plant Health Service System in Nepal

Pests (insects, pathogens, and other pests) are the major agents for crop losses and accounted for around 35% of the crop loss in Nepal (Palikhe 2002; PPD 2012; Kc 2017). Poor crop health, which combines soil fertility, water management, and pests, is the single most important reason for losing productivity. Plant health service in Nepal is relatively poor due to scattered small-scale farmers, limited technical staff, lack of regular updates on recent pest occurrences and crop health management, and inadequate laboratory facilities. There is poor coordination among teaching, extension, research, development, and private agencies, even though their number and size have grown in recent times. At present, there are three major universities namely Agriculture and Forestry University, Tribhuvan University, and Purbanchal University and their campuses run graduate and undergraduate programs in plant pathology, entomology, and plant protection. Similarly, AKCs at district level and Agricultural Section at local government level are major public service providers for plant protection. In addition, Plant Quarantine and Pesticide Management Center (PQPMC), central and provincial plant protection laboratories, National Plant Pathology Research Center, National Entomology Research Center, and related units at different research stations of Nepal Agriculture

Research Center (NARC) are in place for plant health support services at different levels. The decentralization of agriculture service system and local government bodies pave the foundation for the better agriculture advisory services including crop health management in Nepal.

Growing incidences of pests have become a biggest hurdle in increasing food production in Nepal. Increased use of external chemical inputs and continued loss of locally adapted crop landraces and their replacement by exotic hybrid seeds have led to accelerated incidence of pests. As a result, management cost has increased with the additional burden of managing plant health problems without adding food availability. Its impact on crop losses is difficult to estimate because of complex causality in crop loss—multiple biotic and abiotic factors are responsible with differing impacts in different agro-ecosystems. Nevertheless, studies suggest that 20–35% of pre-harvest losses (PPD 2012; Kc 2017) and another 20–30% of post-harvest losses (Bhattarai 2018) could be due to poor crop health management. These losses can significantly be reduced with the adoption of quality plant protection services (Kc 2017) giving due emphasis on better agro-advisory services which in turn contribute to the increased food availability.

9.4 Plant Clinics

Plant health clinics (also referred to as plant clinics, crop health clinics, and rural plant clinics) are a platform and tool developed to deliver quality advisory services for crop health. They are originally developed by the Global Plant Clinic (GPC) of Centre for Agriculture and Bioscience International (CABI), United Kingdom, and piloted in Bolivia in 2003 (Boa 2009). The Plant Clinic is a community-based public service run by extension workers backed by specialists and based at public places like local markets or bus stations (Bentley et al. 2007). It provides advisory services in primary health care for plants. The technicians providing the service are informally called “plant doctors”, who provide recommendations for plant health problems

after looking at the sick crop plants brought to the clinic site. A Plant Clinic generally operates for few hours in a day; its service depends on existing capacities, organizational structures, and social dynamics. It conducts diagnosis of the plant health and gives recommendations based on IPM approach of pest management. Different studies conducted in Bangladesh, Nicaragua, Bolivia, and other countries have largely emphasized the role of Plant Clinics to increase yield and income of farmers due to an easy access to quality services offered from the Plant Clinics along with increased adoption of eco-friendly production practices and improved relationship among plant doctors, farmers and input suppliers (Guerrero et al. 2008; Kelly et al. 2008). Another study in Bangladesh found that problem-solving ability of farmers using the services of Plant Clinic increased by 18% and their income by 33% as compared to that of non-users (Ghosh et al. 2019). These findings show that it is possible to overcome inherent weaknesses in local service delivery and make better use of existing capacities and resources.

9.5 Plant Clinics in Nepal

The concept of plant clinic was first introduced in Nepal in December 2008 by a non-governmental organization, World Vision International Nepal (WVIN), followed by the Society for Environment Conservation and Agricultural Research and Development, Nepal (SECARD) (Adhikari 2009). Since then, the organizations continued Plant Clinics by engaging government officers, scientists, technicians, and academicians (Adhikari 2018; Adhikari et al. 2009). The plant clinic was introduced into the government system in 2011 through a training program to government staff. The then Plant Protection Directorate (PPD) of the Department of Agriculture led the program. This was one of the historic events for the government system in Nepal to adopt a practice from the non-government system. Following in-house trainings to extension staff, Plant Protection Directorate (PPD) recognized plant clinic as an effective extension tool. The

government then approved the norms for implementing plant clinic activities. Gradually, the Regional Plant Protection Laboratories (RPPL) and then District Agriculture Development Offices (DADO) adopted plant clinics in their annual programs. Table 9.1 highlights the major milestones of the plant clinic initiative in Nepal.

The genesis of plant clinics in Nepal can be systematically categorized into three phases: the introduction phase (2008–2011), the integration phase (2012–2014), and finally the scaling-up phase (2014 onwards). Looking into its gradual development, strong collaboration among the government and non-governmental institutions, research and teaching institutions, and private sectors has been the key feature. A formal

agreement was then signed between PPD and CABI in 2013 aiming to strengthen the national plant health system of Nepal through providing technical assistance to government extension staff, operating regular clinics, and building the knowledge bank (Adhikari 2018). Since then, the program has been integrated with existing extension service system with increased acceptance by different stakeholders leading to establishment of plant clinics in 45 out of 75 districts in the country (now there are 77 districts) in 2016 (Adhikari 2012, 2018; Adhikari et al. 2017). In 2017, the concept of e-plant clinic started with use of ICT to revolutionize the national extension system and aid quick transfer of information to farmers via text messages of recommendation

Table 9.1 Timeline of key plant clinic-related events in Nepal

Date	Activities
Dec. 7–9, 2008	WVIN organized first plant doctor course in Lamjung
Dec. 10–11, 2008	WVIN piloted two mobile plant clinics in Lamjung
Jan. 08, 2009	SECARD-Nepal organized first mobile plant clinic in Kathmandu
May 08, 2009	SECARD-Nepal, WVIN, and DADO-Kathmandu jointly organized workshop on plant clinics in Kathmandu
May 10, 2009	Clinic monitoring and electronic data management introduced
Nov. 2009	SECARD-Nepal organized workshop on plant clinics in Chitwan to disseminate concepts in ground
Feb. 28 Mar 1, 2010	WVIN organized module 1 of plant doctor's training in Lalitpur
March 5–8, 2010	WVIN organized modules 2 and 3 of plant doctor's training in Lamjung
Aug. 2–4, 2010	WVIN organized module 1 course in Butwal
Aug. 6, 2010	SECARD-Nepal and the Chamber of Commerce and Industries, Chitwan jointly organized a workshop on 'Solidarity in action and cooperation for plant clinics in Nepal'
Aug. 7–9, 2010	SECARD-Nepal organized module 1 training in Chitwan
Jan. 27–30, 2011	PPD organized module 1 training for its plant protection officers
Sept. 23–25, 2011	WVIN-Kaski organized module 1 training in Kaski
Sept. 25–27, 2011	PPD organized module 1 training for its plant protection officers
March 14–16, 2012	CABI and SECARD-Nepal jointly organized Asia plant wise summit—plant clinics today and plant health systems tomorrow in Kathmandu
2013	MOU signed between CABI and PPD for cooperation in plant clinics
2014	PPD organized modules 2 and 3 training for agriculture officers
March 2017	CARITAS-Nepal started plant clinics through its program

Source Adhikari (2018)

advice on their mobile phones. On the other hand, the plant doctors mentioned that tablet-based clinics would help them in reaching a greater number of farmers backed with information that is more scientifically delivered through the aid of different knowledge bank (KB) tools. By using tablets, pest surveillance in the country would be easier and data could be quickly submitted to a secure central database and analyzed quickly, benefiting stakeholders in the plant health system. This would also help to track the distribution of pests, monitor the quality of advice given to farmers and use the information to improve the service offered by the plant doctors at their clinics.

Nepal's agricultural sector is dominated by smallholder farmers, but the government's inflexible extension services have not benefited them. The private extension service providers and agro-input dealers (agrovets) can be easily accessed by farmers, and they do have largely flexible business model that considers their client needs and demand. That is why many smallholder farmers rely on the inputs and services of the local agrovets. However, due to relative lack of technical knowledge of the agrovets and their profit-earning motives, they generally advise to use unnecessary and large amounts of inputs, which can be harmful to human and environmental health. On the other hand, use of unnecessary inputs increases cost of production and reduces farmers' profit.

As far as the plant health management system of Nepal is concerned, PQPMC at the central level is represented by 15 different plant quarantine offices cover all geographical areas of Nepal and five plant protection laboratories at the provincial level. Two other provinces have yet to set up their laboratories. Plant protection trainings, campaigns, and inputs support are the most common extension services demanded by farmers and are being provided by local governments as well. In the past, APP gave priority to plant protection services, particularly the integrated pest management (IPM) through its agroecosystem management approach. Thereby the IPM policy was drafted in 2013 addressing sustainable increase in production with the appropriate

use of agrochemicals only when and where necessary; however, the government hasn't approved it yet. As indicated in Fig. 9.1, Nepal has established some institutions, adopted mechanisms, and taken initiatives to contribute to six building blocks of the plant health system framework but they are not sufficient to ensure the intermediate and long-term goals.

9.6 Plant Clinics at Operation Level

As advisory services on plant health face problems in reaching out to needy farmers, plant clinics' operation modalities are carried out as both regular and mobile activities. Regular clinics are operated at specified times, dates, and places while mobile clinics are demand-driven and services offered at varying places, dates, and times (Boa 2009).

The operation of plant clinics at local level is supported mostly by extension agents who place on their specialist services in diagnosing the plant samples as plant doctors. Following training modules, extension officers or agriculture technicians organize a planning meeting at a certain venue, time, and date. Dissemination of information is carried out at local level by farmers and other local stakeholders through pamphlets, brochure, and other available media (including FM radio). Farmers are asked to bring their sick crop samples to represent the actual health problems. Plant clinic venue is prepared with pest and disease diagnostic kits, sample problems, and color pictures of major crop problems. Organizers register the farmers' samples and submit them to plant doctors for the examination of the problem. After diagnosis, plant doctors provide verbal as well written information in a specified piece of paper called prescription. The prescription sheet is a well-designed form, which has three major parts: first part used for collecting the farmers' information, second part for description of the plant and its parts, and the third part for diagnosis of specific problems and recommendations. The prescription sheet has at least two copies—one original and one carbonated. Original copy is provided to

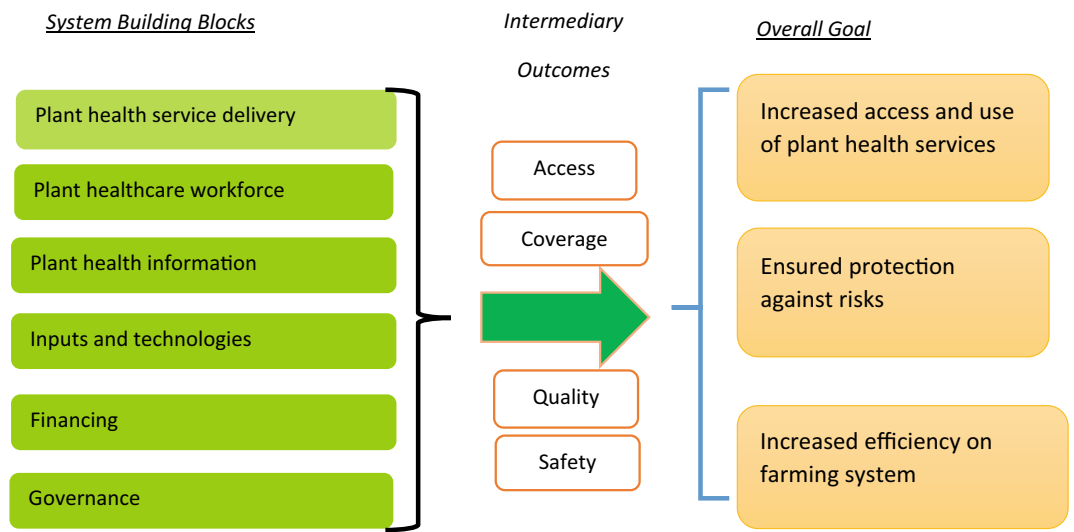
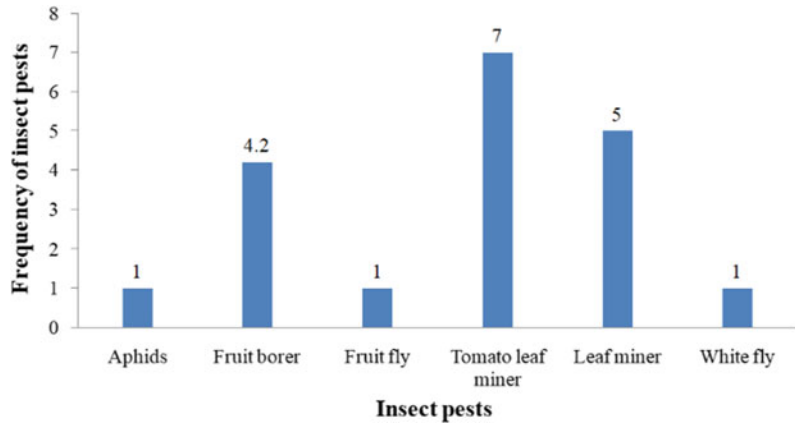


Fig. 9.1 Plant health system framework for Nepal (Source Adapted from Adhikari 2018)

Fig. 9.2 Frequency (%) of insect pests in top crop (tomato) (Source Adhikari et al. 2020b)



the respective farmer and the carbonated copy is kept by the plant doctors. A simplified procedure of plant clinic operation is presented in Fig. 9.2. Both demand-driven and supply-driven approaches are being used to run clinics by different organizations.

9.7 Economics of Plant Clinics

Ideally, plant clinic is considered the best approach to reach a greater number of farmers with limited resources for operation. The farmers may visit the nearby clinic with the problem that they are facing in their crops. In Nepal, different

organizations are operating clinics with similar practices, but the cost of clinic operation varies depending upon technical resources, access to required information, and established norms. Generally, private sector and NGOs do not have enough technical human resources to provide wide range of solutions, so they have been collaborating with universities, NARC, or public extension units on payment basis. As the government has mainstreamed this concept as one of the extension approaches, it has endorsed norms of Rs. 8000 per clinic. In contrast to this, the expenses of NGOs like SECARD-Nepal seem considerably higher (Rs. 10,500) which includes the fees for plant doctors and plant clinic

organizing staff. Considering all other expenses including the personnel and in-kind contribution, it may go as high as of Rs. 15,000 per clinical session.

The number of farmers visiting the clinic with the type of queries varies with the location, level of commercialization, and season. Adhikari (2018) found average of 19 farmers and 27 queries per clinical session in Nepal; this is quite high in comparison to Zhang et al. (2017) who found the average of five queries per clinical session in China. This alone will not help in estimating economic impact of the plant clinic on the farming system. For a complete estimation, we need to compare the cost of the plant clinics and number of beneficiaries and the utility of the services offered. Since the plant clinic covers a certain specified area, analysis of cases, trends, and intensity can help the organizer or the technical person to predict the severity of the problem in that area and to suggest/adopt specific preventive and curative measures right from the beginning. Therefore, it helps in reducing waste due to plant health problems thereby in increasing income and improving food security of the farming households.

Adhikari (2018) found the increased application of chemical fertilizer among both clinic users and non-users farmers in Chitwan but the rate of increments was significantly lower (8.96 kg/ha) among the clinic users which has direct impact on the cost efficiency and long-term impact on sustainable soil fertility. The same study found significant decrease in the herbicide dose (0.33 kg/ha) and herbicide cost among the clinic-participating farmers but increase among the non-participants (0.11 kg/ha). In contrast, the dose of chemical pesticides and their associated cost has significantly increased among the clinic-participating farmers whereas the increment among the non-participants was not significant. Considering all factors of production before and after the plant clinic participation, the net difference in cost of rice cultivation was Rs. 4624/ha lower among the clinic users whereas the net revenue was higher by Rs. 5950/ha with net difference in productivity by 0.26 t/ha among the clinic users.

9.8 Impact of Plant Clinics

The Plant Clinic does not only provide opportunities as an extension tool for consulting and resolving plant health problems but also contributes as a tool for communities serving as a pest survey and surveillance platform. Dynamics, seasonal variability, intensity, and frequency of any pests and their potential damage can be monitored through plant clinics. Systematic management of the plant clinic registers and their analysis in PlantWise Online Management System (POMS) gives an overall idea on pest management strategies to be adopted by the government system. Close and constant vigilance of pests in particular areas is possible through plant clinics. It also helps in finding out presence or absence of any pests in the farmers' fields. Thus, the plant clinics can have multiple impacts on pest survey and surveillance, along with farmers' sensitization to a systematic approach for pest diagnosis, recommendation, and management based on real observation of diseased or pest-infested crop specimens.

Due to limited technical knowledge and skill, farmers in Nepal are applying either lower or higher doses of production inputs than the recommended level. In this context, the role of extension service is to provide appropriate advisory services on optimal use of those production inputs considering the output-cost trade-off aiming for maximum potential benefit. In general, the first impression toward the plant clinic could be something promoting use of different plant protection measures to protect from different pests, but in reality, the scope of plant clinic was found much wider than perceived. Therefore, when farmers get opportunity to meet with local extension staff or subject matter specialists as plant doctor (Bentley and Boa 2004a), they try to get answers to many problems from the samples brought at the clinic. The plant doctors are trained to listen to farmers who visit clinics with problem, so they can identify the root cause of the problem and suggest both the curative and preventive measures. That is why the plant clinic has potential to benefit farmers in different ways.

Farmers are exploring the possible solution to minimize their cost of production or increase revenue by using possible measures and adopting available technologies. The growth trend of productivity reveals that the adoption of modern technology is increasing over time, but the process can be accelerated by responsive agro-advisory services. Therefore, judicious, and rational use of inputs is very important to increase the gross margin of the produce.

The agricultural extension services aim to bring positive changes on knowledge, attitude, and practice of farming activities among farmers so the production, productivity, and quality of products can be increased. Different studies have revealed the effectiveness of plant clinics to increase farmers' knowledge about the cause of crop problems and better management options whether it is about the use of fertilizer or appropriate dose and frequency of pesticides (Adhikari et al. 2015; Adhikari 2018, 2015; Adhikari 2018). As plant doctors advise chemical measures as the last resort to control the crop pests there has been significant decrease in the average dose of chemical pesticide application in Nepal (Adhikari 2018). Studies in Nicaragua and Bangladesh have also witnessed the reduction on use of unnecessary chemicals along with and emphasis toward eco-friendly input by the input suppliers who were linked with the plant clinics. In Nepal, the number of agro-input dealers as plant doctors in plant clinics are very limited (Adhikari et al. 2015). However, in some cases, the cooperatives also having agro-input shops are hosting mobile clinics which may have contributed for increased knowledge and skill of the shop operators in identifying the crop problems as well as recommend appropriate agro-inputs. But the increased knowledge and skill among the extension workers trained as plant doctors are providing more effective services with increased focus on biological and eco-friendly practices (Adhikari et al. 2019).

The community-based plant health clinics have revealed the considerable potential for fundamental improvements of local advisory services through simple innovations in organization, management processes, and services

(Bentley and Boa 2004b; Negussie et al. 2011; Danielsen et al. 2013). The results and lessons obtained so far show that it is possible to overcome inherent weaknesses in local service delivery and make better use of existing capacities and resources. Experience in Kenya has revealed that community-based plant clinics can provide community-level adaptation mechanisms to cope with the changes in pest risks caused by the rapidly changing climate and other drivers (Efa et al. 2011). The coverage of plant clinics in Nepal, perception of plant doctors as well as farmers, and the use of clinic information toward integrated management of the crop pests are in favor of plant clinics. Scaling up this approach to large number of farmers in greater number of districts and in systematic way would help build a robust agro-advisory service system, which can provide timely, location-specific, and relevant information to address the existing and emerging issues.

9.9 Pest Monitoring and Surveillance

The plant clinic database has been a useful tool for the review of specific pest-related problems including the spread, trend, severity, and effectiveness of recommended practices in different countries. Out of the total 3268 entries in Plant-wise Online Management System (POMS) database during September 2013 to July 2016, 298 problems were diagnosed. Of those problems, 233 farmers rated late blight of tomato and potato as the most important problem followed by aphids by 220 and fruit fly by 180 farmers (Adhikari et al. 2020). Furthermore, 7477 queries by 5137 clients from 276 clinic sessions were recorded in plant clinic register of SECARD-Nepal and WVIN till 2015 (Adhikari 2018).

Furthermore, the data of regular Plant clinics at certain locations provide the pattern of specific problem incidence and its severity too which can be considered in succeeding year's management plan. From the POMS database (Table 9.2; Figs. 9.2, 9.3 and 9.4), Adhikari et al. (2020b) reported tomato with highest number (16%) of

Table 9.2 Top five crops registered in plant clinics, Nepal

Crop	Total queries	Frequency (%)
Tomato	909	16
Paddy	418	7.2
Cucumber	347	6
Cauliflower	343	6
Chilli	294	5

Source Adhikari et al. (2020b)

health issues, followed by paddy (7.2%) (Table 9.2). This could be the economic importance of the crops and possible economic loss anticipated by the farmers on these commercial crops.

Out of different problems with tomatoes, leaf miner has been recorded as the most common (12%) insect-pest problem (Fig. 9.2) and late

blight as the most common (23%) disease (Fig. 9.3). The most common recommendations given by the plant doctors were IPM practice with cultural management (65%), followed by regular crop health monitoring (38%), chemical pesticides (34%), biological control (22%), and resistant varieties (4%) (Fig. 9.4). The reasons for only few recommendations for resistant

Fig. 9.3 Frequency (%) of diseases in top crop (tomato) (Source Adhikari et al. 2020b)

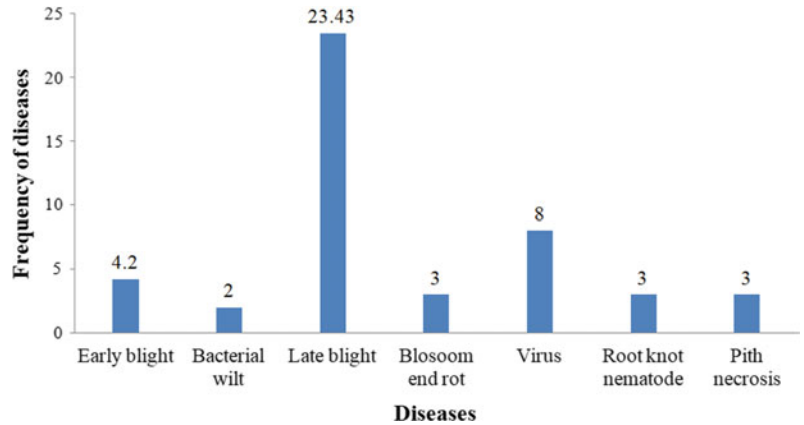
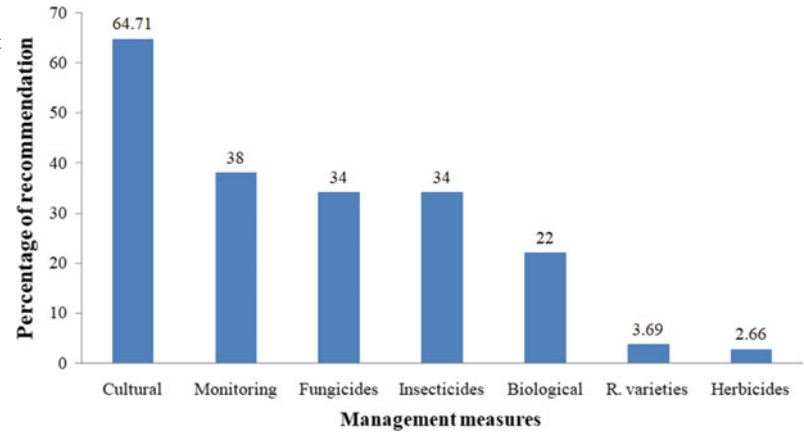


Fig. 9.4 Trend of recommendation (%) by plant doctors (Source Adhikari et al. 2020b)



variety and biological control methods might be due to unavailability of such variety or control measures, which could be the country's priority for research and development.

9.10 Integration of Plant Clinic in Agriculture Extension at the Local Government Level

As Nepal has adopted three levels of governance system in the context of federal Nepal, coordination, cooperation, and coexistence among these entities are imperative. The Constitution of Nepal-2017 has provisioned shared and concurrent responsibilities for agriculture sector development to the federal, provincial, and local governments. The federal government has been primarily responsible for policy formulation and endorsement, plant quarantine issues, whereas the provincial government is responsible for overall coordination and technical backstopping to the local level. The technicians engaged at the local level are technically backstopped in the implementation process. The Agricultural Knowledge Centre (AKC) of the provincial government can play crucial roles in coordination and technical backstopping to various units such as Plant Protection Laboratory (PPL), Nutrient and Soil Testing Laboratory (NSTL), Seed Testing Laboratory (STL), and Agribusiness Promotion Support and Training Centre (ABPSTC). Along with the services in various sectors, they can also support in clinical operations in various elements of crop production.

The local government is the frontline and nearest government for the farmers. Therefore, the broad-based extension provision including inputs support and advisory services is its primary role and responsibility. The agriculture extension personnel available at local government can plan and organize different types of extension activities where operation of plant clinic could be an effective tool to provide advisory services to the farmers.

Since most of the local governments have inadequate extension personnel, which also

limits the effectiveness of advisory service delivery even though the plant clinic can be the ideal means to cater more services with limited resources. Some of the agriculture technicians are operating plant clinics to some extent, yet many agriculture technicians with better knowledge and skills are not able to operate plant clinics. Accordingly, there is inadequate synergy and coordinated efforts in bringing desired level of changes in agriculture. There have been unofficial discussions about the lack of coordination, weak implementation structure, and insufficient number of technical expertise at the frontline. But still, no concrete measures have been taken to improve this situation—even with the knowledge that consultation, joint planning, and implementation mechanisms are vital issues. The AKCs can take lead role on awareness and capacity building through trainings and backstopping, which will enable local government in operating plant clinic sessions.

9.11 Opportunities and Challenges of Plant Clinics Operation in Nepal

The Government of Nepal has recognized the significance of the Plant Clinic as an important component of the extension tool, which is instrumental in solving the plant health problems. In the decentralized Agricultural Extension Service system, the local government authorities need better integration of such services with the enhanced coordination of private and non-government sectors. Strong and well-developed farmers' institutions (farmers' groups and agriculture cooperatives) can implement novel initiatives like plant clinics at the local level. There are many opportunities of running such services by the private sector or through joint ventures. Introduction, orientation, piloting, and feedback system development are steps ahead for the technical staff working under the local government system. The Plant Clinic can be a platform for farmers for better connection to technical specialists and extension staff and can interact on

broad arrays of crop issues including crop protection. Government extension service system needs to build harmonized program and financial norms, modalities, and feedback and monitoring. This makes it easier to introduce plant clinics and scale up to local communities in many districts. Issues relating to operating costs for plant clinics, data management, and diagnostic services in the laboratory are some of the challenges associated with successful operation of plant clinics, which needs to be addressed. Similarly, trained workforce and equipped laboratory facilities are some of the challenges for plant clinic operation. Better coordination with the existing institutions such as NARC, regional laboratories, and private sector agrovet are imperative for the success of plant clinics.

9.12 Way Forward

Federalization of Nepal has opened unique opportunities to take decentralized support service system at the doorsteps of farmers as the agenda of agricultural development has been brought under the jurisdiction of local government. Poor crop health remains an important issue and bottleneck for achieving higher yields required for food and nutrition security. Agriculture section under local government has broad range of mandates, which can outreach to the farmers who are in great need for improved crop health. Given the impact of “crop health” on yield, it should be given priority in the planning of the program and resource allocation. Local Government Operation Act (2016) provides ample opportunities for local government to improve agricultural production, for which a systematic way of introducing and implementing plant clinic initiatives is needed. Local agricultural policies and their directives can guide the planning and implementation authorities at the local level. However, need for adequate number of trained human resources is the key to successful implementation of plant clinics thereby reducing the arbitrary recommendations. The clinics can be run as stationary, mobile, or both as per the local needs.

9.13 Conclusions

The Plant Clinic as a tool for agriculture advisory services for crop health is a novel and customized initiative to resolve crop health problems in the world. Nepal has introduced the plant clinic concept and integrated into the national program. Such clinics have been run in different modes such as regular, mobile, or distant clinics. In the decentralized agriculture service system, local bodies are given immense responsibility and authority, which can formulate appropriate norms, guidelines, and policies. They can plan programs through participatory consultation and engagement of all stakeholders in the society. In such planning, agriculture sector needs to be given priority in resource allocation. Integrated agro-advisory services that may provide the technical as well input supports (e.g., soil testing, seed, fertilizers, and chemical pesticides) may be established in the annexes of the local-level offices. At the same time, there are challenges for the plant health management system because of the weak technical and infrastructural strengths, which could be overcome gradually. Systematic introduction and integration of plant clinics into the existing agriculture programs and operation of plant clinics in cooperation with farmers’ institutions could help develop effective, fast, and reliable diagnostic tools for crop health issues. The provincial research stations and teaching institutes could also run the clinics where appropriate. Similarly, it is crucial to obtain the farmers’ confidence in the plant clinics. Development of online database for pest monitoring and surveillance and the integrated management of crop health problems could be the next step.

Plant clinics have been equally prioritized by the United Nations as they contribute to some of the sustainable development goals (SDGs). Increased food security by increased crop productivity and reduced crop losses contribute to the achievement of SDG 2 (reducing hunger) and SDG 12 (responsible production and consumption). Equally, this approach reduces the hazardous prescription, use, misuse, and overuse of hazardous chemical pesticides while dealing with

crop health. Reduced and judicious use of specific chemicals and encouragement of other non-chemical measures for proper and timely management of crop health contributes to life in soil and below water contributing to SDG goals 14 and 15. This also means a greater recognition of the use of alternative means of pest control through biopesticides and promotion of local materials.

Despite the importance and relevance of the plant clinics in addressing the plant health problems, the authorities in local governments should be convinced of this idea and approach as agriculture services are now the responsibility of the local governments. This needs a close coordination and work out with those political leaders heading the local government so as to incorporate this in their regular programs of agricultural development. Farmers' sensitization for the need of plant clinics can be a better push factor while proactive local government is very crucial for the adoption of plant clinics at the local level. This asks for the allocation of financial resources to train human resources and establish needed laboratory facilities and diagnosis equipment and tools.

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Toxins, Contaminants, and Adulteration in Food: Current Policies and Practices, and Future Strategies for Nepal

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Abstract

Access to safe and quality food is universal human right. It is also assured in Nepal through its constitution and food-related regulations and standards developed and implemented since the 1960s. With population growth and increase in food production, distribution, and trading during the last three decades, Nepal has experienced various issues related to food frauds, intentional adulteration, chemical contaminants, and toxins in the food systems. This has increased socioeconomic burdens by putting extra pressure on the existing food regulatory system. The Government of Nepal has developed Food Safety Policy in order to promote food safety and quality in the country. Various acts, regulations, and standards related to food safety and quality are in place; however, implementation

of laws is often constrained due to limited financial resources allocated to technical and human resources development, and laboratory facilities for chemical and microbiological analysis. Inadequate financial and human resources have also hampered proactive role that three-tier government system needs to play in the implementation of food standards and related guidelines. Consumers could be the major drivers for the provision of safe and quality food; however, majority of the consumers in Nepal are guided by the price rather than the product quality, nutritional value, and their safety aspects. This chapter discusses current policies and practices of food safety and quality in Nepal. It provides insights on major drivers for food safety regulations in Nepal along with the initiatives that local governments can take in formulating and strengthening laws, rules, and regulations in their jurisdictions. It concludes that a system for proactive government responsibility in developing and implementing comprehensive food safety and quality management is important than leaving it to the mercy of open market economy.

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Keywords

Food adulteration • Food safety • Quality •
Regulations and standards • Food system

10.1 Introduction

Food safety despite being an integral part in food security is yet to grab attention among policy-makers and all tiers of government in allocation of resources to local levels in Nepal. Started since 1960s through development of food standards, food act, and regulations, the Government of Nepal needs further strengthening and revision of existing policies to adequately address food-related issues in the context of globalization of food trade and increasing food imports in Nepal. As a member organization of several international organizations including World Trade Organization (WTO) and World Health Organization (WHO), Nepal needs to fulfill many food safety-related obligations to comply with the rules and regulations as a member country. Poor infrastructures for food storage, handling, and transportation combined with lack of strict quarantine checks and analysis of food samples for import permits at customs is putting food safety of the people at further risk. In addition, the formulation of laws, regulations, and policies at local level government including increased investment in food-related infrastructures and laboratory facilities for better functioning are being more critical and relevant after federalization in Nepal.

This chapter provides an overview of the food safety-related issues in Nepal and relates them with the food safety issues in some developed and developing countries. The information was obtained through various scientific articles, public media, and consultation with subject matter specialists which provides the information about the current legislative and institutional framework to address the food safety-related topics including the future prospects for better regulations by the Government of Nepal.

10.2 Food Toxins and Contaminants: Global Overview

Food toxins and contaminants refer more commonly to chemicals and microorganisms present in food. Food and Agriculture Organization of

the United Nations (FAO-UN) estimates around 600 million cases of food-related illnesses with estimated deaths of 420,000 annually throughout the globe (FAO 2019a). Over 200 acute and chronic diseases ranging from illnesses of digestive tract to cancer have been found to be associated with food contaminants (FAO 2019a). In the US, it has been estimated that 9.4 million cases of foodborne illness occur annually with known pathogens and their possible sources of contamination. The US Center for Disease Control and Prevention (CDC) estimates that 48 million people get sick from foodborne diseases causing 128,000 hospitalizations, and 3000 deaths each year (CDC 2020). In Australia, Kirk et al. (2015) reported 4.1 million cases of foodborne illness during 2010 resulting in 30,840 cases of gastroenteritis-related hospitalizations and deaths of 76 persons in that year. Analyses of reported foodborne cases in India suggested 37 outbreaks of foodborne diseases during the 29 years (1980–2009) affecting 3485 people (Vemula et al. 2010). These data clearly reflect the substantial health and socioeconomic cost associated to foodborne issues globally. Realizing the importance of food safety and quality, the United Nations General Assembly recently adopted a resolution proclaiming the observance of World Food Safety Day on 7 June every year. Food Safety Day aims to create public awareness on food safety and quality-related issues, support economic development, and strengthen food, nutrition, and livelihood securities around the globe (FAO 2019b). Food safety is a broad area encompassing physical, chemical, or microbiological hazards which have potential to cause harm to public health. Owing to severe health and financial consequences of contaminants, toxins, and microorganisms in foods, each nation has developed a mechanism (legal and institutional) to ensure safe food trade in the country. Historical evidence suggests that comprehensive regulations of the food safety and quality issues started a long time ago tracing back almost a century in developed countries like USA. However, some of the food laws were found to be enacted several centuries earlier in England which may mark the beginning of the

development of food safety and quality laws to regulate food-related issues (MacMaoláin 2015).

The right to access adequate safe and nutritious food has been recognized as a universal human right in every country around the world. Therefore, safety and quality aspects of food have been regulated with different sets of obligations within each country and some common standards developed internationally with mutual agreement among multiple nations. International food standards known as “*Codex Alimentarius*” or “Food Code” were established in 1963 to regulate the food legislations among the member countries contributing to the safety, quality, and fair practice of the international food trade (van der Meulen 2010). Additionally, after the establishment of world trade organization (WTO), agreement on the application of Sanitary and Phytosanitary Measures (SPS) and the agreement on Technical Barriers to Trade (TBT) have been instrumental in defining the food protection measures at national level and the regulations for trading the food products at international level (FAO/WHO 2003). Therefore, access to safe food is considered as a fundamental human right and is accepted universally through various legal provisions including Universal Declaration of Human rights (Adamson 2004).

Improper handling of agricultural practices, poor hygiene during food production and preparation processes, and use of chemicals, contaminated raw materials, or ingredients are among the more common means to contribute to food-related hazards, i.e., toxins and contaminants (Hussain 2016; Kantiani et al. 2010). Food toxins are derived from the naturally occurring substances which may be produced by fungi, bacteria, algae, or even by plants themselves (Dolan et al. 2010), while food contamination may occur through improper handling of food during production, processing, fortification, and distribution in the food supply chain due to microorganism mediated spoilage or physical impurities or chemical substances. In addition, intentional contamination of food and food products has increased substantially in recent years globally. Consequently, the WHO including the FAO has raised food toxins and contaminants as one of the

biggest global public health challenges (FAO 2019a, b; FAO and WHO 2003, 2018; WHO 2018). This problem has ultimately affected overall food supply systems threatening the food, nutrition, livelihood security, and overall economic and social development. Most common naturally occurring toxins are summarized in Table 10.1, whereas common contaminants and adulterants that affect the food safety and quality are summarized in Table 10.2.

10.3 Food Laws and Regulations: Global Overview

It has been said that “if a food is not safe, it is not a food”. This implies that food safety and quality are integral components of food security system. Assurance of production and distribution of safe food has become an issue of global concern with the increased globalization of food trade. As a result, food safety issues have become more important than ever before throughout the world. Several efforts and provisions have been made to tackle with the emerging and reemerging food-borne issues globally because of their impact on public health, and economy. Historical evidence reveals that various forms of rules and regulations existed in developed countries like USA and the European countries since centuries to regulate the production, distribution, and trade of different food products. Almost all regulations aimed at protecting the health and well-being of the consumers and ensure fair practices in food trade. In the early times, end-product testing and command and control-based regulation was the main model. This long-established system of food control often has gone through significant changes over time to address new food-related issues. For example, Jack-in-the-Box outbreak of *E. coli* O157:H7 in the US in 1993 and Bovine Spongiform Encephalopathy in the UK during the same time resulted in the adoption of more robust food regulatory measures, known as Hazard Analysis Critical Control Point (HACCP) system. This has now become the important aspect of food safety management and regulations around the globe (Weinroth et al. 2018).

Table 10.1 Most common natural toxins present in food sources

Name of toxin	Source	Toxicity	References
Aquatic Biotoxins: Saxitoxin, ciguatoxin, brevetoxin, okadaic toxin, azaspiracid, etc	Aquatic microorganisms such as <i>Alexandrium</i> , <i>Pyrodinium</i> , <i>Dinophysis</i> , and <i>Protogonyaulax</i> including certain toxic algae containing cyanobacteria	Allergic to acute symptoms like diarrhea, nausea, vomiting, and neurological disorders	Balmer-Hanchey et al. (2008), Vilariño et al. (2018)
Mycotoxin: Aflatoxin, ochratoxins, patulin, citrinin, trichothecenes, zearalenone, tremorgenic toxins, and ergot alkaloids	Several primary and opportunistic fungi like <i>Coccidioides immitis</i> , <i>Aspergillus fumigatus</i> , <i>Fusarium graminearum</i> and <i>Candida albicans</i> , etc.)	Mycoses or mycotoxicosis resulting athletes' foot, aspergillosis; feed and food poisoning which has acute and chronic effects on human and animal health	Bennett and Klich (2003), Zain (2011)
Cyanogenic glycosides: Phytotoxin	Secondary metabolites found in several plant species including 26 economically important crops commonly of Fabaceae, Linaceae, Rosaceae, Leguminosae, and Compositae families	Acute and chronic illness depending upon the levels of cyanide released. Examples may include cyanide poisoning, konzo, and tropical ataxic neuropathy associated with consumption of raw or unprocessed cassava (<i>Manihot esculenta</i>)	Bolarinwa et al. (2016), Mlingi et al. (1992), Tyllskär et al. (1992), Vetter (2000)
Mushroom toxin: Amanitin, monomethylhydrazine, orellanine, coprine, muscarine, ibotenic acid, muscimol, psilocin, etc.	Most reported cases of mushroom poisoning are associated the fungal species <i>Amanita</i> . Other important fungal species which are toxic are <i>Chlorophyllum molybdites</i> , <i>Psilocybe</i> , <i>Gymnopilus</i> , <i>Galerina</i> , <i>Lepiota</i> , <i>Gyromitra</i> , etc.	Acute health issues such as gastroenteritis, hallucinations, convulsions, cholinergic toxicity, liver toxicity, and seizures depending upon the mushroom species, type of toxin it produces, and levels of consumption	Broussard et al. (2001), Puschner (2013)

In the US, food safety regulation is governed by a complex system and is administered by a dozen of federal agencies at federal, regional, and local levels. At federal level, four agencies—the Food and Drug Administration (FDA) of the Department of Health and Human Services (DHHS), the Environmental Protection Agency (EPA), the Food Safety and Inspection Services (FSIS) of the US Department of Agriculture (USDA), and the National Marine Fisheries (NMFS) of the Department of Commerce—have been playing a major role in regulating the food safety issues (Merrill and Francer 2000; Weinroth et al. 2018). Their responsibilities and scope of activities have been clearly defined by the acts. For example, Food, Drug and Cosmetic Act (1938), the Pure Food and Drugs Act, the Federal

Meat Inspection Act (1906), and more recently the Food Safety Modernization Act (2011) are the major legislative tools to regulate the quality control and food safety management across the nation. In the same way, local governing bodies and state authorities exercise additional regulatory instruments through their respective administrative mechanisms (Weinroth et al. 2018; van der Meulen, 2010; Vapnek and Spreij 2005).

Likewise, each member country in the EU has its own historically developed food safety system. A series of food incidents during late 1990s within various member countries prompted the EU to develop and adopt the food laws at union level to ensure harmonization of the food safety regulatory systems and facilitate the trade within and outside the member states (European Food

Table 10.2 Most common forms of food contaminants and adulterations

Type of contamination	Source	Toxicity	References
Chemical contaminants	Contamination may occur from several different sources such as soil, environment, air, water, pesticides, food containers, food preservatives, food flavoring agents, disinfection products, etc.	Acute and chronic illness, in some cases deaths	Damalas and Eleftherohorinos (2011) Damalas and Koutroubas (2016) Rather et al. (2017)
Biological contaminants	Contamination may result from different harmful microorganisms like <i>Listeria monocytogenes</i> , <i>Escherichia coli</i> , <i>Campylobacter spp.</i> , <i>Staphylococcus aureus</i> , <i>Bacillus cereus</i> , and <i>Vibrio parahaemolyticus</i>	Acute to chronic health issues (example: major outbreak of <i>E. coli</i> of serotype O104:H4 throughout Europe in 2011)	Navarro-Garcia (2014) Schirone et al. (2017)
Physical contaminants	Contamination may from foreign objects like hair, glass, metal, dirt, and pests in food and food products	Illness and other health issues	Peariso (2007)
Food adulterants	Adulteration may result from addition or mixing of edible or nonedible stuff for profit or other intentional motives to make it substandard foods or accidental, which fails to comply with the definition of safe food by the Food and Agriculture Organization (FAO) and World Health Organization (WHO)	Illness and other health issues	Singh (2005)

Safety Authority 2020). In 2002, the EU adopted the general food law regulation which provided the basis for food and feed law both at union and national levels. This law also established an independent agency known as the European Food Safety Authority (EFSA) which is responsible for overall risk assessment associated with food and feed. This agency also recommends required changes in the legislation. More recently, the EU has made a move toward the sustainable and organic food chain by restricting the use of harmful chemicals pesticides, and fertilizers in the agro-food production system (Weinroth et al. 2018).

Establishment of Codex Alimentarius Commission (CAC) played an important role in protecting public health and ensuring fair trade through adoption of risk-based food safety and quality management system and harmonizing

food standards in global context. CAC is an intergovernmental body established by UN-FAO and the WHO in 1963 and now consists of 188 member countries, the EU, and more than 200 national and international observer organizations from various spheres of food businesses including food industries, professional bodies, and consumer groups. By July 2018, Codex comprises 221 commodity standards, 78 guidelines, 52 codes of practice, more than 5900 maximum residue limits for pesticides and veterinary drugs in food, 4100 provision levels for food additives, and 100 maximum levels for contaminants (USDA 2018). CAC has established the guidelines, codes of practices, and standards for wide range of food products including residual limits of pesticides, veterinary drugs, food additives, food contaminants, and more recently microbial hazards. Codex guidelines are used by member

countries to develop policies and programs in cooperation and participation of farmers, industries, and consumers under national food control system. CAC has been instrumental in creating awareness in food safety and quality including the fairness of trade through scientifically approved risk assessment approach providing maximum protection to public health worldwide (FAO/WHO 2003; van der Meulen 2010).

The SPS and TBT agreements among the member countries of the WTO have supported the governments to regulate the standards on food and food products aimed at protecting human, animal, and plant health at national level through certain regulations, testing and certification procedures, and labeling or packaging requirements. However, this agreement does not permit the national government any protectionist policies without allowing the fair food trade among member countries unless it is based on any scientific principles or reasonings (FAO/WHO 2003). Therefore, the CAC has provided guidelines or recommendations in defining the food standards at national level in harmony with the international standards designed for food safety and quality. Although the member countries are encouraged to follow the codex food standards, this has been a hot debate among the developing and least developed countries regarding their inclusion in their national standards based on the national requirement and technical competency (Debroy 2005). The inability of developing nations to harmonize and adapt the codex standards might have resulted in weak and fragmented policies and regulations, and ineffective monitoring systems in protecting consumer health associated with food safety and quality. Many socioeconomic issues for example food safety and quality awareness, availability of technical expertise and facilities, scale, and nature of business (mostly subsistence and street vendors) have seemed to challenge the implementation of risk-based and harmonized food safety regulations and standards. Consequently, socioeconomic burden of foodborne disease in developing and least developed countries is on the rise (Oloo et al. 2018).

10.4 Food Safety Laws, Standards, and Regulations in Nepal: A Critical Review

Diverse range of food products and culinary dishes are available in Nepal due to its diverse culture, ethnicity, and language. Rapidly growing population in recent decades has resulted in dramatic rise in the annual food demand, for example with an average intake of 2673 kcal/capita/day during 2013 (FAOSTAT 2014). Right of access to food has been recognized as the fundamental right of every citizen under Article 36 of the Constitution of the Federal Democratic Republic of Nepal—2015. Several regulatory frameworks have been created and adopted to address the food security including availability, supply, and trade as well as food affordability, stability, and utilization (Ghale et al. 2018). However, little focus has been put into the food safety, quality, and labeling. Although Food Act was first enforced in 1967 to regulate the food safety concerns including the food standards (Jull 2006), major focus was on preventing adulteration through end-product quality checks rather than quality management of the entire food chain involving the production, processing, distribution, and trading within the framework of “farm to fork” concept. This Act prohibits the sale of adulterated and substandard food products and has already gone through three amendments until now (Bajagai et al. 2020). Based on the Food Act 1966, food regulation came into effect to explain the roles and responsibilities of Department of Food Technology and Quality Control (DFTQC), food inspectors, and technical specifics for quality inspection and labeling in considerable detail (Bajagai 2012); however, overlapping of responsibilities and authorities among different departments and ministries through other acts and regulations remained a big hurdle in food quality control system in the country.

Economic liberalization and increased trend of international trade during 1990s and resultant increase in trade of food commodities have become one of the driving factors to realize the

importance of food safety and quality mechanism and regulatory framework in Nepal. In due course, the Animal Health and Livestock Act 1998 and associated regulations came into effect to regulate the production, sale, and distribution of animal-based food and other products including fish and sea foods. Animal quarantine posts were established in various border custom points under the provision of this Act to monitor the safety and quality of imported animals, animal-based food, and associated materials. When Nepal became the member of WTO in 2004, there was a requirement to amend the existing Food Act 1966 and Food Regulation Act 1970 to make it compliant with the international food safety standards under the provision of SPS and TBT agreements (Khadka 2017). Recent amendments of Food Act and its regulation are mostly based on the guidelines, recommendations, and principles of CAC, the International Animal Health Organization (OIE), and the International Plant Protection Convention (IPPC). Similarly, separate legal provisions for monitoring and control of imported plant and plant products came into effect through Plant Protection Act 2007 and Plant Protection Rules 2010 as depicted by the guidelines and principles of SPS agreement. These regulatory provisions were exercised through the establishment of plant quarantine check posts in various parts of the country aiming to prevent the entry, establishment, and spread of exotic plants, insect pests, and diseases. The Pesticide Act of 1991 and Regulations of 1993 which aim to govern the pesticide use in agriculture and the maximum residue limit of the pesticides in the agricultural products are also considered important regulatory tools in national food safety and quality control system. The Animal Slaughterhouse and Meat Inspection Act and Regulation which came into effect in 1999 and 2001, respectively are also considered highly important as they are instrumental to ensure healthy meat production using slaughterhouses, and distribution of the same in the Bagmati zone (Bajagai 2012; Jull 2006). Additionally, the Consumer Protection Act was enforced in 1999 to protect the consumer rights and interests related to quality and safety of the

foods including labeling requirements. This Act has the provision for the establishment of Consumer Protection Council to support the government in consumer-related issues (Khadka 2017). Table 10.3 presents the summary of legislative measures (acts, regulations, directives, and policies) developed and implemented by the Government of Nepal to regulate food safety.

Despite having several institutional and regulatory provisions for more than 50 years along with their amendments at different times, incidences of food adulteration, misbranding, and distribution and sale of unsafe foods and associated illnesses and fatalities are on the rise. This reflects on the dark side of ineffective food control mechanisms throughout the country. The non-compliance of some of Nepal's regulatory provisions with international guidelines and standards merely because of the lack of resources and governmental willpower is imposing risks to its international business and in winning confidence of international communities (Bajagai 2012; Singh 2005). On the other hand, scarcity of food and lack of consumer knowledge on its safety and quality aspect has been contributing to consumption of poor-quality food. Lack of formal institutions and mechanisms to record foodborne illnesses and food quality issues in Nepal play a significant role in overshadowing the importance of food safety and quality. Common food safety and quality-related issues highlighted at different times by the public media include mushroom poisoning, pesticide poisoning, food poisoning in rituals, and alcohol poisoning (Lama 2008).

10.5 Cases of Food Toxins and Contaminants in Nepal

10.5.1 Mycotoxins

Aflatoxin is the most studied mycotoxin in Nepal (Karki et al. 2003). Studies on mycotoxins in Nepal was started as early as 1980, where a survey finding on aflatoxin incidence in corn was reported through annual bulletins of Central Food Research Laboratory (CFRL) of Nepal (Karmacharya 1984,

Table 10.3 List of major legislations governing food safety in Nepal

Area	Acts and regulations
Human food and animal feed	Food act 1966 and food regulation 1970
	Food safety policy 2019
	Mother's milk substitute (Control of sales and distribution) act 1992 & Rules 1994
	Feed act 1976 & feed regulation 1984
	Directives on export–import inspection and quality certification system in Nepal 2006
	Directives on safety and quality production for meat processing industries 2016
	Directives on requirements for processed drinking water industry 2017
Animal Health and quarantine	Animal health and livestock services act 1999 & Rules 1999
	Animal slaughterhouse & meat inspection act 1999 and regulations 2001
	Animal quarantine working guideline 2007
	Animal transportation standard 2007
	Animal quarantine PPR vaccination directive 2009
	Fish fingerling standard 2004
	National surveillance plan for HPAI 2008
Plant protection and quarantine	Plant protection act 2007 and regulation 2009
	Plant quarantine process manual 2012
	Pesticide act 1991 & rules 1993
	Pest free area declaration national directive 2008
	Directives on export–import inspection and quality certification
Other related legislations	Customs act 2007 & regulation 2007
	Export and import (control) act 1957 & rules 1977
	Nepal quality (certification mark) act 1980 & regulation 1983
	Consumers' protection act 1997 & regulation 1999
	Environment protection act 1996 & regulation 1997

1988). Another routine monitoring conducted by CFRL reported that among 379 samples of food, feed, and feed ingredients collected from various areas of Nepal, almost half (182 samples) were found to be contaminated with aflatoxins (CFRL 1989). It is notable that 82% of poultry feed, 77% of feed, 35% of corn flour, 35% of fried salty peanut, 24% of corn grain, 13% of roasted unshelled peanut, and 2% of feed ingredient samples were contaminated (CFRL 1989). A study conducted by Shrestha and Amatya (1997) using 273 food samples reported that aflatoxin level was substantially higher than the maximum allowable limit in peanut, butternut, poultry feed, corn, and corn flour with 9.3 to 9333 ppb. Shrestha (1997) also reported that among 200 samples of maize,

peanut, and their products, 16% raw peanut samples had high aflatoxins content, with B1 (30 to 1610 ppb) and B2 (175 ppb), being the most prevalent among 14 different types of aflatoxins. There are several fungi that produce toxins in foods. Studies show that *Fusarium* species and *Aspergillus* are the most prominent mycotoxins-producing fungi in Nepal as evidenced from the analysis 141 corn samples collected from different regions of nepal (Rai et al. 2013). Koirala et al. (2005) reported that among 832 samples including cereal and pulses, nuts, vegetable oil/butter, 32.8% of them were contaminated with aflatoxin (B1 or B2). Additionally, 18% of the total samples were observed to contain the aflatoxin level of more than 30 ppb which is substantially higher than the

maximum allowable limit in food products. The range of aflatoxin B1 was from 54 to 1806 and B2 was from 4 to 1560 ppb in the samples. Recent study on consumption of certain food items, dietary diversity, and seasonality on potential aflatoxin exposure in Banke district of Nepal during the pregnancy period showed that 94% of the women out of 1675 were exposed to aflatoxin resulting from maize and ground nut consumption with higher level during the winter months (Andrews-Trevino et al. 2020). Similar studies in rural southern district of Nepal (Sarlahi) during 1999 to 2001 suggested significant exposure of pregnant women to aflatoxin B1 with levels ranging from 0.45 to 2939.30 pg aflatoxin B1-lysine/mg albumin in 94% of the samples resulting from consumption of contaminated staple grains (Groopman et al. 2014).

Although *Fusarium* spp. causes several types of mycotoxins, very limited information about it is available in Nepal (Desjardins et al. 2000a; Desjardins and Busman 2005). Among them, two studies on 68 maize samples, 28 wheat samples, and 48 rice samples 97% of maize and 5% of rice samples contained *Fusarium verticillioides* which are known for producing Fumonisin (Desjardins et al. (2000a, b). Another Fumonisin-producing pathogen *F. proliferatum* was present in 4% of maize, 26% of wheat, and 38% of rice samples. Similarly, *F. graminearum* known for producing Trichothecene was present in 24% of maize, 56% of wheat, and 40% of rice samples.

The maximum allowable limits for common mycotoxins vary with the food products and are country-specific. However, as per the provision of DFTQC, this should not exceed 20 ppb in common foods and 50 ppb in milking cattle feed. Therefore, an integrated approaches to aflatoxin reduction, including regulatory, agricultural, and food safety interventions across the value chain and at the household level are essential.

10.5.2 Mushroom Poisoning

Various types of mushrooms grow in backyard, farms, and nearby forests in Nepal during the rainy season. Many ethnic groups have been

consuming mushroom historically and trading locally for the income (Aryal 2009). However, many incidents of mushroom poisoning have been continually being reported in many parts of the country. Due to misidentification, mushroom poisoning occurs by ingestion of fruiting bodies containing toxic compounds. Majority of mushroom poisoning is associated with the consumption of *Amanita*, *Gyromitra*, *Gallerina*, and *Lepiota* species which all contain a cytotoxin compound known as amatoxin (Patowary 2010). Every year many cases of mushroom poisoning and associated fatalities are reported in different media, but the exact number of cases along with their clinical profiles are scarcely available in Nepal (Das et al. 2007). Every year mushroom poisoning claims about 15–20 deaths (Adhikari 2004). In 2005, 41 people were admitted to hospital in Tansen due to mushroom poisoning, out of which 12 people died resulting from acute liver and renal failure (Joshi et al. 2007). In 2008, 62 cases of mushroom poisoning were reported in different national newspapers like Annapurna Post, Gorkhapatra, Kantipur (Aryal 2009). A retrospective study of the mushroom poisoning in B.P. Koirala Institute of Health Sciences (BPKIHS) during the period of 2002 to 2006 showed that 27 cases with severe acute symptoms were admitted in the hospital. Among them, 10 cases also had their other family members affected with two deaths (Syed et al. 2009). Hospitalization in BPKIHS due to mushroom poisoning increased to 60 with 4 deaths in 2009 with majority from being rural areas (Chaudhary et al. 2013). In July 2020, five members of a family died after consuming wild poisonous mushroom with additional three members in critical conditions in Jajarkot district of Nepal (The Kathmandu Post, July 31, 2020).

A community-level sensitization for identification of the poisonous mushroom by local government through literacy classes, placing of hoarding board to identify the poisonous mushrooms are imperative. Molecular, genetic, and chemical characterization of mushrooms should be conducted to systematically work on mushroom poisoning at national level.

10.5.3 Pesticide Poisoning

Pesticides are commonly used in agricultural systems to combat infestation of various pests. Despite potential benefits of pesticide use in increasing crop productivity, there are growing concerns regarding the adverse impacts of unsafe and inappropriate application of pesticides on human and environmental health (Ntzani et al. 2013). Due to lack of knowledge on pesticide types, their poisoning level, safety precautions including protective clothing and other measures human exposure to pesticides are a common phenomenon in developing countries like Nepal. Lack of strict regulations on waiting period before harvesting and selling the product to market, chemical pesticide residue is quite common in fresh fruits and vegetables. Therefore, pesticide poisoning is increasingly becoming a major public health problem resulting in short, medium- or long-term health impacts (Konradesen 2007; Eddleston et al. 2002). Although the exact number of cases are not available at national level, some studies based on hospital records suggested the increasing trend of pesticide poisoning. Majority of cases admitted to the health care facilities are reported to be intentional suicidal attempt, but the health impact associated with the exposure of pesticides from agro-food system has not been documented yet. The study on pesticide poisoning cases admitted in different hospitals of Chitwan districts during April to December in 2015 showed 439 acute poisoning cases. These cases represented the 12 districts including Chitwan and the most used cases ($n = 393$) were intentional for suicidal attempts while 46 cases were non-intentional (Gyenwali et al. 2017). Data from five major hospitals in Nepal in 2002 reported that 256 cases of pesticide poisoning were observed in a period of six months with majority cases being intentional ingestion of organophosphorus compounds followed by zinc phosphide and aluminum phosphide resulting the death of 42 people (Gupta and Joshi 2002). A survey study on health costs associated with non-intentional pesticide poisoning suggested an average of US \$16.8 per household annually (Atreya 2005). Likewise,

annual health cost in Nepal is estimated to be US \$2.14 million and environmental cost ranging from US \$13.10 to 73.87 million annually (Atreya 2006).

10.5.4 Adulterations and Additives

Food adulteration is one of the most growing issues in Nepal although extent of food adulteration is poorly documented. Food adulteration results from the addition of unauthorized inferior substances to food or removal of ingredients from food altering its natural composition and deteriorating the overall quality of the food. Some of the most common ways of intentional food adulteration in Nepal involve mixing of undesired or unwanted materials like brick powder to ground spices, natural honey adulterations with sugar and corn syrup, mixing small stones with food grains to increase the weight, adding nonedible color to the processed food, mixing cheaper cooking oil (e.g., soybean oil or palm oil) with mustard oil, mixing mustard seeds with argemone seeds (prickly poppies), mixing of paraffin wax with castor oil, addition of water in milk, mixing papaya seeds in pepper, mixing of starch and wheat flour in turmeric powder, mixing of vegetable ghee or animal fat with animal ghee and mixing potato or taro with ghee. Reports from the DFTQC and some survey studies including the national media reveal the incidence of intentional food adulteration at different times (Limbu et al. 2020).

10.6 Food Safety and Quality System Development in Nepal

Consumption of unsafe and poor-quality food leads to development of health-related problems for economically active populations thereby decreasing their ability to earn for livelihood along with expenses on health. Nepal needs broad food safety and quality framework with robust system of food safety and quality monitoring, implementation, and surveillance at all tiers of government and customs. Nepal has

number of food test laboratories at national and regional levels, and a reference laboratory at national level is accredited to international testing system and with neighboring countries. This means, there is a system of food quality testing and certification; trained human resources are also available though in smaller number than required. Production environment in many cases is clean with clean air, clean water, uncontaminated soils, and locally grown seeds. This is especially for smallholder farmers who produce food for their own use and not for market. But the agriculture production for the market especially in terai and nearby urban centers like Kathmandu valley, Chitwan, Pokhara has already seen indiscriminate use of chemical fertilizers, hazardous pesticides, and growth hormones. This haphazard use of the chemicals should be regulated under Nepal good agricultural practices (GAP) or similar certification schemes for production and processing.

10.7 Major Drivers for Regulatory Environment

10.7.1 Health-Conscious Consumers

Increased awareness of quality and safety of the food and financial ability and willingness to purchase safe and quality food are the key driver for the production, distribution, and trade of better quality and safer products in the market. The demand and strong voice of consumers will push government to introduce and implement of food safety and quality regulations. In open market system, competition among the providers determines its affordability and costs (FAO 2018).

10.7.2 Proactive Government

Proactive government is another driver which asks producers, suppliers, and traders of the foods to meet given food standards, implements guidelines, and makes strict monitoring and compliance checks. Some routine and sporadic checks are conducted throughout the country

during festive season to check adulteration, food frauds, and microbiological tests in street foods and sweets. Random checks are also the measure to control the food fraud and contamination but the human resources of the regulating bodies and their budget allocation for this purpose is quite negligible given the scope of the task. More than 2000 food samples were collected and inspected as a routine inspection annually which involves more than 1000 hotels and 1300 food industries (Bajagai et al. 2020). Local governments have high level of authority and responsibility to introduce bills, regulations, or standards at local level to ensure quality and safety of food transacted in their geographical jurisdictions; however, lack of human resources and infrastructure is a major hurdle in effective implementation and successful regulation process. This should be coupled with laboratory services to validate the results from food-related frauds or adulteration, and power to facilitate the process for implementation and give sanction to the wrongdoers if they were intentionally doing so (Fig. 10.1).

10.7.3 Infrastructures and Skills Set

Successful implementation of the food-related legislation is also crucial for generating the evidence needed to apply any punishment or penalty to a person or an agency who doesn't abide by the legislation. This needs laboratory facilities with recent technology, which should be fast, accurate, and convincing, and accredited by national and international institutions. Investment in the development of skilled human resources is very crucial for achieving the outcome of the improved management of safety and quality of food.

As a responsible authority for food safety and quality control, the DFTQC has its food technology and quality control offices in six provinces, division offices in 24 districts, and 12 food import/export quality certification offices with testing services (DFTQC 2016). DFTQC provides inspection, monitoring, and testing of food items in grocery stores and food industries to ensure the safety and quality of the food commodities throughout the nation. The inspection is more

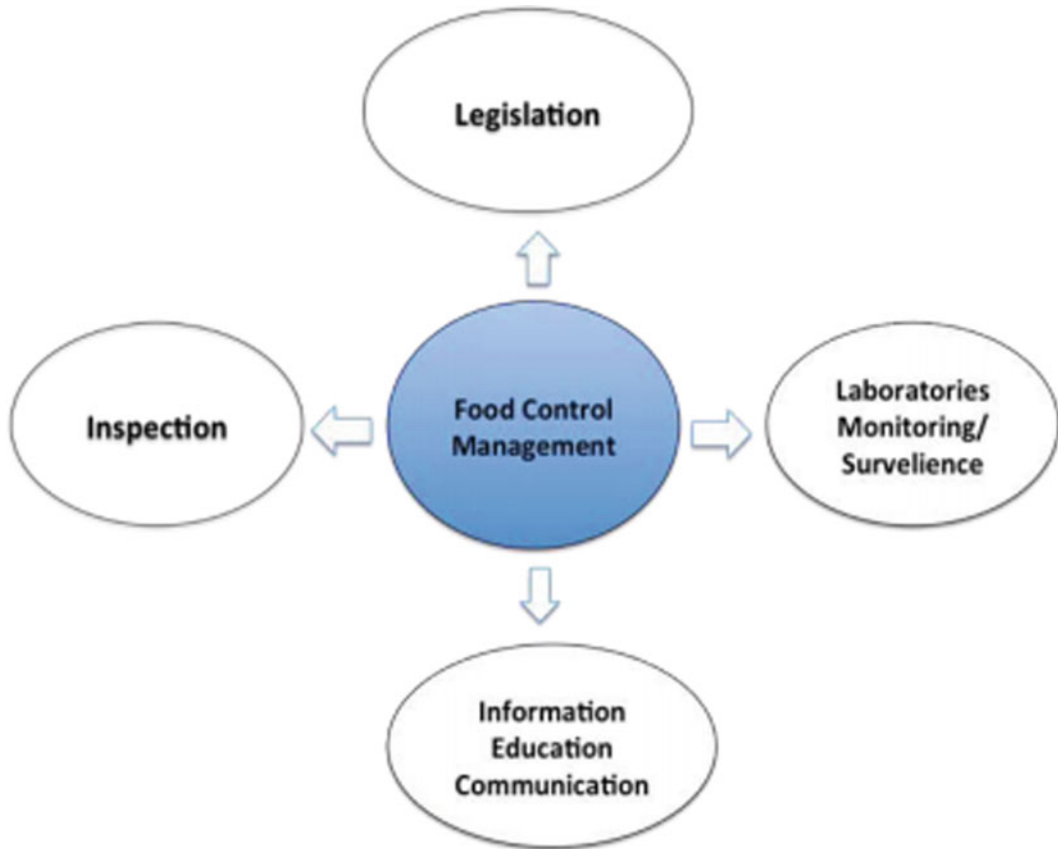


Fig. 10.1 Overview of the national food quality control system (Source Adapted from Bajagai et al. 2020)

frequent during major festive seasons or seasons of high business. Apart from the inspection of food items at the point of production, processing, and sale, DFTQC also deals with production licensing to food-related industries, grading of hotels and restaurants based on their hygienic status and sanitation protocol, and providing inspection stickers. DFTQC also provides laboratory services to facilitate surveillance and monitoring and organize consumer-awareness campaigns for mass sensitization on food-related issues and form and mobilize rapid response teams for emergency situations. An average of 1200 industries inspections are conducted every year while more than 700 hotels and restaurants are inspected, graded, and provided the stickers based on their excellent, medium or poor hygiene and sanitation conditions. DFTQC has come up with separate hotel restaurant guidelines for

systematic implementation of basic food hygiene and sanitation practices as well.

10.7.4 Market and Price

Market and price are the major and decisive drivers for any intervention for safety and quality assurance (Sharma 2006). With increase in consumers' awareness of quality and safe food the consumers are willing to pay few cents more for the quality or organic or similar branded foods, but the notion often forgotten is "food" means "safe and quality food". The extra costs of ensuring safety and quality will eventually add up to the price tag of the food. If consumers are willing to pay for that extra cent, then market will deliver safe and quality food. However, setting up of the national food standards is government's

responsibility. The industry and private business can set their own standards in line with or above the national standards.

and local governments are not equipped with any resources for implementation of federal policies and local legislations.

10.8 Implementation Status of Food Safety in Nepal

Despite the plethora of laws, standards, policies, rules, and regulations related to food safety and quality regulations in Nepal, the production, distribution, and sale of substandard and adulterated foods and poor hygienic conditions in food premises is still prevalent. The main reason behind this situation is the lack of government's proactiveness and readiness to allocate resources for the successful implementation of food safety system and strengthening the food control mechanism. Currently, food quality control and regulation is mandated to DFTQC as the central body. It is poorly staffed and has less than 100 food and feed inspectors to undertake food quality monitoring, inspection and certification all over Nepal. This is less than one food inspector per 300,000 population and is not enough to effectively implement the food safety regulation (Bajagai et al. 2020). In addition to the human resources, the laboratory facilities and associated physical infrastructures remain a major issue regarding implementation of available legislative measures. Unsafe food handling in domestic commercial businesses that supply food and food products is miserable (Bajagai et al. 2020). Only some sporadic checks and campaigns through DFTQC are in place whereas a systematic implementation of available food standards right from production to consumption level is required. Nepal has now become a major importer of food, but the technical capacity in quarantine facilities (food import, export, and certification offices) at entry points is miserable (Adhikari et al. 2021). Practical implementation of import regulations is almost impossible with the given level of human resources and laboratory facilities. This is highly overlooked area of concern in food safety and quality. Furthermore, several state

10.9 Policy Recommendations for Federal Nepal

Handling and management of food contaminants and toxins ask for establishment and implementation of robust food safety and quality system at all levels. Although national Food Act, regulation, food safety policies, and food standards are updated and revised to address recent incidences of toxins and contaminants in foods, their systematic implementation through adequate allocation of financial and human resources and provisions of clear duties, responsibilities, and power to implement these regulatory provisions is still lacking. The resource allocation for the decentralization of the food quality assurance at provincial and local levels is also seriously lacking. Trained human resources, laboratory, and other infrastructures, and exercising power to deal with the issues on food safety and quality is yet to be implemented.

Food toxins, adulteration, and contaminants come under the broad food safety and quality framework. There exists legislative, institutional, and overall government presence to ensure the safe food to the public but the current hazard-based approach focusing on end-product testing and control rather than risk-based preventative approach is hindering the systematic development and implementation of food safety and quality system in Nepal. The widespread food safety issues are mainly related to the weak implementation of legislation rather than the absence of such legislations and guidelines.

Nepal has developed many legislations, standards, policies, and guidelines complying with international standards. It is also a signatory of the international convention related to food safety and quality. But there has been inadequate and ineffective enforcement of such guidelines, standards, and legislation at the ground level due to lack of technical human resources and

sensitive laboratory testing equipment to meet the national and international standards. The current legislations should be updated through stakeholder's consultation to authorize provincial and local governments in practicing and strengthening their role in assuring food safety at their respective jurisdictions. It could be high time for the Government of Nepal should introduce risk-based food safety and quality control systems with food safety risk analysis, risk minimization, risk management, and communication as per the CAC (FAO and WHO 2003).

Food safety is a serious public health concern with multiple impacts on health and economy. Involvement of major stakeholders namely consumers forum, public health authorities, food scientists, technical service providers, and food businesses is necessary for systematic implementation of food quality-related legislations. Current legislation divides the authorities to chief district officers to local governments who lack the technical capacity for effective implementation. Appropriate amendments of legislations to establish clear roles of public health authorities and local government bodies in coordination with food scientists and public health experts would be needed. A close coordination among the food scientists and the public health inspectors could be more effective to ensure safe food supplies. Public health experts with some food-related qualification could train food businesses, supply chain service providers, producers, processors, handlers, retailers, and food servers on safe food handling to minimize any toxins, contaminants, and others affecting the inherent quality and safety.

As a major importer of food, Nepal could be proactive in controlling unsafe, substandard, and contaminated foodstuffs at the entry point rather than after it enter to Nepalese market. Establishment, strengthening, and technology-based quality monitoring and surveillance system equipped with laboratory facilities and sufficient technical and human resources at the quarantine checkpoints to regulate the import of substandard and adulterated foodstuffs should be strictly enforced.

A systematic change in policy, practices, and facilitation approach needs to be adopted by the government. The Food Act 1966, Food Rule 1970 and respective guidelines need timely updates to be in line with international, national, and industry standards. The proactive steps to promote preventive quality assurance schemes like GAP, good manufacturing practices (GMP), good hygiene practices (GHP), and HACCP/ISO22000 should be made mandatory to the industries producing foods. Consumers' education programs through consumer forums and government entities should be organized along with regular school and university curriculums to make all aware of the safety and quality issues in food. Development of Nepal GAP by government is very crucial step for food safety and quality regulations. Encouraging and facilitating the implementation of Nepal GAP could be very important turning point for Nepal's food safety.

10.10 Summary and Conclusions

Proactive government institutions, responsible food stakeholders, and highly aware consumers are the major drivers for the successful implementation of food safety and quality-related legislation into practice. Government as a regulator and implementor of the food safety policies and legislations working with stakeholders including food manufacturers, traders, retailers, food scientists, and consumer associations can implement food-related laws, standards, and policies into action. Food industries should be made responsible for maintaining the quality and safety of food products according to legal requirements; while the media should be induced and closely aligned to work on these issues to promote the good food practices, create awareness among consumers and expose the irresponsible stakeholders. A culture of strong coordination and partnership between all actors in food supply chain with ethics and conscience is urged. Systematic investment in consumer education for civil rights, capacity development

of state-owned and private entities, and research and technology development through educational institutions can be crucial steps to help attain goal of safe and quality food for the consumers. Food safety and quality have not received enough attention in setting of Sustainable Development Goal (SDG) by United Nations however its being an interface of health, agriculture, and industry, it might have been over-arched but seems underestimated and overlooked. A coordinated action among countries in implementation of food safety and quality rules would be an important milestone in achieving targets on SDG 3 “Good Health and Well-Being” or SDG 2, “Zero Hunger” set by the UN’s 2030 agenda for sustainable development adopted by all member countries. Addressing the food safety and quality issues will help address these SDGs.

Local Government Operation Act (2017) gives responsibility of public health and food safety to local government jurisdiction. For effective implementation of food regulations at local level, formulation of legislative measures (laws, acts, guidelines, policies), development of technical human resources, laboratory facilities for testing, and allocation of financial resources from three tiers of government are imperative.

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Regenerative Agriculture for Sustainable Food Security and Livelihoods in Nepal: A Proposal for Multi-scalar Planning Framework

Jagannath Adhikari and Jagadish Timsina

Abstract

This chapter essentially examines Nepal's agricultural policies in the light of inadequate performance of Nepal's agricultural sector. It then suggests a planning framework for a 'regenerative agriculture'—a holistic systems approach to integrate various local resources that underpin agriculture or food production activities and other enterprises and repair the problems in ecosystem created by unwise practices. It is argued here that such integrative resource management leads not only to sustainable agriculture through conservation of resources, but also to higher production and availability of diversified, safe and nutritious foods and helps generate more income and employment. This all eventually leads to improved livelihoods for farmers. Moreover, this system further contributes to building resiliency to emerging environmental, climate

change and trade problems in situations like COVID-19 pandemic that breaks down long-distance supply and demand chains of food products and inputs required for farming. In addition, such an agricultural system promotes other business opportunities like health-concerned agro-ecotourism, thus fetching premium prices for the products. Accordingly, this regenerative agricultural system is, in fact, in line with Nepal government's policy of food sovereignty, whereas the current conventional system followed has eroded this very aspect. Finally, the chapter presents a multi-scalar policy and planning framework for the development of regenerative agriculture that has potential to complement various SDGs, especially SDG 1, 2, 12, 13 and 15.

Keywords

Conventional agriculture • Biodiversity • Sustainability • Multi-scalar planning framework • SDGs

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11.1 Introduction

Nepal started to focus on development in earnest since the early 1950s after political change that led to fall of an inward-looking dictatorial regime to an open politics. All the plans and programmes since then and up to the early 1990s have strong focus on agricultural development

(Dahal 1997; Chapagain 2001; Stiller and Yadav 2018). The initial thrust in agricultural development was thus in expansion of farmland especially in *Terai* (lowland plains in the south bordering to India) and agricultural modernization through improved seeds and fertilizers and chemical inputs (Chapagain 2001). However, expansion in farmland halted in early 1970s as the country reached a limit on such expansion. Then, there were efforts to modernize the agriculture and increase yield and productivity of land with the use of modern inputs, especially improved seeds and chemicals like fertilizers and pesticides along with expansion of irrigation facilities. This shift in technology had also been facilitated by the green revolution technology that was successfully implemented in India. Nepal's plans like Agriculture Prospective Plan (APP: 1995–2015) and Agriculture Development Strategy (ADS: 2015–2035) are very much informed by the experience of areas where green revolution was successful, especially in Punjab, India (Cameron 2009; Paudel et al. 2016). Analysis of these policies and the performance of agriculture sector in Nepal raises three fundamental concerns on the approaches taken in Nepal for agricultural development:

Firstly, Nepal could not increase production at the desired level (as discussed below) and many farmers gave up farming leaving their land fallow; 30–40% of the farmed land has remained fallow now, especially in the hills and mountains (Paudel et al. 2014, 2020; Adhikari et al. 2020). The important policies and the approaches to agriculture development (like APP and ADS) are now found to be less relevant or supportive to improve the smallholding farming and farmers' welfare (Roka 2017; Dahal et al. 2020), though to some extent, food production has also grown. Secondly, questions have also been raised in India as to the impact of green revolution, especially on environment and farmers' well-being. In Nepal, this approach was adopted without much state support to farmers, especially in the guise of neoliberal policies. In India, however, there has been a huge support to farmers from the government (Adhikari 2021). These included guaranteed purchase of farm

produce with minimum support price and heavily subsidized inputs like fertilizers, pesticides and irrigation. This made India able to produce surplus cereal grains within a short time of adoption of green revolution technology and now there is a new problem of surplus grain management (Kaur 2019; Press Trust of India 2020). Similarly, corporate control of technologies like seeds and chemicals, soaring prices of these inputs and farmers' loss of their indigenous technologies like local seeds have created new problems for farmers like inability to make profits, indebtedness and loss of land. As a result of these new problems, including growing scale of farmers' suicides, farmers' protests are also going on in India (Mashal et al. 2021; Thomas and Johan 2017; Walden et al. 2020).

Thirdly, the approach that was taken for agricultural development was based on the experiences of the industrialized countries. This approach, including the new technologies, was aimed to release rural people for industrial labour in urban areas and the surplus production to support or create an industrial base so that people would get off-farm employment. This, in essence, means an integration of agriculture and industry and then the surplus income fostering a service sector. In Nepal's case, however, a base for industrial development was not created. The geopolitical location of the country in the periphery of global capitalist development (Blaikie et al. 1980) and land-lockedness obstructed industrial development. Rather, whatever traditional industries were there, they also declined because of the globalization and market integration. Youths have now taken migration to work in foreign countries as a main way to support their families. Work in foreign countries also generates more income than farm work in Nepal (IMF 2020: 4–5). Because of growing overseas migration for work, remittances now contribute more to national economy than any other sector. In 2018/19, about 8.2 billion USD entered Nepal as remittances, which is equivalent to about 30% of GDP (Prasain 2019a). Nepal now depends heavily on imported food (Prasain 2019b; Adhikari et al. 2021). On the other hand, agriculture has still been the main sector to employ people

even though its contribution to GDP has been falling steadily (ADB 2019). Therefore, it is imperative to improve this sector to enhance the livelihood of most of the population, who are dependent on agriculture.

11.2 Initiatives to Improve Agriculture

Realizing the importance of agriculture to feed the country and to create a base for industrialization, Nepal's various plans and policies since the early 1950s prioritized 'agriculture', even though budget allocation to agriculture declined after mid-1990s. Then the new thinking that Nepal is not suitable for agricultural development took hold among the planners and development partners, who suggested that it be left to the market for its development and that self-sufficiency in food is not important if food security can be met through trade (Pyakuryal et al. 2005). This led to the policies like government's withdrawal from supporting agricultural sector. Rather, government was thought only as a facilitator. This idea informed policies like APP (1995–2015) (APROSC and John Mellor Inc. 1995) and ADS (2015–2035) (MoAD 2014). APP had the following objectives: raising the growth rate of agricultural sector from around 3 to 5% annually during 1995–2015 and reducing the share of population living below the poverty line from 42 to 15%. The main strategy was to increase the usage of modern agricultural inputs (fertilizers, improved seeds, chemicals and irrigation) to enhance productivity. The APP envisaged that the hill region would reach food self-sufficiency and even supply a modest amount to the mountains by the end of 10th plan (2007) and Terai would generate exports. This was far from being realized (Cameron 2009; Dahal et al. 2020). There has been decline in poverty from 42% in 1995 to 25% in 2010 (CBS 2011) and to 18.6% in 2018–19 (Bhusal 2019), but this came mainly from remittances. Farms with less than 1 ha continued to be poverty pockets (CBS et al. 2006) and dependency on food-import accelerated (Adhikari 2021).

The shift in development thinking discussed above also meant that budget allocated to the Ministry of Agriculture consistently declined from the early 1990s. In the 1970s, government's main priority was agriculture with about one-third of the budget allocated to this (Stiller and Yadav 1979). In the 1980s, it was reduced to about 16%, in early 1990s to 10–12% (Adhikari 2015) and from mid-1990s to 2020 from 2.4% to 3.1% (Dahal et al. 2020: 7). Dahal et al. (2020: 8) argue that the decline of budgetary resources for agriculture had a major impact on the performance of the APP itself. As a matter of fact, development partners then had (even now) not endorsed (do not even now) a goal/policy of self-sufficiency in food or food sovereignty. The emphasis in all the budgets was improving crops and commodities with use of modern inputs without considering resource-conserving technologies and agro-biodiversity or producing quality foods (Dahal et al. 2020).

The current policy (ADS) rests on four pillars of agricultural development—governance, productivity, commercialization and competitiveness—about 72% of the total budget required for ADS is to be used in these four components. There are two main criticisms of ADS: (i) it is not relevant for the smallholder farmers who constitute more than 80% of farmers in the country (Roka 2017) and (ii) it has only agribusiness focus and less concern for sustainability of agriculture, resource-use efficiency, agro-biodiversity management and livelihood improvement for small and marginal farmers (Dahal et al. 2020). Like APP, ADS has also emphasized cash crops for income generation rather than food crops for food self-sufficiency. This is not in line with Government's overarching principal policy as shrouded in the constitution (2015) that Nepal will follow principles of rights to food and food sovereignty to fulfill the food security. Moreover, there has been a restructure in the political and administrative system, especially the creation of federal state with three tiers of governments and local governments now have legislative, judicial and executive powers. Nepal Government considers that this restructuring, especially the devolution of power and resources at the sub-national level is

conducive for implementation of agriculture and other development activities related to SDGs (NPC 2017: 17). But this new provision has not informed ADS (Dahal et al. 2020).

There has been slight increase in food production in Nepal in absolute terms, but food deficit has been increasing. The data from 1990/91 to 2016/17 indicate that there was food deficit from 1991/92 till 1998/99 followed by some surplus for succeeding eight years and then fluctuated. On the other hand, there has been some improvement in nutritional status (MoH et al. 2012, 2017), which was mainly due to increase in food consumption made possible by increased remittances and improved public health services.

It is noteworthy that food production has not been keeping pace with the increase in the use of chemical fertilizers (Fig. 11.1). Though use of fertilizer and other chemicals is still low in Nepal as compared to other South Asian countries, it is increasing at a fast rate and mainly large farmers have benefitted from the government's subsidized fertilizer policy.

In terms of crop productivity, the average yields of rice, wheat and maize are steadily increasing, though compared with other South Asian countries crop yields are low with large yield differences between Nepal and those countries (Fig. 11.2) (Table 11.1). In the 1960s, Nepal had relatively better yields of cereal crops

(Sharma 2002). From the 1960s till 2000, the average cereal yield in Nepal has fallen from 157 to 61% compared to the South Asian average. Yield growth rates in India and Bangladesh are much higher than in Nepal. A study of yield variability in South Asian countries during 1961–1965 and 2006–2010 showed that Nepal's cereal yields grew at the slowest rates (Poudel and Chen 2012). In contrast, with the rapid progress in food production, India has converted itself from a food deficit (import-dependent) to a food surplus country (Adhikari 2021). Bangladesh has also rapidly increased the production due to use of high-yielding rice varieties and maize hybrids and is becoming self-sufficient in food (Ahmad 2016; Byron and Hasan 2020).

An interrelated issue with underperformance of the agricultural sector has been food security, especially the growing dependence on other countries for food products. This is seen to pose problems in case of emergencies, disasters and trade barriers from time to time (Adhikari et al. 2020). Nepal had surplus food until the 1970s and its crop productivity was highest in South Asia until the 1960s. But slowly, Nepal's production could not keep pace with population growth rate and meet internal demand. Hence, import of food has been growing since early 1980s with exponential growth since the mid-2010s. For example, in 2018/19, Nepal's food import amounted to Rs 220 billion (Prasain

Fig. 11.1 Use of fertilizers and changes in yields of major crops (*Source* Agriculture statistics, ministry of agricultural development 2019)

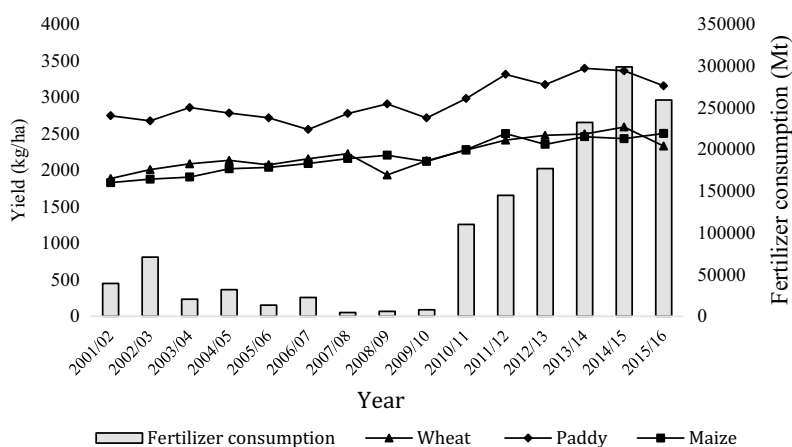
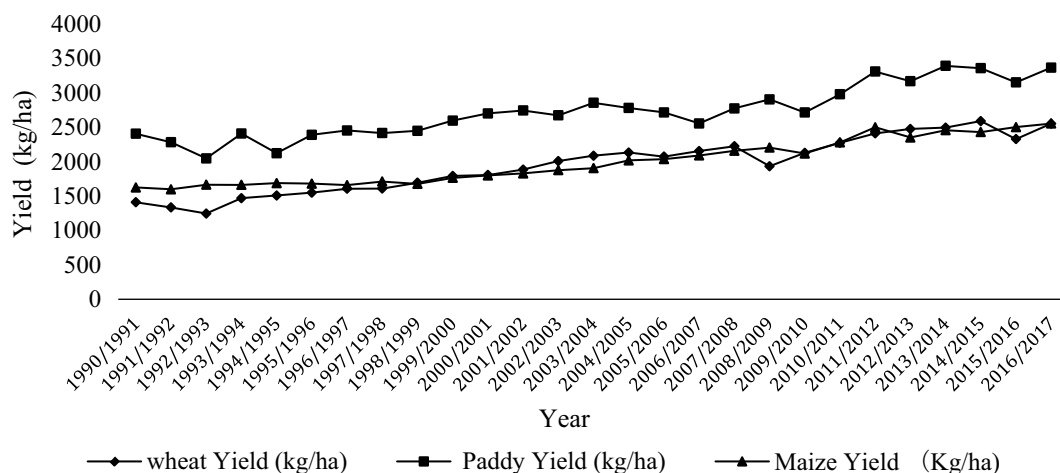


Table 11.1 Yield gap between Nepal and the best-performing countries in Indo-Gangetic plain of South Asia (2019)

Crops	Best-performing country (t/ha)	Nepal (t/ha)	Gap (t/ha)
Rice	Bangladesh (4.73)	3.76	0.97
Maize	Bangladesh (8.01)	2.81	5.20
Wheat	India (3.53)	2.84	0.69

Source FAO Stat (2020)

**Fig. 11.2** Yield rates of major crops 1990/91 to 2016/17 (Source Agriculture statistics, ministry of agricultural development 2019)

2019a) and spending Rs. 51.8 billion for cereals only (rice Rs. 24.59 billion, maize Rs. 12.55 billion, wheat Rs. 6.84 billion). In 2007/08, trade deficit in food products was Rs 11 billion, which increased to Rs. 173 billion in 2018/19 (Adhikari 2021). Even in basic commodities like cereals and pulses, Nepal's dependence on other countries, primarily on India, has grown rapidly. In 2018/19, Nepal imported about 14 million tonnes of cereals but exported almost none (Adhikari 2021). There was some export of soybean oil (Rs. 20 billion) in 2019/20, but this was first imported from other countries and then exported to India. Until 2014, Nepal exported lentils, especially to Bangladesh, but then the trend has reversed due to reduced production. Now Nepal is becoming dependent on India and Bangladesh for lentils, which is the constituent of staple diet 'Dal-Bhat' and a major source of protein for poor people. This all shows Nepal's worsening agricultural sector (Joshi 2020).

Various factors have accounted for the stagnation in productivity and loss of self-reliance in production of needed food products even though Nepal has resources and ability to produce different types of food products within the country. Small and fragmented land holdings, lack of infrastructures like irrigation facilities, accessibility for marketing and purchase of inputs, appropriate technology, land degradation, climate change and lack of overall support for farmers are the factors causing low productivity in agriculture. Shortage of farm labour is another significant constraint in agriculture, which is related to high magnitude of outmigration of young males to other countries for work. Low income and uncertainty or risks in farming have pushed these people for such work, but there are also pull factors like higher income from non-agricultural works and foreign jobs (IMF 2020). In general, off-farm work provides higher income than on-farm work. For example, annual

agricultural labour productivity is only \$794 compared to the non-agricultural labour productivity of \$3,130.

Agriculture research and extension have high potential to contribute to increased production in agriculture. However, as said earlier, there has been low investment in this sector, especially in development of technologies and practices that are adaptable to Nepal's context, particularly to support poorer farmers (FAO n.d.; The New Humanitarian 2013). The World Bank estimates that two percent of the AGDP should be invested in agricultural research as it produces substantial dividends, with an internal rate of return that can be as high as 20–50%. Though most developing countries in the region spend about 0.4%, Nepal invests just 0.17% which is now declining (FAO, n.d.; The New Humanitarian 2013). Whatever research has been done, it is mostly confined to three main cereals -wheat, maize and rice. Local crops often considered minor are more resilient to climate stresses, nutritious and are an integral part of local diets and local agro-biodiversity. However, these have never received priority in the national agriculture research and extension system. Improvement of these local crops would help preserve diverse agro-genetic pools and food diversity with high nutrition and adapt to climate change.

Climate change has become a big constraint in farming and it has already adversely affected food production and peoples' livelihoods. The results that are seen now include frequent drought, soil erosion and land degradation through landslides, river cutting and floods and decline in crop production (Thapa and Hussain 2020; Hussain et al. 2016). The unpredictable rains or prolonged droughts and topsoil erosion degrade lands and negatively affect the farming practices (Budathoki and Zander 2019; ICIMOD 2013). Given that Nepal's conventional approach has not been sufficient to address the issues like increase in food production, improvement in food security and augmentation of farmers' income, a new approach is required that leads to overall improvement in farmers' livelihood as well as production of more food. The new approach should also be able to address and

adapt to emerging challenges like climate change and possible breakdowns in supply chains due to disasters like pandemics and market failures.

11.3 Regenerative Agriculture as an Alternative Way Out

This paper proposes an approach of 'regenerative' agriculture as a way for the holistic integration of resources and enterprises to produce more food sustainably and to generate additional income and employment. Given that 'regenerative agriculture' is 'both an attitude and a suite of practices that restores and maintains soil health and fertility, supports biodiversity, protects watersheds and improves ecological and economic resilience' (White 2020: 799), it can contribute to various SDGs in particular related to poverty (SDG 1), zero hunger (SDG 2), improving health and well-being (SDG 3), climate change (SDG 13) and environmental conservation (SDG 15). It also encourages continual on-farm innovation for environmental, social, economic and spiritual well-being. It is found to be resilient to climate change impacts and helps in carbon sequestration (Lal 2020). Its key techniques include conservation tillage (no or reduced tillage); diversity in crops/plants/animals for synergy and mutual benefits; rotations and cover crops; less disturbance on the agro-ecosystem; and agro-forestry (Elevitch et al. 2018).

The features of regenerative agriculture closely resemble with the traditional farming system in Nepal, which is essentially an integrated and mixed farming system that maintains a diversified combination of crops, animals and trees aimed at fulfilling family food requirements from the farm itself (Adhikari et al. 2020). A wide variety of open-pollinated seeds in such farms improved through selection process is used to grow different types of crops, some of which are required for cultural purposes too. All the inputs, including compost, farm-yard manure, fodder and seeds are produced at the farm or within the community, which is exchanged if necessary. Crop rotations, fallowing, mulching and planting of cover crops/trees are also practiced in such farms. Such

traditional agricultural systems have been the main repository of many crops and cultivators (Johns et al. 2013), which have helped maintain a rich agro-biodiversity. The mixed farming systems combining various types of local cereals and pulses have not only improved soil fertility and agro-biodiversity but also provided important nutrition to the people. The conservation of local crops and livestock landraces and traditional practices promoted agro-biodiversity and strengthened farmers' capacity to cope with different types of adversities. Today, climate change and the loss of agro-biodiversity are the two most challenging threats and traditional agricultural systems are found to be resilient to the impact of climate change and promoting biodiversity (Altieri and Nicholls 2017). However, a study (Adhikari et al. 2020) has demonstrated that the traditional farming systems are gradually eroding and the traditional food crops—also known now as future smart foods—are gradually disappearing with serious implications for sustainability of the agro-ecosystems. Examples of such traditional food crops, which used to be grown mixed with other crops include finger millet, amaranths, common kidney beans, buckwheat, mix of pulses such as black gram, green gram, horse gram and soybeans.

Regenerative agriculture aims at restoring the traditional time-tested practices and crops with new innovations that help improve soil health/fertility and resilient capacity, produce more nutritious food and generate more income. Because of this base in traditional practices, regenerative farming system has a high probability to be adopted by farmers in Nepal. The sustainability of these systems has been attributed to integration of three main components of the farming system—crops, livestock and trees—in the farmland, with diversity of each component. These components can support each other for synergy through recycling, balance of farm inputs and resources. Livestock produce manure and draught power for the farmland; farm crops and trees provide fodder to livestock; farm trees also protect crops and help in water retention; and all components produce food for the humans (Khadka and Ghimire 2005; Timsina 1997;

Dhakal et al. 2022; Poudel and Thapa 2018). Now, the tendency of keeping livestock has been declining owing to shortage of labour due to outmigration. As a result, the balance is breaking down needing more chemical fertilizers and pesticides. Because of the importance of livestock in farmland, regenerative agriculture practices now suggest integrating livestock with crops even in the specialized farms of industrialized countries (Payne 2019).

By developing and conserving natural resources mainly soil and water, regenerative agriculture can use less energy but produce more food. For example, The Rodale Institute in USA has shown from its 30-year comparative study of plots farmed with conventional agriculture and regenerative organic practices that the corn yields in the latter matched with the former (Rodale Institute 2014; Rhodes 2017: 108). The organic systems used 45% less energy and were more profitable than the conventional systems mainly because the former avoided the use of synthetic nitrogen fertilizer. Greenhouse gas emissions were also 40% greater from the conventional systems compared to the organic systems. A detailed report (Niyogi et al. 2017) on practices of permaculture in India reveals that farmers are receiving higher crop yields from this system. For example, it cites an example of a permaculture farmer who says, 'while conventional sunflower seeds have 30% oil content, the seeds grown on the permaculture farm are sturdier and bigger in size and have 40% oil content (ibid). Another example, also from USA, provides evidence that though regenerative farming systems yield lower than the conventional systems they increase profits and simultaneously produce quality food through reduction of pests and increase of soil organic matter (SOM) while conserving natural resource base (LaCanne and Lundgren 2018: 1).

Comparing crop yield obtained with organic sources of nutrients and with chemical fertilizers from several studies, Timsina (2018) reached a conclusion that yield with organic sources is 20–25% lower than with the chemical fertilizers because supply of required nutrients for higher production is limited in organic fertilizers. He

suggests a combination of organic and inorganic sources of nutrients for higher productivity and Evergreen Agriculture (an extension of agro-forestry) as a possible model to generate more organic nutrients and produce more food to achieve food security. Despite terminological differences between ‘regenerative’ and ‘Evergreen Agriculture’, there are several commonalities and regenerative agriculture, in fact, takes agro-forestry as its core component. The elements of agro-forestry are presented in the proposed model of regenerative agriculture for Nepal (Fig. 11.4). In addition, it is also important that income of smallholders also needs to be augmented through other non-farm enterprises but based on local resources, as land alone cannot provide full livelihood benefits for the smallholder farmers. A meta-analysis of refereed publications also revealed that crop yields in organic farms are lower than conventional, though yields under organic systems are likely to be more resilient to the extreme weather accompanying the climate change such as during drought when organic corn yields were 28% to 34% higher than conventional (De Ponti et al. 2012). Figure 11.3 shows that the transition from conventional to organic farming is a long process calling for gradual reduction in use of non-organic inputs, which need to be substituted by more potent organic sources for nutrient supply. The above findings suggest that a strong research and development is important to make this transition possible.

Taking above findings into account, it can be argued that in Nepal where external inputs (fertilizer, other chemicals) are expensive and climate change is causing extreme weather, regenerative agriculture can become more remunerative due to

reduced production costs and higher premium price of its quality produce. However, even though there is such potentiality, this has not been practically realized in Nepal because of lack of consumers’ awareness on food quality and lack of a certification system that is accessible and affordable to the farmers. This suggests that more efforts are required to make consumers aware of how food is produced and how it affects their health. Looking into the health costs, organic regenerative farming is certainly better than conventional systems as chemicals (e.g. pesticides, herbicides and hormones) are associated with various diseases on humans (Hu et al. 2015, Nicolopoulou-Stamati et al. 2016). Hence, it is argued that productivity of farming should be measured in terms of health or well-being per hectare and not just on grain production per hectare (Shiva and Singh 2016). Regenerative food production systems that simultaneously sequester more carbon and bring social benefits to poor food producers and their communities are thus essential (Anderson and Rivera 2020). In such case, farmers can, in near future, also get extra income by accounting the carbon they store (sequester) in soil through sustainable practices, for example, no or reduced tillage, cover crops and mulching (Wesseler 2020).

11.4 A Planning Framework for Regenerative Agriculture in Nepal—A Proposal

The challenges of smallholder farmers, who dominate the agricultural sector in Nepal, cannot be resolved through piecemeal basis looking at the yield of crop(s) alone. A systemic approach

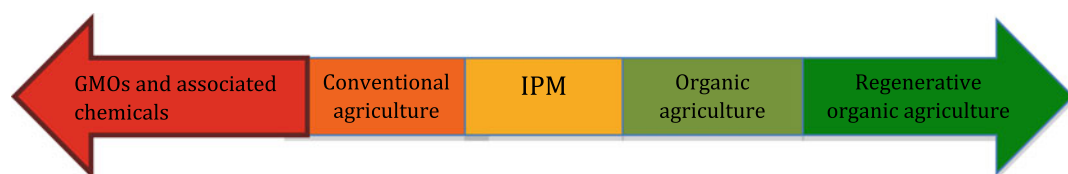


Fig. 11.3 Transitioning from resource intensity towards resource efficiency for greener future with regenerative agriculture (Source Proposed by authors)

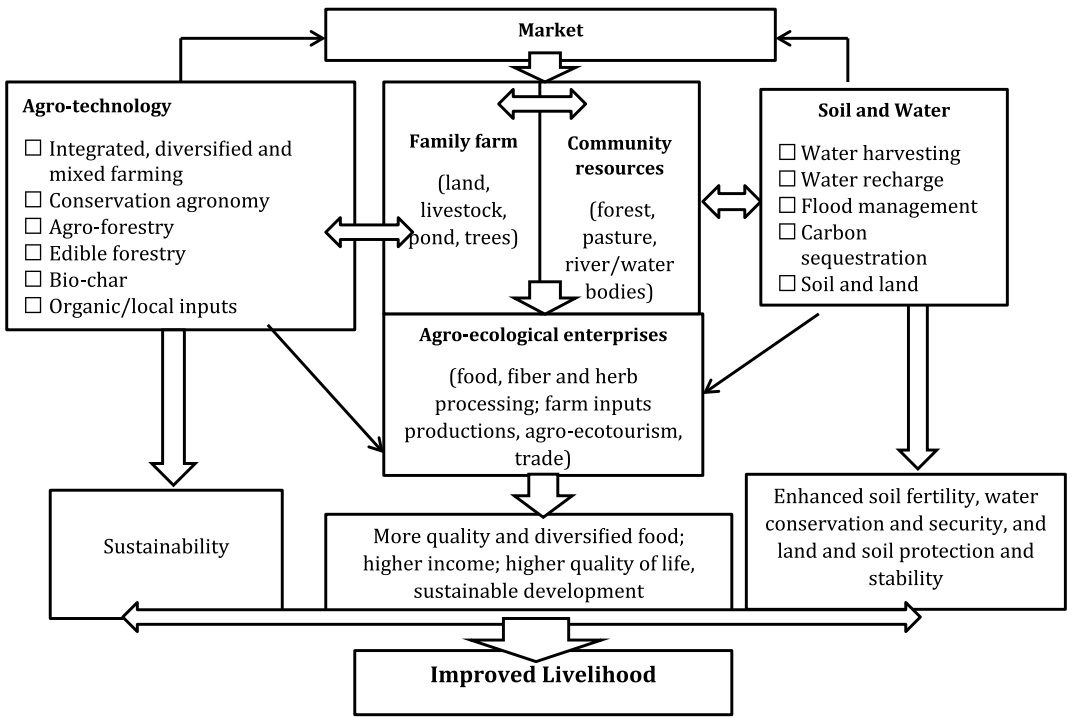


Fig. 11.4 A proposed schematic framework for bottom-up integrated planning of regenerative agriculture and agrarian livelihoods at the community level (A policy environment to enable communities of a landscape to integrate and complement their plans for synergy and mutual benefits based on comparative advantage and resource sharing is required. In the same way, similar

practice of planning is also required at the bioregion level that enables integration of planning for mutual support, exchange and resource sharing can be attained. Capacity building and skill development including empowering of farmers and communities are important and the roles of different stakeholders in this process are highlighted in Table 11.2) (Source Proposed by authors)

looking at multiple dimensions of the problem—social, economic, ecological, geographical, political and scientific—is required to find solutions to the underlying causes that have crippled Nepalese agriculture. Amidst their difficult reality, Nepalese farmers can also tap into opportunities that come from living in a bio-diverse and culturally rich country to build solid foundation for an agricultural or agrarian system, which can feed people while building richer soils and more resilient agriculture that can adapt to the adversities. A contextualized approach of ‘regenerative agriculture’ would be suitable to provide solutions and best practices to meet the challenges. This is the only win-win solution to the dysfunctional food system at local and global scales, which can also transform the lives of farmers and make them the guardians of the land (White

2020). Regenerative agriculture can be easily adaptable as it integrates many of traditional practices such as mulching for preserving soil quality, intercropping and crop rotation. In the context of global food system being dysfunctional to face the challenges of environmental crisis, large food miles, climate change and food safety and quality, it is imperative to build local system, which considers these challenges. This has also been seen during COVID-19 in Nepal and Asia as a whole (Adhikari et al. 2020; Dixon et al. 2021).

Regenerative agriculture ultimately paves way to regenerative organic agriculture—if all inputs are made from local natural resources without resorting to chemicals from industries. This would be an ideal stage of regenerative agriculture, which avoids expensive inputs imported

from ‘outside’ and thus reduces the production cost and generates more local employment (NRI 2021). In addition, conservation agriculture, which could lead to regenerative agriculture, is also gaining momentum around the world (Belloti and Rochecouste 2014; Fujie 2015; Kassam et al. 2015; EU 2019; Magar et al. 2022a, 2022b). In other countries too, a search for alternatives to conventional agriculture has also been going on. For instance, European Commission (EU) has recently released an ambitious policy package to tackle climate change and become the first carbon-neutral continent by 2050 (EU 2019). In its farm-to-fork-strategy package which aims to mend the unsustainable food systems, specific actions points are identified and Member States are incentivized to help the continent transition towards agriculture practices that can not only produce food but also increase the biodiversity, restore the soil fertility and reduce the use of pesticides, insecticide and chemical fertilizers. In Australia, conservation agriculture has become popular in winter crops and this has been developed mainly through farmers’ innovation and sustained R&D (Belloti and Rochecouste 2014). Likewise, in Japan, conservation agriculture has been promoted as a part of agri-environmental policy to reduce environmental load from agricultural sector or improve water quality in watershed areas (Fujie 2015).

Amgain et al. (2022) reviewed the research on conservation agriculture activities in Nepal to date and concluded that this has great potential for increasing crop yields and profits and resource-use efficiencies and achieve food security and sustainability of food systems but needs policy support to scale up the technology and enhance its adoption by smallholder farmers. The Sikkim State in India has followed an approach of ‘organic farming’, which can also help move towards regenerative agriculture. Sikkim Government declared in 2016 that the whole state would ban using chemicals in all its lands. Sikkim’s transition to organic agriculture is facilitated by minimum use of chemical fertilizers as well as locally existing knowledge of agro-ecological traditions such as diverse bio-cultural

foods, local seed regeneration, diversified cropping system, mixed farming, crop rotation and mulching, which are important contributors to food security, biodiversity and well-being (Meek and Anderson 2019). Despite these forward moves, it could take some time to transition from conventional to regenerative agriculture.

11.4.1 Pathway for Transitioning into Regenerative Agriculture

Regenerative agriculture is making inroads in countries where farm sizes are bigger, especially in developed countries. However, it is still seen difficult in the context of smallholder agriculture, as there is urgent need to generate more income as well as food and small farmers have difficulties to wait for future income that might come from ecosystem improvement. On the other hand, it is important that this should also be done for sustainability of production and for more accessible food supply as smallholders still produce 70–80% of the world’s food supply (Meulesteen and Duurland 2020).

There is no exact or prescribed norm for regenerative agriculture, but a range of methods can be considered. The main idea here is that a rethinking of the farm into a farming system in which all crops and practices work together holistically that help to produce synergy is important. A system’s regenerative capacity needs to be analyzed by looking at two main factors: agronomic efficiency and plant functional diversity (Meulesteen and Duurland 2020). For this, regenerative practices that lead to more production of diverse food in totality and generation of more income are important. In Nepal’s context, these practices could be agro-forestry and reduced or no till, production of food in forests and water bodies, production of farm inputs locally including production of quality seeds in which farmers have control and production of other enterprises based on natural resources like herb processing, ecotourism and farm tourism. In this context, the following simplified conceptual diagram (Fig. 11.3) has

been proposed to illustrate the path from the resource-intensive conventional agriculture towards resource-efficient and environmentally friendly regenerative agriculture. Transitioning from the situation in red to the situation in green can take place in two ways: (1) either it be a step-by-step process that requires a consistent alignment between all the stakeholders involved in the food value-chain—starting from farmers to consumers to researchers, government, policy-makers and investors; and/or (2), it can be a radical process that arises when status-quo is no longer possible due to external reasons—climate crisis, pandemics or conflicts. Especially for Nepal, taking a resource-efficient path (path 1) is the most strategic one as in such a case abrupt disruption would collapse the system. So, there is a need to follow a step-wise method to slowly reduce the use of these harmful inputs by developing alternatives through research and development that are rooted in local resources. The use of plant clinics and IPM (Tambo et al. 2021) is one step forward in this transitioning

process. More potent organic fertilizers are to be developed through research to boost up nutrients required for higher productivity (Timsina 2018). On the other hand, the reverse path like adopting GMOs and all chemicals that are associated with this method for immediate increase in food production could be like a palliative cure; this will also make Nepalese agriculture (and farmers) dependent on multi-national agri-business companies increasing their vulnerabilities resulting from market manipulations. It would have other adverse impacts like loss of diversity of traditional foods and increased dependency on bigger companies for inputs, as high technology to produce GMOs is not accessible to farmers. This dependency, especially for seeds, could have devastating effect on resource-poor small farmers who are gullible to debt-trap (Adhikari 2014, 2021). As modern seeds like GMO are expensive and require other expensive inputs, it is not a good option for resource-poor farmers with small-fragmented land, where they are already struggling to meet basic needs. The risks of failure

Table 11.2 The role of different stakeholders in transitioning from conventional agriculture to regenerative agriculture (RA)

Activities	Government	Private sector	NGOs/civil society
Research	More research fund allocation for RA to development appropriate technology and inputs based on local resources for all types of farmers, especially suitable for smallholders	Involvement in research on a public–private basis Enterprise development based on local production, local crops and resources	Advocacy Involve in participatory/collaborative research along with farmers
Extension	Holistic extension to promote various aspects of livelihoods (see Fig. 11.1)	Dissemination of information promoting businesses with social benefits	Awareness of extension agents Training of extension agents
Support to farmers	Insurance Support to produce inputs and products locally Guaranteed pricing Accessible certification	Sourcing food and other products from RA Premium price to RA produce Investment in RA in collaboration with smallholders for production	Protecting rights of the farmers Social marketing of RA products Helping in certification (training and organizing farmers)
Support to consumers	Awareness Strict quality control methods	Effective distribution of RA products (marketing) Awareness	Awareness Protection of consumers' rights in quality, price and availability so that RA products get due justice

(Source Proposed by authors)

become too costly for them. On the other hand, there is a growing realization around the globe that the current chemical-based industrial and globalized agriculture contributes to and is also highly vulnerable to, crises like climate change (Tian et al. 2020). In the above transitioning pathways, different stakeholders need to play their roles for efficient and effective transition as illustrated in the following Table (Table 11.2).

11.4.2 A Framework for Bottom-Up Policy and Planning for Regenerative Agriculture

Regenerative agriculture calls for integrated use of all local resources for maximizing food production and other local enterprises for income and employment that leads to improvement in all livelihood capitals (Box 11.1).

Box 11.1: Livelihood Capitals **Financial capital**—income—both cash income and in-kind income like food and economic capital like stocks of resources; access to loan interest and collateral-free credits/loans.

Social capital—social networks, cooperation, knowledge exchange and support services.

Physical capital—basic infrastructure that people need for making a living—like transport and communication, shelter, water and sanitation system, research and extension services, supportive/enabling policy instruments, access to markets.

Natural capital—natural resources such as soil conditions, land and water situations, biodiversity and forests for the production of food and other materials and for carbon capture and sinking.

Human capital—health, education and skills.

Source Adapted from DFID (2000)

A holistic or system planning for agriculture development (at the farm level as well as different landscapes or bioregion levels) in Nepal should consider both private resources like land and animals and common resources like forests, pastures and water bodies. There are many community-based activities—like sharing and polling together labour, seeds and resources—for mutual support and community cultural and social life, which are also part of their agrarian life and livelihood. In recent times, these communities have also taken some formal organizational roles in terms of accessing markets as a group or getting group loans. Accordingly, Nepal has opportunities for this purpose along with challenges. These opportunities are:

- Diversified landscape and high bio-cultural diversity still maintained through traditional farming methods preserving various indigenous foods, which are now considered future smart foods;
- Hard-working farmers;
- Strong community;
- Natural beauty for ecotourism and trekking;
- Many plants with medicinal effects for therapeutics purpose;
- Community resources like forests, ponds and water bodies, where food can also be produced;
- Relatively less use of modern inputs like fertilizers and pesticides, even though it is growing rapidly in peri-urban areas that aim to produce cash crops for the market; and
- Great possibilities of enterprises like processing food and fibre and producing organic farm inputs and herbal medicines at the local level.

On the other hand, small and fragmented holdings, growing population pressure on land and climate change are adding constraints for the farmers. Disasters induced by climate change and unsustainable use or extraction of resources are other problems. Government is also not able to support farmers adequately through subsidies and market support.

To use the opportunities and resolve the challenges as stated above, we propose a model of regenerative agriculture in Nepali context, which is presented schematically in Fig. 11.4. This model has the following basic principles.

- **First**, solutions are sought in the intersection of natural systems and the human social systems. Nepal is still a repository of traditional knowledge that links these two systems in unique ways. Existing traditional/indigenous knowledge needs to be used as a base, on which further regenerative agriculture-based methods are to be used/developed to produce more food and other capacities/capitals required for sustainable livelihoods. For this, practices like preservation of local seeds and their improvement through farmers' participation, intercropping, crop rotation, use of animal manure, mulching of soil with mixture of straw and animal manure for weed management and better soil quality, need to be used as a base, on which further conservation agronomy-based methods such as use of zero tillage and scheduled irrigation are to be used. Further innovation in producing more potent bio-fertilizers and bio-pesticides is also possible in this approach for greener agrarian economy. However, there is still less adoption of these technologies in Nepal (ibid). On the other hand, the experience of LI-BIRD reveals that adoption and scaling up of alternative sustainable technologies depend on how they are demonstrated, packaged/bundled, communicated and incentive mechanisms negotiated (Gautam et al. 2020; Gauchan et al. 2020; Joshi et al. 2020). Specifically, LI-BIRD's experience shows that the following strategies could help in promoting adoption and scaling up of technologies: (i) there is higher chance that the blending of local knowledge and practices with science and technology can maximize benefits to the farmers and help accelerate adoption/scaling up; (ii) technologies that are affordable and within the technical know-how and managerial reach of farmers and generate tangible benefits to the local communities (return on investment) are most likely to be sustained and scaled up;

and (iii) when local communities are given the seed money, with adequate capacity-building support, they are able to leverage significant additional funds to achieve their adaptation/sustainable farming goal.

- **Second**, interventions or activities are to be applied at four levels: households, communities, landscapes and bioregions. For example, activities like rainwater harvesting, improved composting and cultivation of local indigenous crops like millet are seen effective at the household level (Gautam et al. 2020); activities like community pond, community seed bank, participatory plant breeding are seen effective at community level (Gauchan et al. 2020); activities at the landscape and bioregion levels that are seen effective include watershed conservation, mutual exchange of products that could be suitable in the given agro-ecology. A synergy needs to be developed among these levels by giving attention to some specificities of the mountains notably: inaccessibility, fragility, marginality, vulnerability and diversity and niche (unique production opportunities with comparative advantage to mountain areas compared to other regions) (Jodha 1998). People and communities have addressed these specificities and have devised place-specific responses since long. In the same line, new activities are to be designed or promoted with maximum flexibility so that these are suited to local specificities at the local (community) level. Then, the design should link all communities in a landscape and all landscapes in a bioregion and then link all the bioregions. The exchange between landscapes and bioregions would help fulfill the deficits in foods in each region through market/exchange. This would also help to conserve and produce indigenous food systems with more production of food. However, this calls for a policy environment that enables communities of a landscape to come together for planning so that there is synergy based on their competitive advantage and resource sharing. The same applies at the bioregion so that different landscape-level activities are coordinated and mutually supported.

- **Third**, Participatory and Collaborative Action Research approach is to be followed to empower households, communities and bioregions to evaluate risks and negotiate strategies among stakeholders to minimize the impacts of challenges (for example climate change or market inaccessibility). Such action research is proven effective in, for example, participatory plant breeding, community seed banks for conservation of biodiversity, community-based biodiversity management, market-led conservation of biodiversity for better livelihoods (Gauchan et al. 2020; Joshi et al. 2020). Such a research approach is also required for further innovations (in food production methods or other activities; more potent organic sources for nutrients) that would be adoptable in the local conditions. Such action research examines the interactions and relationships among actors and researchers in social settings seeking opportunities for improvement. As designers and stakeholders, they work with their colleagues to propose new courses of action based on the experience of the interventions that help their community improve work practices and promote greater exchange of knowledge through the establishment of ‘Community of Practice’ network as a learning tool.

The above basic issues are presented schematically as follows (Fig. 11.4) as a framework for policy-making and planning taking a community into account. In this framework, both private farmland and community resources (mainly land/soil, water and trees/forests) are important and they underpin each other and generate many inputs for each other. People also derive food and other livelihood resources from the community resources. For example, Adhikari et al. (2017) show how forest can be made as a food production site and a source of income from NTFPs, for which a holistic planning of farm-forest is required. Similarly, conservation agriculture could be employed as a resource-conserving technology (Adhikari 2017; Amgain et al. 2022; Dixon et al. 2021).

Planning at different scales could be linked to have a synergy in the production of foods and their availability to people. This planning process would lead to local/regional self-sufficiency in food with the generation of additional incomes for farm households through ecological enterprises (ecotourism, production of farm inputs, food processing, etc.). Based on these principles and learning, a model of activities for different levels are suggested in the following Table (11.3) that will help link communities horizontally and vertically to larger spatial (planning) units.

It is expected that this approach of bottom-up planning for regenerative agriculture and agrarian livelihoods through spatial integration of adjacent landscapes/bioregions will reduce many weaknesses of the industrial/specialized food system like high food miles (i.e. the distance travelled by the food and energy required to make the food available at a certain spot through transportation, packaging, preservation, etc.). It will also help reduce chemical and biological pollution of soil, air and water and at the same time improve availability of quality food at the local level and generate additional income at the household level. In this sense, this approach will help achieve many SDGs, mainly related to poverty (SDG 1), zero hunger (SDG 2), improving health and well-being (SDG 3), climate change (SDG 13) and environmental conservation (SDG 15).

11.5 Conclusions and Policy Implications

This study of potentiality of regenerative agriculture in Nepal’s context has important policy implication for making agriculture sustainable and pro-poor by improving the total livelihood of smallholder farmers and by producing quality foods for other consumers. Given that principles of regenerative agricultural practices resemble those of traditional farming systems in Nepal, it can be easily adopted by the smallholder farmers. However, large-scale adoption of this practice also calls for a total shift in policy environment

Table 11.3 A model for the activities in the framework of regenerative agriculture and agrarian livelihoods (proposed by authors)

Unit of engagement	Components of ecosystem to be improved	Some proven examples	Outcomes
Micro-level (household or farm level)	• improving micro-climate • increasing biodiversity • efficiency in use of resources and energy • micro-enterprises, conservation economy projects • improving equity and social justice	conservation agronomic practices like zero tilling, mixed cropping, combining fodder/fruit trees with crops, diversified cropping system, crop rotation, indigenous and minor crops, rainwater harvesting, improved composting, Bio-gas production in some regions	Sustainable and resilient households, farms with adequate livelihood opportunities
Community-level	• improving community resources and the commons • increasing biodiversity • increasing efficiency in the use of community resources and energy • micro-enterprises, conservation economy projects • improving equity and social justice	Community forestry producing NTFPs and income, water ponds, biochar production, seed banks and plant breeding with farmers, participatory research in agro-biodiversity, community-based resource and biodiversity management, leasehold land grant for poorer households, river-bed cultivation in winter season, homestay for agro-ecotourism, herb/NTFP processing	Sustainable communities and creating more livelihood opportunities
Bioregions	• improving resources at bioregion level and sharing • increasing biodiversity • increasing the efficiency of resource use and energy use • creation of bioregional foodsheds, watersheds and biodiversity preserves • improving equity and social justice	Watershed conservation, nature conservation (conservation area approach) for ecotourism, river conservation to control erosion and landslide and river cutting	Sustainable bioregions with more opportunities for better livelihoods
Himalayan region	Dissemination, sharing, networking and mutual learning visits	National parks and conservation areas managed by people for income generation; federations of farmers and resource users for learning and networking	Sustainable Himalayan ecosystem

that helps in multi-scalar planning for livelihood improvements by utilizing the local resources so that there is high multiplier impacts within the society in the creation of employment and income opportunities. A policy environment to enable this framework to be used at different scales is to be created. The federal structure and the devolution of power and resources to the sub-

national levels provide a suitable enabling environment but at the same time, planning agencies and people are to be trained and their skills improved for this purpose. Moreover, policy environment that enables communities of a landscape to come together to integrate their plans for regenerative agriculture based on comparative advantage, exchange of inputs and

products and sharing of resources for mutual benefits and that helps private agencies to come together with public agencies for supporting farmers and marketing their products with premium price is required. Government support in research and development and in protecting farmers and their interests and promoting regenerative agriculture through incentives, at least in the initial period, would play a vital role for quick adoption of this approach.

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Conservation Agriculture Technologies for Cropping Systems Sustainability and Food and Nutrition Security in Nepal

12

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Abstract

Recent global experiences on sustainable intensification of smallholder cropping systems show that improving food security and income with reduced production inputs and increased systems sustainability would be possible through the adoption of conservation agriculture (CA) technologies. CA-based sustainable intensification follows three principles in farming, viz. minimum soil disturbance, crop residue retention, and diversified and sustainable crop rotations. CA aims

at improving productivity, reducing production costs, and increasing farmers' income through reduced use of labor, energy, and other farm inputs, and improving the sustainability of cropping systems. Resource-conserving technologies (RCTs) include at least one of the three principles of CA and aim at reducing the use of external inputs. This chapter reviews the application of CA and RCTs for improving the sustainability of cereal-based cropping systems mainly in the context of Nepal but with relevance to the Eastern Indo-Gangetic Plains. The review,

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complemented with the authors' own results from several on-station and on-farm experiments, demonstrated that the CA and RCTs practices viz. dry direct-seeded rice, unpuddled transplanted rice, and zero-tillage maize, wheat and legumes with the retention of crop residues can increase grain yields and profits and save labor and water use compared to conventional tillage practices. No or minimum tillage along with residue retention can also suppress weeds, increase opportunity for crop diversification, improve soil physico-chemical and micro-biological properties, enhance nutrient- and energy-use efficiencies, and reduce greenhouse gas emissions. CA practices encourage the use of land leveling, farm mechanization, and precision crop production. CA and RCTs have also the potential for reducing soil erosion in sloping hilly areas and undulating land with narrow terraces. Despite several advantages, these technologies have however not been fully mainstreamed in the national agricultural research and extension system of Nepal. Knowledge gaps among extension workers, farmers, and other citizens, unavailability of farm machinery, trade-offs in using crop residues for improving soil fertility and animal feed, land fragmentation, poor rural infrastructures, and inadequate policy support are the major adoption barriers of CA-based technologies. The review concludes that there is an urgent need to institutionalize the CA and RCTs to attain the sustainability of cropping systems and achieve food, nutrition, and livelihood security of the growing population.

Keywords

Terai • Hills • Multi-criteria assessment • Direct-seeded rice • Zero tillage • SWOT analysis

12.1 Introduction

Nepal and the large areas of Eastern Indo-Gangetic Plains (EIGP) of South Asia follow traditional agricultural practices, where farmers

practice intensive soil tillage, low or negligible chemical (external) inputs, and subsistence farming (Adhikari et al. 2021; Timsina 2018). This system of agriculture although partially meets the daily household survival needs, offers low returns/income with less prospects for improving the livelihoods of the smallholder farmers (Adhikari et al. 2021). The increased population pressure, labor outmigration, high cost of production, and high energy inputs in farming in the EIGP demand for increased food and income using input-efficient technologies. Resource-saving conservation agriculture (CA)-based technologies/practices and appropriate mechanization are some examples of such input-efficient technologies (Aryal et al. 2021). Further, due to the increasing impact of climate change and rainfall variability in crop production, farmers in the region are more vulnerable to climate change-related stresses than ever before (Paudel et al. 2020a).

In Nepal, due to the low productivity of major staple cereals, for example, rice, wheat, maize, and millet yields of less than 2.47, 2.23, 1.40, and 1.14 t ha⁻¹ respectively in hills and 3.49, 2.87, 2.94, and 1.07 t ha⁻¹ respectively in the Terai region (MoAD 2019), achieving food security for the increasing population is a huge challenge (Gauchan et al. 2022; Rasali et al. 2020). Hence, the country is importing hefty amounts of cereal grains every year. The country imported 0.54, 0.14, and 0.35 million tons of rice, wheat, and maize grains worth 232, 38.4, and 90.8 million US\$, respectively in 2017 (FAOSTAT 2020). Gauchan et al. (2022) estimated cereal demand for 2030, 2040, and 2050 and concluded that unless cereal productivity is sustainably increased with the use of improved and resource-saving technologies (RCTs), the country will continue to face a food deficit requiring import every year. Agronomic research has also shown the existence of huge yield gaps (>8 t ha⁻¹ in rice, >6 t ha⁻¹ in maize, and > 4 t ha⁻¹ in wheat) between climatic potential and farmers' fields (Krupnik et al. 2021; Timsina et al. 1995, 2018, 2021), which can widen further due to the impact of prevailing global climate change. Such yield gaps suggest the need and

opportunity to improve food security by increasing farmers' yields by reducing gaps. To reduce such yield gaps, climate-resilient agricultural practices are needed. CA-based RCTs can offer a range of promising adaptation and mitigation measures in EIGP including Nepal (Paudel et al. 2020a; Magar et al. 2022b). RCTs include at least one of the three principles of CA aiming at reducing the use of external inputs and hence would be equally useful for Nepal and the EIGP.

Maintaining and improving the sustainability of smallholder food production system is important for achieving Sustainable Development Goal (SDG) No. 1 (No poverty), No. 2 (End hunger, achieve food security and improve nutrition, and promote sustainable agriculture), No. 5 (Gender equality), No. 6 (Ensure availability and sustainable management of water and sanitation for all), No. 12 (Ensure sustainable consumption and production pattern), and No. 13 (Take urgent action to combat climate change and its impact) (UNDP 2017). To meet these SDGs and improve food and nutritional security in Nepal, agricultural productivity must increase substantially through sustainable intensification (SI). SI aims at producing more food with efficient use of production resources while reducing environmental footprint, building resilience, preserving natural capital, and improving the flow of environmental services (Pretty et al. 2006; Pretty and Bharucha 2014). Research in South Asia has demonstrated that CA or RCTs can provide a pathway for SI with ample opportunities for adopting such technologies in Nepal (Bhatt et al. 2021; Amgain et al. 2020; Dixon et al. 2020; Gathala et al. 2013; Hobbs et al. 2008; Hobbs and Gupta 2003; Islam et al. 2019; Jat et al. 2020; Kumar and Ladha 2011; Kukal et al. 2010; Kumar et al. 2016; Pretty et al. 2006; Timsina et al. 2010b). Thus, the objective of this chapter is to review and provide the current state of research and technology readiness on CA or RCTs for their adoption, and advice these technologies to the extension, research, and policy-makers for their mainstreaming in all tiers of the Nepal government (Federal, Provincial, and

Local) to meet the food and nutritional security of the increasing population. Wherever deemed necessary, the relevance of these technologies to the EIGP and South Asia is also discussed.

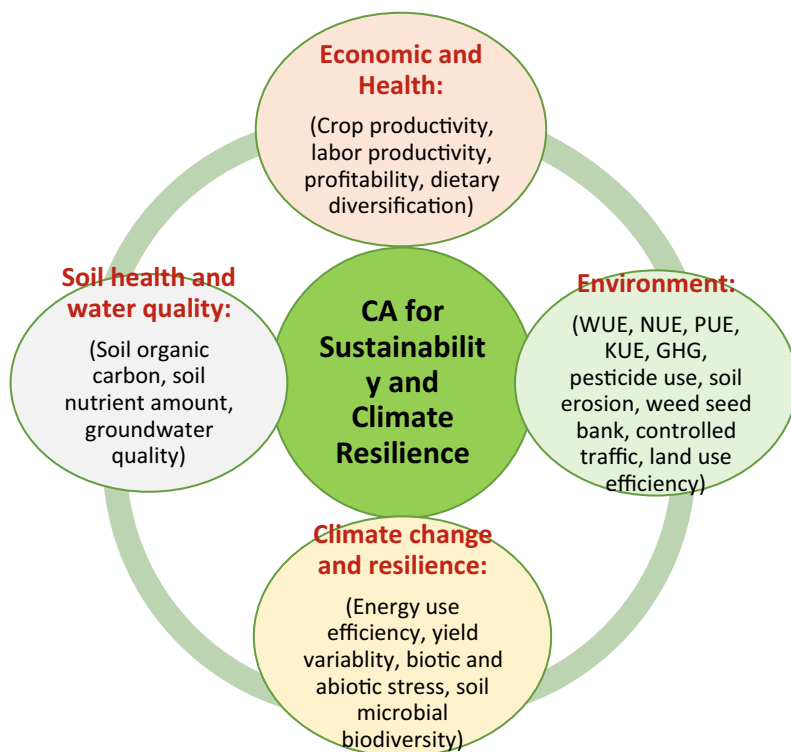
12.2 CA for Increasing Productivity and Sustainability: A Conceptual Framework

CA offers a set of improved crop production practices that aim to maximize the farm profits in the long run by optimizing agricultural production while conserving inputs, such as labor, fuel, seeds, fertilizer, pesticides, and water, and minimizing or mitigating impact on the natural resources (Amgain et al. 2019a; Dixon et al. 2020; Pretty et al. 2006). The wider areas and broadened practices of CA have resulted in a wide range of definitions. CA follows three principles, i.e., minimum soil tillage, crop residue retention on the soil surface, and sustainable crop diversification (FAO 2017; Hobbs et al. 2008; Friedrich et al. 2012, 2017; Kasam et al. 2018; Saharawat et al. 2010). CA is defined as a “resource-conserving agricultural production system to achieve acceptable profit together with high and sustained production levels by conserving natural resources and environment” (FAO 2007). It is also defined as “management of soil, water, and agricultural resources to achieve ecological, social, and economically sustainable agricultural production” (Jat et al. 2020), “resource-efficient or resource effective agriculture” (Hobbs et al. 2008). All definitions centered around the basic principles of CA. Further, a new terminology “conservation agriculture-based sustainable intensification” (CASI) has also been recently used in literature (Islam et al. 2019; Dixon et al. 2020). CASI technologies are synonymously being used as CA or RCTs in literature and RCTs contain at least one component of CA: we use all three terminologies synonymously in this review.

For the sustainability of the crop production system in Nepal and the EIGP, we conceptualized the CA with four pillars and each with relevant indicators, i.e., economic and human health

Fig. 12.1 Four sustainability pillars and indicators that CA improves: a conceptual framework. (Source Authors' conceptualization).

WUE = water use efficiency;
NUE = nitrogen use efficiency; PUE = phosphorus use efficiency;
KUE = potassium use efficiency;
GHG = greenhouse gas emission



condition, environment, soil health and water quality, and climate change and resilience (Fig. 12.1). A sustainable production system that uses CA is suggested to have all four pillars and their indicators strengthened/improved over conventional practices. To maintain food security and economic growth, gain in crop productivity should come from efficient use of all resources, including land, labor, water, energy, and chemicals, along with a lower environmental footprint and building resilience (Rockström et al. 2017).

12.3 Development and Scaling-Up of CA-Based Technologies in Nepal

12.3.1 Conservation Agriculture and RCTs: Past, Present, and Future

From the early 1980s, several initiatives and projects were launched in Nepal with the objectives of resource-saving using CA-based

technologies especially in rice- and maize-based systems. To make the crop production system more productive, profitable, and resilient, these initiatives made a series of testing, development, and promotion of different CA-based technologies especially in the Terai region (Table 12.1).

12.3.1.1 Testing and Verification of CA-Based Technologies

Among the CA and RCTs evaluated in south Asia, zero tillage (ZT) especially in wheat (ZTW) is the most common RCT, first initiated in Indian and Pakistani Punjab in the 1980s for wheat planting (Pandey and Gurung 2017). Later, ZT and other RCTs were introduced in other regions of India, Pakistan, and Bangladesh in the 1990s (Friedrich et al. 2012, 2017). In Nepal, no-till wheat was grown by farmers at the bank of Ridhi Khola in Palpa and in Bhaktapur before the commencement of wheat research. Research on no-till wheat in Nepal was first started in Janakpur and Bhairahawa during 1970s with the objective of minimizing yield losses due to terminal heat stress caused by late planting

Table 12.1 Timeline on the progress of evaluation and scaling of CA-based technologies in Nepal

Year	Government initiatives and projects	CA/RCTs	Geographical coverage	References
1980	India government	Zero tillage wheat (ZTW)	Indian and Pakistani Punjab in South Asia	Pandey and Gurung (2017)
1980	Rice–wheat consortium via Nepal agriculture research council (NARC)—6 +5national wheat research program (NWRP)	ZTW, direct-seeded rice (DSR)	Rupandehi, Kapilvastu, Nawalparasi	Giri (2001)
2000–2001	NWRP, Bhairahawa	ZTW, DSR	Rupandehi, Kapilbastu	NARC/NWRP Report (2001)
2014–2015	National maize research program (NMRP/NARC) and CIMMYT–Nepal with different commodity programs	Zero tillage (ZT) and residue management in maize	Terai, Chitwan; Central hills (Gulmi)	Karki et al. (2014a), (2015a)
2014	CIMMYT, Nepal; NMRP and agriculture implements research station, Ranighat, Birgunj, Parsa	ZT and residue management in maize CT, ZT, and PRB with, residues management in rice–wheat system	Chitwan Parsa	Dahal et al. (2014), Karki et al. (2014b), Khatri et al. (2014b), Paudel et al. (2015), Sah et. al. (2014)
2015–2018	NMRP and CIMMYT, Nepal	ZT and planting geometry in maize	Chitwan	Karki et al. (2015b), Lamsal and Khadka (2019)
2013–2015	NMRP, regional agriculture research center (RARS), Parwanipur, NWRP, Bhairahawa, and CIMMYT, Nepal	ZT and residue in wheat; DSR	Bhairahawa and Parwanipur	Karki (2015), Tripathi (2015), Bhurer et al. (2013)
2009–2021	Cereal systems initiatives for South Asia (CSISA) [CIMMYT and IRRI Nepal managed project]	ZTW, DSR, CA-Rice, CA-Wheat, CA-Maize, laser land leveling, Brown manuring	Rupandehi, Chitwan, Nawalparasi, other Terai districts	https://csisa.org/about-csisa/overview/
2014–2021	The sustainable and resilient farming systems intensification (SRFSI) project, CIMMYT, Bangladesh	Crop diversification and rotations, reduced tillage using machinery, DSR, ZTW, ZT maize, ZT lentil, unpuddled transplanted rice, efficient water and residue management practices	Eastern Indo-Gangetic plains (Dhanusha and Sunsari)	https://aci-ar.gov.au/about-aci-ar , Islam et al. (2019), Brown et al. (2021), Magar et al. (2022a, b)

Source Authors' compilation

(Giri 2001). However, the area covered by CA or RCTs in Nepal is still quite low. On the other hand, adoption of CA or RCTs under rice–wheat (R–W) and rice–maize (R–M) cropping systems has increased remarkably in the recent decades in India (Alomia-Hinojosa et al. 2018; Farooq and

Siddique 2014; Jat et al. 2009). Besides, the adoptions of raised bed planting and laser land leveling (LLL) are also increasing, mostly in the northwest IGP (Bhatt et al. 2021; Bhan and Behera 2014). Such positive development in India indicates these technologies might gain

popularity among farming communities and youth service providers in Nepal too if precision machinery, herbicides and fertilizers, and favorable policy supports are provided to service providers and farmers. Most widely practiced CA/RCTs in Nepal include zero-till wheat (ZTW) and maize (ZTM) (Dahal et al. 2014; Karki et al. 2014a, 2015a; Khatri et al. 2014; Sharma et al. 2018; Paudel et al. 2015; Karki 2015, Tripathi 2015). Several CA-based technologies have been verified and tested by conducting a series of on-farm demonstrations and training events in different crops across the Terai region of Nepal (Table 12.2).

12.3.1.2 Comparative Advantages of CA/RCTs Over Conventional Practices in Hill and Terai Regions

Soil health indicators: Few studies comparing the effects of reduced tillage (RT) or ZT and conventional tillage (CT) on soil properties and crop yields were conducted for several crops in both mid-hills and Terai of Nepal. McDonald et al. (2006a, b) compared the effect of six tillage and crop establishment practices in R–W systems on soil physical properties and yield on a silt loam soil of Khumaltar, Kathmandu for two years. In rice season, the saturated hydraulic conductivity was higher in DSR than in puddled transplanted rice (PTR) plots, but bulk density (BD) was higher in the PTR than DSR plots. However, in the wheat season, there were no significant effects on BD, soil moisture retention characteristics, and root development patterns. Laborde and McDonald (2019) reported improvement in soil physical properties in the mid-hills after two years of conversion from conventional to CA-based maize–rapeseed and maize–wheat systems. They further reported that in hills and mountains, soil erosion rates and soil and nutrient losses from the terraced lands with intensive tillage could vary considerably and could be reduced through RT practices. Brown and Shrestha (2000) and Partap and Watson (1994) reported higher losses of SOM, N, P, and K up to 150–600, 7.5–30, 5–25, and 10–40 kg ha⁻¹ yr⁻¹, respectively from terraced lands under

CT than under RT. Tiwari et al. (2009) reported that RT with residue retention in a maize–cowpea rotation was more effective in maintaining soil fertility and increasing farm income compared to the conventional maize–millet rotation.

In a similar study, Atreya et al. (2005) reported lower total annual soil and nutrient losses in RT compared to CT in Kathmandu valley. Atreya et al. (2008) also reported significantly lower annual and pre-monsoon soil and nutrient losses with RT and rice straw mulching compared to CT without mulching. Tiwari et al. (2008a) reported that RT decreased runoff by 7–11% and soil loss by 18–28% compared to CT in a mid-hill region in central Nepal. Tiwari et al. (2008b) demonstrated higher losses of SOC, total N, available P, and exchangeable K from the intensively cultivated vegetable fields than from the RT fields. RT had higher soil surface roughness due to the small ridges formed by intercultural operation and higher ground cover due to retention of crop residue, resulting in reduced runoff and increased infiltration compared to intensive vegetable production and farmers' practice with intensive tillage. These findings suggest that RT alone would not effectively reduce runoff and soil loss in the upland hill terraces and that RT with residue retention would be required to mitigate early rainstorm impact. Overall, these studies suggest that RT could be a viable option for minimizing soil and nutrient losses without sacrificing crop yields in the mid-hills of Nepal.

A few studies have also compared CA with CT in Terai region of Nepal. Ghimire et al. (2011) reported that soil under a R–W system sequestered a significantly higher amount of SOC in 0–50 cm soil depth (more pronounced effect at 0–15 cm) under ZT than CT. The addition of crop residues to the ZT plots had greater SOC sequestration but there was no effect on soil N. Their findings suggest that a R–W system under ZT with residue retention than under CT with or without residue retention sequestered more SOC in Terai. Paudel et al. (2014) also compared the carbon sequestration in CA and CT after five crop cycles in Chitwan, Central Terai. They observed that ZT with

Table 12.2 CA-based technologies tested and verified in Nepal

Operation	CA/RCTs	Crop	Geographical area tested/developed/scaled	References
Pre-crop land management	Laser land leveling	Rice, wheat, maize	Central Terai, Far-western Terai	CSISA (2013)
Crop establishment	System of rice intensification (SRI)	Rice	Eastern and Central Terai Nawalparasi, Western Nepal	Dahal et al. (2014) Sah and Bastakoti (2014)
	Brown manuring	Rice	Central Terai	Marahatta (2017a)
	Unpuddled rice transplanting	Rice	Central and eastern Terai including Dhanusha, Sunsari, Kapilvastu, and Rupandehi	Devkota et al. (2016), Magar et al. (2022a, b)
	Dry and wet-direct seeding	Rice	Terai	Bhurer et al. (2013), Bastola et al. (2020), Magar et al. (2022a, b)
	Zero tillage Zero tillage, bed planting, and conventional tillage	Wheat and maize Rice–wheat	Terai and hills Eastern and central Terai	Karki et al. (2014a), (2015a), Dahal et al. (2014), Khatri et al. (2014), Sharma et al. (2018), Paudel et al. (2015), Karki (2015), Tripathi (2015), Magar et al. (2022a, b), Sah et al. (2013), Magar et al. (2022a, b)
Weed management	Integrated weed management (IWM); weed management in DDSR	Rice, wheat, maize DDSR	Terai Terai	Bhurer et al. (2013), Shah et al. (2020)
Tillage and residues management	Organic carbon sequestration	Rice–wheat	Terai	Paudel et al. (2014), Karki and Shrestha (2014)
Fertilizer management	Site-specific (precision) fertilizer management	Rice, wheat, and maize	Kaski, Lamjung, and Chitwan	Amgain et al. (2019b), Marahatta (2017a), Timsina et al. (2021), (2022)
	Precision fertilizer application LCC-based N management	Rice, wheat Direct seeded rice	Western Terai districts (Rupandehi, Bardiya, Kailali, etc.) Terai	Park et al. (2018), Subedi et al. (2018)
Pest management	Bio-control; dry and wet-direct seeding	Rice, R–W	Terai	Bhurer et al. (2013), Bastola et al. (2020)
	Bio-fertilizers for N-fixation	R–W and R–M	Terai	Karki et al. (2014a), (2015a), Dahal et al. (2014), Khatri et al. (2014), Sharma et al. (2018), Paudel et al. (2015), Karki (2015), Tripathi (2015)

(continued)

Table 12.2 (continued)

Operation	CA/RCTs	Crop	Geographical area tested/developed/scaled	References
Soil management	Crop residue anchored on soil surface	Rice and maize	Terai and hills	Karki et al. (2014a), (b), Dahal et al. (2014), Pandey and Kandel (2019), Bastola et al. (2020)
	Crop rotation, residue retention, and inter-cropping	Maize and wheat	Terai	Paudel et al. (2015), Khatri et al. (2014)

Source Authors' compilation

residue retained plot sequestered $0.91 \text{ g kg}^{-1} \text{ yr}^{-1}$ SOC which was 22.6% higher than conventionally tilled residue removed plots. Their research suggests that CA with residue retention sequesters more SOC than CT without residue retention.

Economic and environmental indicators: A recent simulation study in a central mid-hills district showed that the maize yields under CA were either similar to, or lower than, CT, while there were no effects on the subsequent rapeseed and wheat yields under the maize–rapeseed and maize–wheat systems (Laborde and McDonald 2019). Tiwari et al. (2009) reported that RT with residue retention in a maize–cowpea rotation increased farm income but not maize yield compared to the conventional maize–millet rotation in the Kathmandu valley. Atreya et al. (2005, 2008) and Acharya (2017), on the other hand, reported that maize yield in mid-hills performed inconsistently under RT and CT though production cost was consistently lower in RT than CT.

Devkota et al. (2016, 2019) conducted farmer-participatory on-farm trials with a CA-based R–W system during 2011–2017 in western Terai. Both DSR and ZTW produced similar or higher grain yields with lower production costs, higher water productivity, and higher net profit than the CTW. DSR followed by ZTW increased the R–W system productivity, reduced total production cost, increased net profit (by US\$ 347–572 per ha), and reduced climatic risk of growing crops compared to CT. Their results demonstrated that in areas with low early rainfall, DSR permits the

timely establishment and significantly boosts yield and maintains yield stability. Karki et al. (2014a, b) also concluded that, compared to CT, CA significantly reduced the production cost and increased income without any yield penalty in a maize–wheat system in central Terai.

Dixon et al. (2020) and Magar et al. (2022a, b) concluded that CASI can strengthen the food–water–energy nexus by increasing food productivity, increasing energy- and water-use efficiencies, reducing GHG emissions, improving household food security and income, reducing labor and production costs, providing substantial benefits to women, expanding social capital, and strengthening system resilience in the EIGP, including Sunsari and Dhanusha districts in Nepal Terai. These socio-economic benefits were important drivers of smallholder adoption of CASI, underpinning the prospects for widespread scaling (Magar et al. 2022a).

12.3.1.3 CA/RCT-Based Machineryes Testing and Verification

During the process of testing and verification of CA/RCTs in Nepal, several types of machinery in cereals production value chain, e.g., computer-assisted laser leveling equipment, seed drills for two- and four-wheel tractors, mini-tillers, and pesticide and fertilizer applicators, which are useful from soil/land preparation and crop establishment to crop harvesting, were tested and verified (Brown et al. 2021) (Table 12.3). Considering the urgent need for farm mechanization especially to reduce the production cost, minimize youth migration, minimize fallow lands, save energy, water, and

Table 12.3 CA/RCT-based machineries tested and verified in different locations in Nepal

Operation	Machinery	Geographical Tested/Developed/Scaled	References
Pre-crop establishment	Laser land leveling	Bara, Parsa, Dhanusa, Sunsari	CSISA (2013). National Agricultural Engineering Research Center (2019), Agricultural Implement Research Centre (2018), Sustainable and Resilient Farming Systems Intensification (2018), Brown et al. (2021)
Tillage and ploughing	Minitiller (6.5 hp)	Mid-hills (Kavre, Sindhupalchowk)	National Agricultural Engineering Research Center (2019), Brown et al. (2021)
	Powertiller (12–18 hp)	Mid-hills	Prime Minister Agricultural Modernization Project (2020)
Seeding and crop establishment	Power-tiller operated bed planter	Parsa, Lalitpur	National Agricultural Engineering Research Center (2020)
	Raised bed planter/permanent bed planting	Parsa	National Agricultural Engineering Research Center (2017, 2018, 2019), Agricultural Implement Research Centre (2018)
	Power tiller operated seed drill	Rupandehi, Bara, Parsa	Various reports
	Multi-crop planter	Dhanusa, Sunsari, Bara, Parsa	Sustainable and Resilient Farming Systems Intensification (2018)
	Zero-till drill (paddy and wheat)	Banke, Rupandehi, Bara, Parsa, Sarlahi, Dhanusa, Sunsari,	National Agricultural Engineering Research Center (2017, 2018, 2019), Brown et al. (2022)
	Happy turbo seeder (wheat)	Parsa (AIRC and farmers' fields)	Agricultural Implement Research Centre (2018)
	9- and 11-row seed-cum-ferti-drill for Dry-DSR (paddy)	Bara, Parsa (AIRC and farmers' fields)	Agricultural Implement Research Centre (2018)
	Drum seeder for Wet-DSR (paddy)	Bara, Parsa, Udayapur	Agricultural Implement Research Centre (2018)
	Jab seeder (maize)	Kavre, Sindhupalchowk	National Agricultural Engineering Research Center (2018)
Weed Management	Precision maize planter	Bara, Parsa, Dang Banke	Agricultural Implement Research Centre (2018), CSISA (2020)
	Conoweeder (Paddy)	Parsa, Lalitpur, Kailali, Bardiya	CSISA (2020), National Agricultural Engineering Research Center (2019), Agricultural Implement Research Centre, Parsa (2018)
	Rotary weeder (Paddy, maize)	Parsa, Kavre, Lalitpur, Dang. Banke	CSISA (2020), National Agricultural Engineering Research Center (2017)
	Dryland weeder (vegetables)	Lalitpur, Jumla	National Agricultural Engineering Research Center (2020)
	Self-propelled weeder (sugarcane and maize)	Bara, Dang	Agricultural Implement Research Centre (2018)
	Modified tractor driven cultivator (maize, sugarcane)	Parsa, Chitwan	National Agricultural Engineering Research Center, Khumaltar (2019), Agricultural Implement Research Centre (2018)

(continued)

Table 12.3 (continued)

Operation	Machinery	Geographical Tested/Developed/Scaled	References
Herbicides Application	Mini-tiller driven sprayer	Dhankuta, Sindhuli	National Agricultural Engineering Research Center (2019)
	Boom sprayer	Parsa	National Agricultural Engineering Research Center (2017)
	Knapsack sprayer	Throughout the country	
Fertilizer Application	Urea applicator/fertilizer spreader	Western Terai, Lalitpur, Kailali, Bardiya	CSISA (2019, 2020); National Agricultural Engineering Research Center (2017); Brown et al. (2021)
Straw Management	Tractor driven round baler	Bara, Parsa Kanchanpur	Agricultural Implement Research Centre (2018); CSISA 2020

Source Authors' work

labor resources, and reduce drudgery, Nepal Government formulated Agricultural Mechanization Promotion Policy in 2014 (FAO, 2014) and implemented Prime Minister Agriculture Modernization Project (PMAMP) throughout the country (MoALMC 2018).

12.3.2 Performance of Key CA/RCTs

12.3.2.1 Direct-Seeded Rice

DSR is an alternative rice establishment method in which rice seeds are broadcast or directly seeded in the dry or wet tillage (puddled) field instead of transplanting the seedlings in the puddled field. Common DSR technologies in Nepal are:

- (i) *Wet direct-seeded rice (WSR)*: This is an old method of rice establishment and is common in Jhapa and Morang districts in the eastern Terai region and high rainfall areas of other Terai districts. In this method, rice seeds are soaked for 24–72-h and then the sprouted seeds are broadcast or sown in lines using a drum seeder under wet tillage and puddled soil (Bedari et al. 2020). Despite being efficient in resource use, its adoption however is low, mainly due to non-uniform stand establishment with hand broadcasting and unavailability of herbicides for weed control (Dhakal et al. 2015). But with the availability of drum-seeders
- and selective herbicide molecules, this method might emerge as the potential alternative to puddled transplanted rice (PTR) in double rice cropping lowlands and high rainfall areas in the future.
- (ii) *Dry direct-seeded rice (DSR)*: This is an ancient method of rice establishment in the hilly areas, especially in the western mid-hill districts of Gorkha, Lamjung, Tanahun, Parbat, Syangja, Palpa. It is known as *Ghaiya Dhan*, grown mostly in rainfed upland unbunded terraces with seeding in March–April. *Ghaiya* rice seeds are broadcast after 2–3 passes of dry tillage followed by hand weeding and 30–45-day old seedling transplanting in dry or moist (but unpuddled) soil. However, in recent years, due to labor shortage for manual seedling transplanting, intercultural operation and weeding, and due to labor becoming more expensive and lack of mechanization, the area under dry DSR (*Ghaiya Dhan*) is decreasing in hotspot hill districts.

However, with the development and import of 4-wheel tractor-drawn 9- and 11-rows seed-cum-fertilizer drills and 2-wheel tractor-drawn Chinese seed drills (with 4 and 6 row-seeders) for strip and full tillage, mechanized DSR is now taking momentum in the Terai region for the last few years. Using these seeders, rice seeds and fertilizer are drilled in line preferably in leveled

field with Laser Land Leveler after dry tillage. Marahatta (2017b) conducted three on-farm trials (farmer as replication) to compare DSR and PTR in rice and CA and CT in maize for two years (2011 and 2012) in Sunuwal, Nawalparasi district in western Terai. The detailed methodology of these experiments has been reported in Marahatta (2017b). These results showed no yield difference between DSR and PTR (Table 12.4, Fig. 12.2), but due to the lower cost of cultivation, DSR was found profitable (Fig. 12.2). These results are consistent with several other studies in Bangladesh, Nepal, and India (Gathala et al. 2013; Sharma et al. 2004; Singh et al. 2001; Tripathi et al. 2005; Timsina et al. 2010a). As Nepal Terai receives almost sufficient rainwater (>1300 mm) during rice planting season (June–October), even under rainfed conditions and without supplementary irrigation, the performance of DSR can be good and this technology is now being adopted by farmers in high rainfall areas (Devkota et al. 2019).

Further, we conducted a series of on-farm experiments with paired treatments comparing different types of DSR with PTR in six central and western Terai districts (Chitwan, Nawalparasi, Rupandehi, Bara, Parsa, and Bardiya) for five years during 2011–2015. In these experiments, conventionally tilled DSR (CT-DSR) and zero tilled DSR (ZT-DSR) each with and without residue retention were compared with PTR without residue retention (Table 12.4). The results showed a non-significant difference in mean yield between DSR and PTR, though significantly higher rice yield was obtained under CT-DSR and ZT-DSR with residue retention compared to PTR (Table 12.4). DSR without residue retention (under both CT and ZT) had a lower yield than PTR. PTR had low weed pressure and better crop establishment. Similar results for DSR and PTR were obtained in a study in the EIGP in northwest Bangladesh (Timsina et al. 2010a; Hossain et al. 2020). CT-DSR had a similar grain yield but high cultivation cost to ZT-DSR after 4 years of cropping. Similarly, Gathala et al. (2011) observed 9–10%

higher rice yield under ZT with residue mulch compared to CT or ZT without residue in northwest India. These results are due to better soil moisture (Singh et al. 2016) and higher nutrient availability (Yadvinder-Singh et al. 2004), and higher weed suppression through providing a physical barrier on the surface (Schuster et al. 2019). Incorporation of residues in these studies was, however, disadvantageous as it increased the short-term immobilization of inorganic N with plants showing N deficiency and resulting in lower yield under residue retention in CT-DSR. However, residue incorporation/retention exerts a beneficial effect as it increases soil organic carbon content and the immobilized N returns to the soil after residue decomposition. N rates need to be increased by 15% in the rice season under the R–W system to compensate the amount of N immobilized due to the incorporation of crop residues (Yadvinder-Singh et al. 2004).

The on-farm trials' paired comparison data (Fig. 12.2) showed that the optimal number of effective tillers ($\sim 200\text{--}300\text{ m}^{-2}$), increased number of grains panicle⁻¹, reduced sterility percentage, and improved harvest index are needed to obtain a high yield from DSR. Compared to PTR, a yield penalty of 17% was observed in ZT-DSR without residue, but DSR yield increased by 5% with residue retention. ZT-DSR with residue retention had a higher thousand-grain weight and lower grain sterility with a reduced yield penalty. Saharawat et al. (2010) also reported that the number of effective tillers was 9% higher in DSR compared to PTR. Too high ($>300\text{ tillers m}^{-2}$) in DSR was not required as it created competition among the tillers resulting in decreased yield.

12.3.2.2 Zero Tillage in Wheat

The yield and economics data for the same districts (as for DSR above) in Fig. 12.3a, b revealed no difference in yields of ZTW (with residue) and CTW (without residue). ZTW sown after rice matured earlier by 10–12 days. As wheat is timely planted after ZT, yield reduction due to terminal heat stress is avoided as is

Table 12.4 Comparison of yield between different types of DSR and PTR across large numbers of on-farm trials in six Terai districts in Nepal during 2011–2015

Establishment methods	Grain yield (t ha ⁻¹)	Establishment methods	Grain yield (t ha ⁻¹)	Establishment methods	Grain yield (t ha ⁻¹)	Establishment methods	Grain yield (t ha ⁻¹)	Establishment methods	Grain yield (t ha ⁻¹)
DSR#	4.14	CT-DSR	3.97	CT-DSR + R	4.18	ZT-DSR	3.77	ZT-DSR + R	4.32
PTR	4.24	PTR	4.16	PTR	4.50	PTR	4.52	PTR	4.10
Mean diff	-0.10	-	-0.18	-	-0.32	-	-0.75	-	0.22
No. of paired trials	150	-	38	-	32	-	16	-	64
SEm (±)	0.08	-	0.20	-	0.14	-	0.23	-	0.11
T-value	-1.26	-	-0.94	-	-2.23	-	-3.25	-	1.95
P at 0.05	ns	-	ns	-	*	-	**	-	*

Source Authors' work

includes all types of DSR; CT-DSR, conventional tillage-direct seeded rice; PTR, puddled transplanted rice; + R, with residue; ZT-DSR, zero tillage direct-seeded rice; Mean diff., mean difference; SEm (±), standard error of the mean of the mean difference series. Ns, non-significant; * significant at 0.05; ** significant at 0.01

common for late-sown wheat after CT. Residue retention improved wheat yield with all N application rates (Fig. 12.3b).

12.3.2.3 Zero Tillage in Maize

The yield and profit comparison of maize under ZT and CT for the same six Terai districts showed significantly higher yield with ZT (8%) than CT (Fig. 12.4), whereas the yield variation was observed across N rates, varieties, and residue management. The results from the omission trials in ZT wheat showed a high N rate (150–210 kg ha⁻¹) producing significantly higher yield (by 44% and 20%) than low (60 kg ha⁻¹) and medium N rates (120–135 kg ha⁻¹), respectively. In maize, compared to CT, 4% higher yield was observed under ZT with residue retention. The yield advantage of 11% was recorded for the improved variety under ZT as compared to that under CT whereas the yield advantage was 16% for hybrids.

Karki et al. (2014a, b), from an on-station experiment with the maize–wheat system at Rampur, Chitwan, reported that ZT maize without residue retention was counter-productive while with residue retention it had 6% higher yield than under CT without residue retention, indicating that ZT can replace CT. ZT maize saved labor and the production costs related to field preparation and crop establishment and increased profits compared to CT maize. Similar results for maize have been noted in northwest Bangladesh (Islam et al. 2019; Rashid et al. 2019).

12.3.2.4 Surface Seeding in Wheat

In this system, no land preparation is needed and the sprouted wheat seeds are broadcast onto the saturated soil either in standing rice crop either before or after harvest (Hobbs 2001). In Nepal, surface seeding of wheat, lentil, and *Lathyrus* is mostly used in areas where long-duration rice varieties are cultivated and difficult to timely drain out water from the field to allow timely field preparation and seeding. This system offers advantages in terms of timely sowing, reduced risk of bird attacks, and decrease production cost. Tripathi (2010) reported that the benefits of

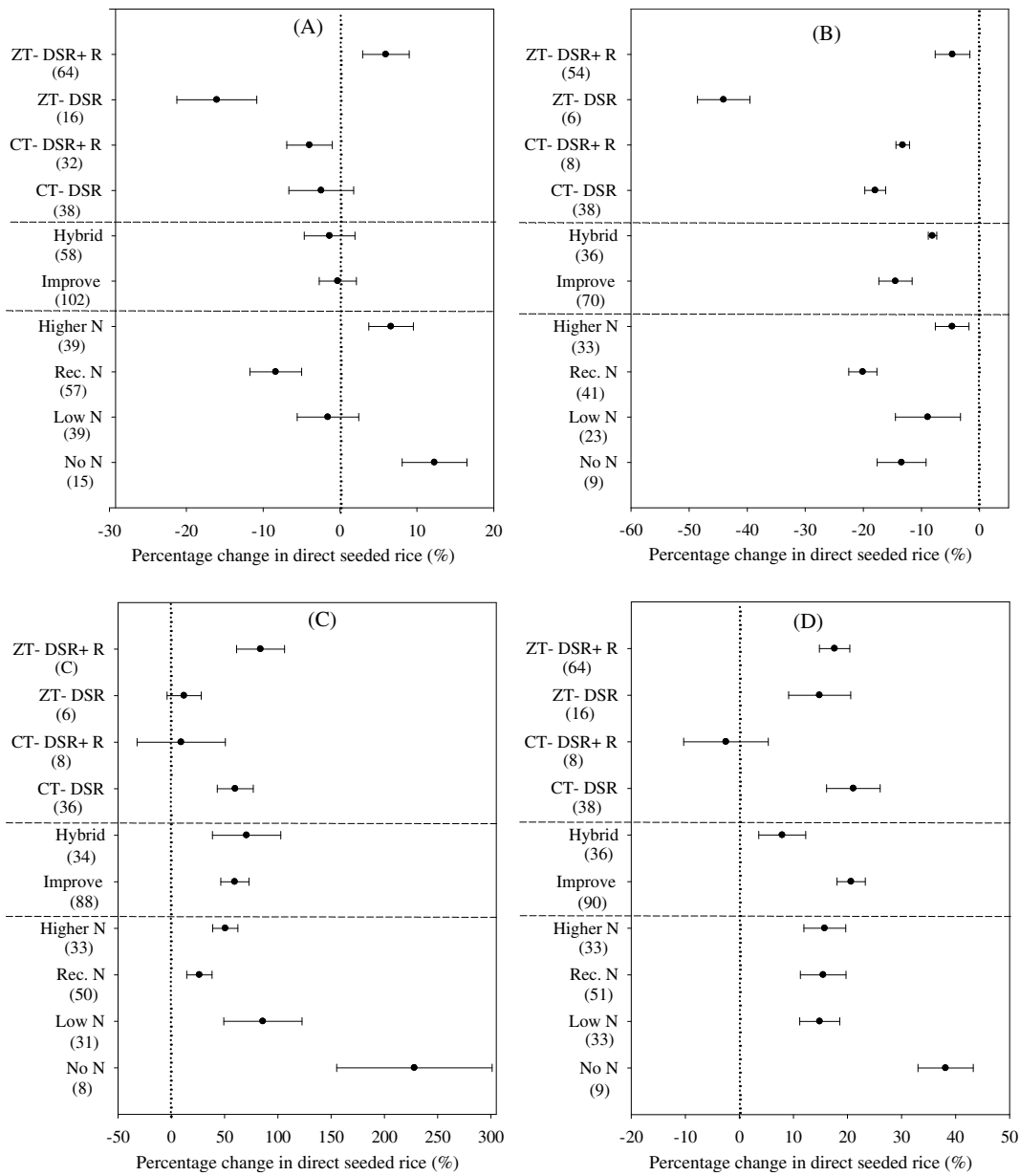


Fig. 12.2 Influence of different establishment methods and residues, varieties, and N input on the **a** yield change, **b** cost of cultivation, **c** net returns, and **d** B:C ratio of DSR

relative to PTR. The number of paired observations included in each dataset is presented in parenthesis. *Source* Authors' unpublished data

surface seeding of wheat are even more pronounced in terms of cost savings and returns compared to when it is sown under ZT or RT after draining the saturated soil. The saving in cultivation cost with surface seeding of wheat under ZT was more than 150% compared to CT.

12.3.2.5 Brown Manuring in DSR Field

Brown manuring is a technique of growing green manuring crops viz., *Sesbania* sp. or *Crotolaria juncea* @20–30 kg ha⁻¹ together as an inter- or mixed-crop when DSR is sown. Brown manure crop is killed at 30 days after rice seeding (before

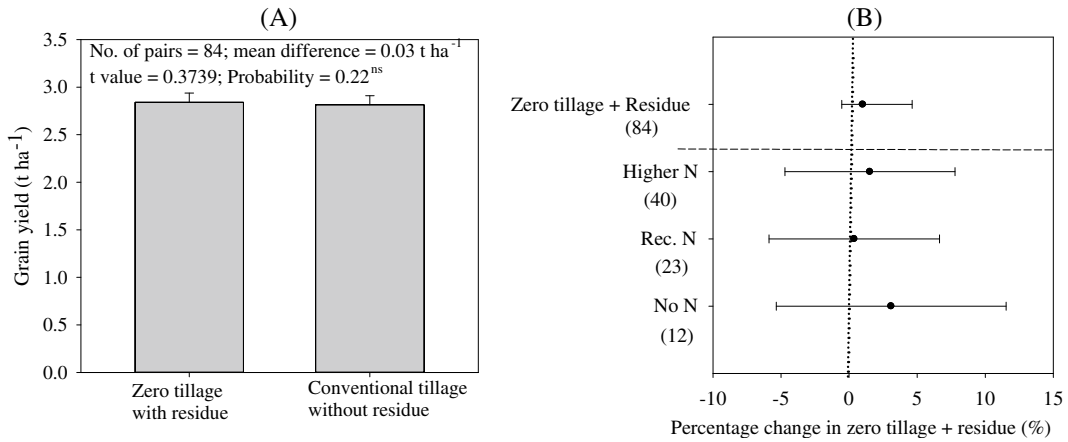


Fig. 12.3 Influence of ZT with residues and CT without residues on **a** grain yield of wheat and **b** grain yield of ZT wheat at varying N levels relative to CT wheat. The

number of paired observations included in each dataset is presented in parenthesis. *Source* Authors' unpublished data

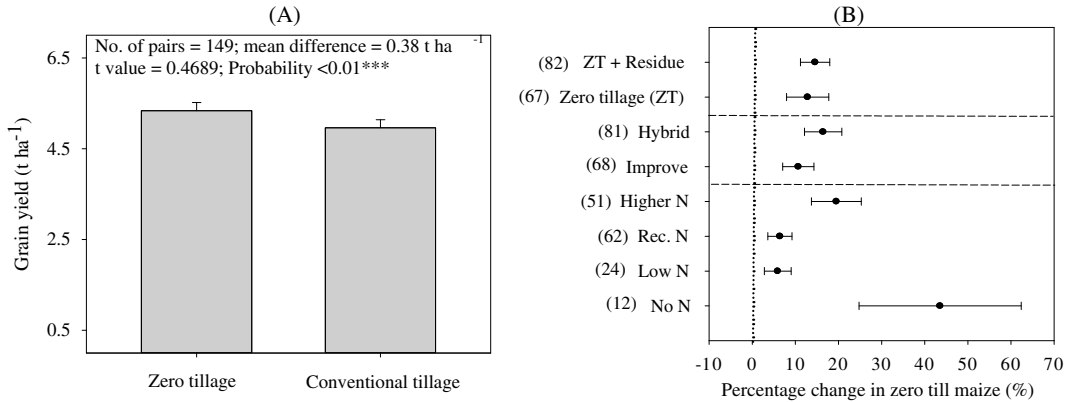


Fig. 12.4 Influence of ZT and CT on **a** grain yield of maize and **b** percentage change in grain yield of maize under ZT with or without residues, hybrid and improved varieties, and N levels relative to that in CT without

residue. The number of paired observations included in each dataset is presented in parenthesis. *Source* Authors' unpublished data

mid-tillering stage) through the application of selective post-emergence herbicides for enriching the soil organic matter. Co-cultured *Sesbania* or *Crotalaria* sp. is knocked down and allowed to kill by spraying 2,4-D ethyl ester @0.5 kg a.i. ha⁻¹ (Gaire et al. 2019). The dead leaves of green manure crops fall on the soil and decompose fast to supply N. This practice allows the green manure crops to decompose in the soil surface which minimizes weed pressure and increases soil fertility leading to an increase in DSR yield (CSISA 2020).

12.3.2.6 Inclusion of Mung Bean in Rice–wheat and Rice–maize Systems

R–W and R–M are the dominant cropping systems in Terai and lower elevation areas in mid-hills (Timsina and Connor 2001; Timsina et al. 2010b). Intensifying R–W or R–M systems with mung bean (during the fallow season) can increase yield and income from mung bean as well as from the annual cropping system. The inclusion of mung bean optimized the cropping system by reducing production costs, increasing

income, and improving soil properties in Nepal (CSISA 2019, 2020). A study on the rice–maize–mung bean system in Bangladesh also showed that though there was no significant yield advantage from CA (permanent or fresh beds, strip tillage, and zero tillage with residue retention) in mung bean, there was a reduction in production cost and increase in farmer’s income. There was however increase in total system productivity, decrease in total production cost, and increase in income from the cropping system (Rashid et al. 2019). Another study across eight districts in the EIGP, including two districts from Nepal Terai, also showed the benefits of including mung bean in the R–W or R–M systems in terms of increasing systems productivity, profitability, and water productivity (Islam et al. 2019; Dixon et al. 2020). These findings from the EIGP demonstrate the potential of mung bean in R–W and R–M systems for sustainable intensification.

12.3.2.7 Scaling-Out of Appropriate Machinery for Enhancing Mechanization

The increasing adoption of small-scale mechanization in Nepal is associated with an acute labor shortage due to out-migration. The use of small-scale mechanization (“mini-tillers”; 6–8 hp with 90–130 kg weight) for rice cultivation in mid-hills increased rice yield by 1.1 t ha⁻¹ (Paudel et al. 2019a, b). Mini-tillers are replacing traditional bullock-driven agriculture, especially in the hilly region. These tillers can be used for row-cropped weeding in maize and sugarcane, for pumping water from groundwater, and for connecting reapers for rice and wheat harvesting (CSISA 2020; Brown et al. 2021).

Another small-holder farmer-friendly successful tool is “Seed and Fertilizer Spreader” (Brown et al. 2021). Park et al. (2018) analyzed the benefits of such a low-cost chest-mounted spreader as a small-holder mechanization option for wheat in Nepal. Using the spreader for spreading seed and fertilizer increased crop stand uniformity, yield stability, labor efficiency (by 52%), and profitability compared with the hand broadcast application of fertilizers (CSISA 2019,

2020). Another scale-appropriate machinery for all sizes of farmers is “laser land leveling” (LLL), which is getting momentum in South Asia. Despite its numerous benefits, its adoption, however, is taking place at a slower rate than anticipated. In the northwest IGP, however, the adoption intensity of LLL was more likely to be higher among large farmers though there was a negative association between land holdings and the proportion of laser-leveled lands (Aryal et al. 2018).

Mechanical harvesting by 2-wheel tractor (15–22 hp) operated and self-propelled “reaper” is highly flourishing in Nepal’s R–W systems (Brown et al. 2021). For farmers living in the flat areas in hilly regions (where 2-WT can work) and those with the fragmented lands in Terai (where combines are not operational) who keep rice and wheat straw to feed livestock, it is possible to harvest rice using a reaper. Until September 2020, an estimated number of more than 4100 reapers have been sold by the machinery importers in Nepal which are estimated to cover around 17,000 ha of rice and wheat (CSISA 2020). With rotavators, farmers lose about 284–309 kg of wheat and US\$ 93–101 of profit ha⁻¹ season⁻¹ despite US\$ 11–15 ha⁻¹ cost savings for land preparation. Wheat yield reduction in rotovator used field was due to soil pulverization, which caused water stagnation during irrigation, soil structural damage, and hardpan formation at 15–20 cm soil depth which impaired wheat root growth. So, new policy and extension efforts are required that discourage rotavator use and favor more sustainable tillage practices (Paudel et al. 2020b).

12.4 Multi-Criteria Assessment of CA/RCTs

Multi-criteria assessments of CA become useful to understand and analyze the tradeoffs among input use, yield, profits, and environmental consequences of the technologies and provide a sound basis for food security assessments and planning. Such assessments for CA/RCTs have been conducted in the EIGP but are lacking in

Nepal. Here we present such assessments from two initial studies from Nepal: one comparing DSR and PTR in the western Terai and another comparing four alternative tillage and crop establishment practices for a R–W system in the eastern Terai.

12.4.1 Trade-Offs Among Inputs Use, Yield, and Net Profit in DSR and PTR

A trade-off analysis was conducted using data from on-farm trials mentioned above in Nawalparasi in the western Terai (Marahatta 2017b). Due to the high seed cost of hybrid compared to the improved DSR variety, the latter was slightly better in terms of profitability. The percent benefit with N omission compared to N application was also higher for DSR than PTR; however, the gross and net returns in DSR were 22 and 43% higher for N application compared to N omission (Fig. 12.5). Despite the yield loss under DSR, the cost of cultivation was drastically reduced, and more profit was obtained (Fig. 12.2). PTR had the lowest B:C ratio. Though the highest yield

loss occurred for ZT-DSR without residue retention, the highest reduction in cultivation cost made net profit and B:C ratio from it comparable with CT-DSR with residue retention. ZT-DSR with residue retention compensated the cost of the residue by yield improvement and was best in terms of profits.

12.4.2 Trade-Offs Among Yield, Inputs Use, Energy-Use Efficiency, Water Productivity and Global Warming Potential in R–W Systems

A series of on-farm trials, conducted across three CASI and one CT treatments in the R–W systems in Dhanusha (rainfed) and Sunsari (irrigated) districts during 2014–2017, compared grain yield, inputs use (labor, N, P, and K fertilizers, irrigation, herbicide, etc.), energy-use efficiency (EUE), and total global warming potential (TGWP) (Magar et al. 2022a, b). For both crops and locations, there was a significant trade-off among yield, energy inputs and EUE, and TGWP

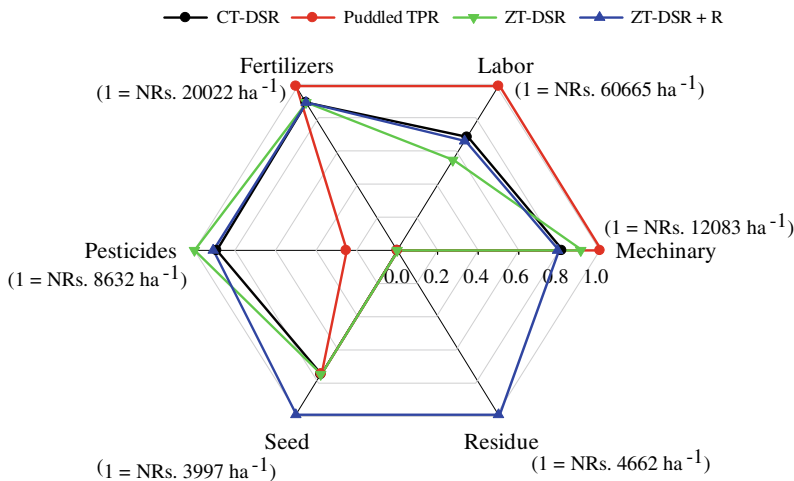


Fig. 12.5 Cost (NRs ha⁻¹) of different input categories for different rice establishment methods (Variable means are normalized on a 0–1 scale, with 1 representing the highest absolute value of that variable. The highest absolute value is also shown for each parameter. The cost

is estimated for the year 2018/19, based on the consumer price index and services (Exchange rate NRs to USD = 105). Source Calculated and drawn from Marahatta (2017b)

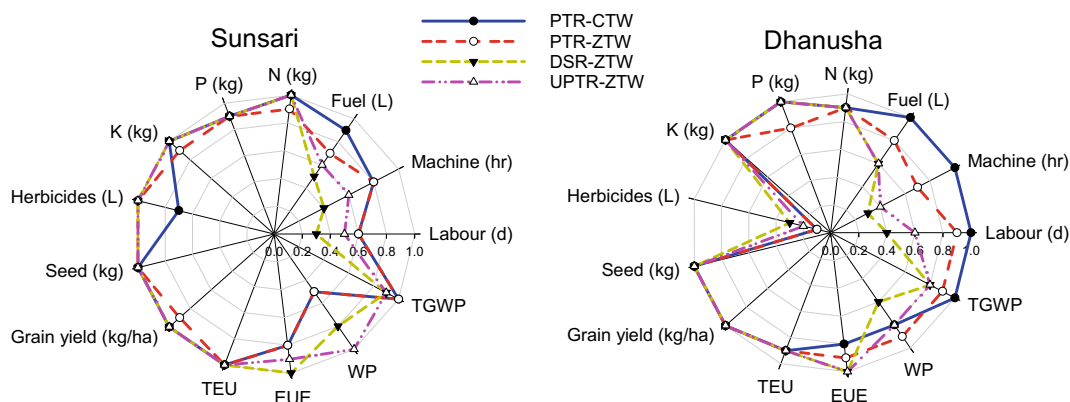


Fig. 12.6 Trade-offs among different inputs use, grain yield, total energy use (TEU), energy use efficiency (EUE), water productivity (WP), and total global warming potential (TGWP) in CT compared with three CASI practices in R–W system in Sunsari (irrigated) and Dhanusha (rainfed) districts. N = Nitrogen; P = Phosphorus; K = Potassium;

PTR-CTW = puddled transplanted rice fb. conventional tillage wheat; PTR-ZTW = puddled transplanted rice fb. zero tillage wheat; DSR-ZTW = dry-direct seeded rice fb. zero tillage wheat; UPTR-ZTW = Unpuddled transplanted rice fb. zero tillage wheat. (Adapted from Magar et al. 2022b)

(Fig. 12.6). In both crops, the conventional method (PTR-CTW) recorded the highest energy use in labor, machinery, and fuel leading to the highest TGWP. Despite the higher amount of herbicide used in DSR-ZTW (a CASI treatment), the TGWP was low indicating the trade-off due to low energy use through other inputs. In the R–W system under irrigation, machinery, and fuel were contributing to the highest TGWP, while under rainfed, the highest energy input in labor, machinery and fuel in PTR-CTW contributed to the highest TGWP and the lowest energy use in the alternative CASI practices contributed to the lowest TGWP.

12.5 SWOT Analysis of CA/RCT-Based Technologies

Strengths, weaknesses, opportunities, and threats of the CA and RCT's were analyzed in 2020 involving multiple stakeholders after field visits of the on-farm experimentations in Terai regions of Nepal after reviewing the various research findings on CA in Nepal and the EIGP. The major SWOT of CA and RCTs is summarized in Box 12.1. There are several strengths and opportunities of the CA and RCTs despite some weaknesses and threats.

12.6 Constraints and Challenges for Adoption of CA/RCTs in Nepal

Despite numerous advantages in terms of economics, environment, human health, resilience to climate change, and soil health, CA is still one of the least adopted technologies by farmers in Nepal. Adoption of at least one of the three CA principles accounts for about 4.1% of the total cropland in Asia, 1.5 million ha in India (Kassam et al. 2019), and a few thousand ha in Nepal (exact data not available) as CA currently has several adoption barriers (Magar et al. 2022a, b). Appropriate machineries can facilitate the adoption of zero or minimum tillage and residue retention. Brown et al. (2021) studied the binary rates of adoption of nine type of machines (including those used for zero or minimum tillage) across Nepal Terai and found adoption rate varying from 0.9% (laser land leveler) to 30.7% (4-WT seed drill), with 1.8% for 2-WT seed drill. Of these, 4-WT seed drill and 2-WT seed drill are used for zero or minimum tillage. Devkota et al. (2019) stressed that coordinated efforts among government, private sector, and research and extension organizations are required to overcome the bottlenecks for the adoption of CA and

Box 12.1 SWOT analysis to identify opportunities and adoption barrier of CA and RCTs in Nepal

Strengths (S)	Weaknesses (W)
• Evidence-based scientific knowledge generated to solve the multiple complex problems • Availability of RCT-based farm machinery (LLL, ZT seed and fertilizer drills, bailing machines) • Availability of herbicides and weed control tools • International collaborations (CG centers CASI Platform, CSISA, etc.) • Curriculum on CA and RCTs in academic institutions • Critical manpower for CA& RCTs R&D • Creation of some production hotspots for RCTs (e.g., DSR in Chitwan, Rupandehi/Nawalparasi, Bardiya/Kalilali) spontaneously after project interventions	• The intensive tillage-based mindset among the farmers, agricultural technicians, and policymakers • No data on the actual area under various CA and RCT-based practices and responsible agency to estimate them • Knowledge gap among the stakeholders • Inadequate scale-neutral equipment and machinery • Inadequate knowledge-intensive Ca and RCT-based package of practices • Weed infestation in DSR and ZT and herbicide resistance • Changes in pest dynamics • Government policies not favorable for CA or RCTs • Land fragmentation and problem for land consolidation and commercialization • Poor market and storage infrastructures • Inadequate research thrusts on CA or RCTs in research institutions • Extensive areas under sloping hill agriculture with poor accessibility • The existing unfair custom duty tax provision for CA and RCT-based machinery spare parts
Opportunities (O)	Threats (T)
• Nepal has now three levels of government (Federal, Provincial and Local); the Federal government develops the policy, provincial governments monitor, and the local governments plan and execute as per their own needs • People are accepting that residue burning and repeated tillage are harmful to the farm, community and regional level • CA and RCTs-based farm-machineries are now being available in the Nepalese markets • Academic courses on CA and RCTs in graduate and post-graduate programs of AFU, TU and FWU in Nepal started since 2012 • International collaborations (CG centers CASI Platform, CSISA, etc.) • Curriculum on RCTs in academic institutions • Critical manpower for CA& RCTs R&D • Creation of some production hotspots for RCTs (e.g., DSR in Chitwan, Rupandehi/Nawalparasi, Bardiya/Kalilali) spontaneously after project interventions	• Adopting CA or RCTs may, in the short term, involve costs and risks. Switching to CA or RCTs quickly may appear too risky • Crop might fail to produce the yield at par with conventional agriculture in initial years/seasons • Many non-conventional biotic factors like soil-borne pathogens might emerge due to infected stubbles kept as residue • Weather and climatic conditions and heavy flooding after rainfall might not be favorable for DSR

Source (Authors' own work)

RCTs. From the stakeholders' perception analysis conducted with the multi-stakeholders (same for SWOT analysis), we found the following major issues that are limiting the adoption (adoption barrier) of CA and RCTs in the cereal-based cropping systems of Nepal.

12.6.1 Complexity of the Farming Systems

Complexity within the farming systems like the fragmentation of agricultural lands poses a serious problem for the adoption of CA- or

RCT-based machinery. Likewise, landscape-driven irregular bunding of the field plots is also a hindrance in operationalizing the CA or RCTs. Lack of crop residue, lack of biomass valorization technologies, and competing use of residues for crop and livestock are other challenges in adoption of ZT with residue retention.

12.6.2 Unavailability of Right Machinery and Other Inputs

As stated by Brown et al. (2021), though recently there is some level of adoption of CA-friendly machineries, both machinery production and supply value chains are at the incipient stage in Nepal. Currently, it is almost fully import-based, and manufacturing, repair, and after-sales services are not well established. The availability of appropriate machinery has also been handicapped by limited resources among domestic manufacturers in both public and private sectors.

12.6.3 Inaccessibility of Financial Credits

The poor economic status of farmers results in low investment capacity for the adoption of new technologies. The agricultural credit facility is much less than required. The ever-changing interest rates together with complex rules and regulations of financial institutions make farmers hesitate to take loans to purchase the inputs such as machinery and herbicides required for the practice of CA or RCTs.

12.6.4 Disrupted Agricultural Extension Systems and Technical Knowledge of the Citizens

Extension systems in Nepal have not been regularly promoting CT practices although the benefits and suitability of CA or RCTs are well

known to most agriculture extensionists. Also, there is a huge gap in implementing need-based technology interventions in the current extension systems as a proper linkage among three levels of government has not been well established yet (Dahal et al. 2020). Further, the technical knowledge of such “Citizen Science” is low in the ground-level extensionists, development workers, other stakeholders, and the citizens.

12.7 Policy Issues and Implications

Nepal has produced a series of policy documents in recent decades broadly for agriculture modernization and commercialization. The third objective of the Agriculture Mechanization Promotion Policy 2014 (MoALMC 2018) vows to promote the RCTs. Also, National Climate Change Policy (2019) has prioritized the adoption of low carbon-emitting and energy-efficient technologies and crop diversification options but has not specified RCTs or CA. Following policy initiatives are suggested that provide insights into policy issues for promoting CA or RCTs in Nepal which can also have relevance to other countries in South Asia and particularly in the EIGP.

12.7.1 Priorities of Support Initiatives

Separate policy documents or guidelines should be formulated by the Directorate of Agriculture and institutionalize CA and RCTs in the government’s regular activities and ongoing and upcoming projects and programs. The priority for agricultural mechanization technologies for Nepal has advocated addressing labor shortage and drudgery reduction (Biggs and Justice 2015). These include scale-appropriate harvesting machinery such as reapers, mini-combine harvesters, threshers, and seeding and crop establishment machineries such as seed drills for RT, ZT and DSR, and rice transplanters under puddled and unpuddled conditions.

12.7.2 Strengthening Machinery Value Chain

Access to information, availability of machinery technologies and skills development for their use at the local level, and assurance of finance are the keys to strengthen the machinery value chain among the citizens are required. CA or RCTs need the approaches of “Citizen Science” for greater impact. Takeshima (2017) highlighted the need for policy-related research in mitigating the accessibility of tractor custom hiring services and identifying appropriate regulatory policies for mechanization. Assuming machinery availability as a major bottleneck for the adoption of DSR or ZT, a study suggested that the availability of custom hiring centers and service providers for the communities at the local level could potentially increase the service provisioning of seed drills for DSR and ZT in wheat or maize (CSISA 2020). Paudel et al. (2019b) suggested developing targeted cost-sharing programs and bolstering machinery service provisioning to reach multiple farms thereby increasing mini-tiller adoption considering the lower willingness to pay at present. Another area of potential policy intervention is ensuring spare parts availability of RCT-based machines by lowering custom duties and facilitating in-country production.

12.7.3 Gender Dimension

Female-headed households are reported to have a lower probability of mini-tiller adoption in the mid-hills of Nepal with a larger gap in food-insecure households (Paudel et al. 2020c). This indicates that the agricultural extension department of the government needs to prioritize female-targeted and food-insecure households inclined mechanization policies to reduce the adoption gap of mini-tillers and other RCT-based machines. Concrete policies and action plans are to be formulated for equitable access to agriculture machinery for both men and women (Silwal and Khanal 2021).

12.7.4 Scaling-Up of CA/RCTs

Resource conserving technologies like DSR, ZT or RT, and mechanization technologies are complex systems compared to CT practices like manual transplanting of rice seedlings and broadcasting seeds of wheat, maize, and other crops. A potential idea to scale-up those technologies could be developed through social networking and the establishment of for example, “Farmers Platform” so that they can act as influencers (Skaalsveen et al. 2020; Snow et al. 2021). In the context of less efficient machinery service business, it is mandatory to expand the network of “seed drill service providers” as most capital-constrained small and medium farmers cannot purchase seed drills for their own use (Keil et al. 2016, 2019). Hence, scaling up initiatives for CA or RCTs needs to strengthen the service provision model (Kafle and Paudel 2018; Keil et al. 2017; Taylor et al. 2011). Additional approaches or ideas to augment scaling initiatives strategically are establishing innovation platforms for selected technologies, utilizing location intelligence, and grabbing the benefits of remotely sensed images for preparing spatial suitability maps of CA or RCTs. The government programs like Prime Minister Agriculture Modernization Project (PMAMP) and Smart Krishi Village should embrace these approaches in their plans to scale out CA or RCTs aiming at increasing production sustainably.

12.8 Conclusions and Recommendations

Even though CA and RCTs have been moderately to fully mainstreamed in other South Asian countries, they have not been mainstreamed in the national agricultural research system of Nepal. The major reasons for that are knowledge gaps among researchers, extension workers, and farmers, inadequate farm machinery and tools, trade-offs in using crop residue for soil fertility improvement and animal feed, prevalence of smallholder farmers lacking finances to purchase

machinery, poor rural infrastructures, and inadequate policy support. The undulating and sloping lands with narrow terraces further restrict the use of farm machinery in the hills and mountains of Nepal. This chapter suggests that there is an urgent need to test, verify, and scale-out various CA and RCTs across the mid-hills and Terai regions of Nepal to increase productivity, profitability, and sustainability cropping systems and to achieve food and nutrition security in the country. To meet this goal, the following key recommendations are suggested. Those recommendations can also be applied to other countries in South Asia, particularly in the EIGPs.

1. To achieve SDGs 1 (No poverty) and 2 (Zero hunger), CA needs to be mainstreamed in different departments under the agriculture ministry's planning and implementation activities.
2. To achieve SDG 13 (climate action), climate change mitigation and adaptation technologies like DSR and ZT are to be mainstreamed in the climate change-related policies, planning, and management mechanisms.
3. To achieve SDG 5 (gender equality), women-friendly technologies should be promoted in smallholder farming communities as women are increasingly involved in managing household activities in addition to farming activities due to male outmigration. Future plans and policies should be oriented toward empowering farm women by designing gender-friendly programs and activities aiming at reducing the gender gap.
4. RCTs heavily rely on mechanization. The country should have short-, medium- and long-term plans to promote and strengthen the machinery value chain along with the proper supply of other agricultural inputs like seeds and fertilizers. A concrete plan to initiate/establish machinery production units/industries in Nepal should be devised and implemented. To know the key drivers of success and adoption of machinery at both individual farmer and community levels through custom hiring-based service providers, a detailed research study utilizing both quantitative and qualitative approaches needs to be carried out.
5. The federal and provincial line ministries and associated research and extension bodies should develop a joint plan of action to scale-out the CA and RCTs making the local government a prime implementer of the plan. Regular brainstorming workshops among multiple stakeholders including GOs, NGOs, private sectors, and experienced international experts are required to get feedback on the ongoing and past activities on CA and RCTs.

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Urban Agriculture as a Wellbeing Approach and Policy Agenda for Nepal

13

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Abstract

Urban Agriculture (UA)—a system of growing foods within and around the city areas using available non-commercial, commercial, and hybrid technologies—is an emerging approach in the recent development of agriculture and food systems. UA has substantial

social, economic, and environmental wellbeing outcomes with broader policy implications for sustainable urban development, which is confronted with the challenge of feeding the rapidly growing urban population in developing countries. Given its potential benefits, this chapter investigates how can this be realized in Nepal's context for the welfare of society and sustainable development. It particularly focusses on the policy agenda that is required for this realization. Rapid rural–urban migration and increased trends of urbanization have made UA an essential approach to meet the growing demand of healthy, diversified, fresh and quality food. It uses multidimensional and multifunctional approaches to farming through the fusion of traditional and modern technologies. For the realization of its benefits, it is important to investigate the wellbeing dimensions of UA and how these dimensions are related to achieving sustainable development goals by making cities and communities sustainable, minimizing hunger, and adapting to climate change. This chapter concludes that the selection of proper indicators, formulation of robust policy and program, development of institutional and human resources, and coordination among multiple jurisdiction should be the major actions for optimum wellbeing from UA practices in Nepal, which we believe could also apply to other developing countries with similar context.

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Keywords

Economic · Environmental · Framework · Social · Wellbeing indicators

13.1 Introduction

Urban agriculture (UA) is one of the major components of a sustainable city for feeding people and making city attractive through urban farms and gardens (Mason and Knowd 2010). UA, a system of food production within or nearby city is a multidimensional and multifunctional concept that deals with the issues of food security, livelihood, social cohesion, leisure, environmental stewardship, and sense of belonging (Rogus and Dmitri 2015; Rich et al. 2018; Van Tuijl et al. 2018). There is no universal and unique definition of UA. However, UA is perhaps most simply defined as food production activities in homes or plots within urban or peri-urban areas (Orsini et al. 2013). The major intention of UA is to feed urban residents with diverse, safe, and quality food at reduced distance and cost, and with minimal use of external resources and production inputs. UA is a practice of growing and distributing food in and around cities that benefits people in various ways, directly or indirectly (McDougall et al. 2018). Factors like rapid urbanization, concerns around climate change impact of conventional agriculture system and food insecurity, the need for healthy and diversified foods, and innovative lifestyle have encouraged growing foods in or near cities in the form of urban farming (Martellozzo et al. 2014; Tornaghi 2014).

The concept of UA was introduced in the early nineteenth century in response to food insecurity and poverty within countries such as Germany and the United States of America when they were impacted by war or economic depression. According to Clinton et al. (2018), proper implementation of UA at a global scale can save up to USD 100 billion per year through food production, nitrogen fixation, energy savings on inputs use, pollination, climate

regulation, soil formation, and biological control practices. Due to UA's multiple economic, social, and environmental wellbeing services, it is getting attention worldwide. UA's economic, social, and environmental wellbeing dimensions have been studied in isolation, and a multifunctional and dynamic research approach is needed to integrate those dimensions into a single domain to support sound policy formulation for sustainable UA practices in cities. Available or underutilized urban spaces can improve cities' food and nutrition security and enhance economic activities across the agricultural food supply chain.

The objective of this paper is to explore the economic, social, and environmental dimensions of UA that relate to the United Nations Sustainable Development Goal (SDG)-2 by identifying appropriate policy, program, and indicators in the context of Nepal. The information presented in this chapter is collected through a review of published papers, government and non-government reports, and interactions with different stakeholders that are undertaking functions of promoting UA in Nepal. Urban agricultural activities aid in achieving SDG Goal 2 with a particular focus on ending hunger, promoting food and nutritional security, and developing sustainable agriculture (Monica and Gupta 2018). Food and nutritional security is the key concern in the urban areas of Nepal, and this chapter aids in developing better policy options for promoting UA as a tool for food security and wellbeing.

13.2 The Emergence of Urban Agriculture

Globally, UA has evolved in response to several drivers including, war (Zilans et al. 2016) or poor economic conditions and growing environmental concerns in urban areas (Kemp 1977). Increasing food prices, environmental concerns, and a growing interest in achieving self-sufficiency during the 1960s and 1970s were recent factors for driving growth in UA (Gaynor 2006). After the 1980s, developed countries like Australia,

New Zealand, the USA, the UK, Canada, and European countries like France, the Netherlands, and Germany promoted UA for social and mental wellbeing rather than food production (Petts 2005). In a developing country like Cuba, UA was a major source of livelihood (Nugent 2000) and now Cuba is progressing in agriculture through the implementation of sustainable UA practices. The contribution of UA toward food security, urban resilience, resource conservation, and transformation of the urban landscape into farms requires plans (Deelstra and Girardet 2000). The success of UA depends on how planning is done and implemented through coordinated efforts based on the types of farming and functions provided.

13.3 Types of Urban Agriculture and Variations

There are variations in UA practices across the world. The major UA sites are home gardens, community gardens, vacant lots (allotments), school gardens, balconies, and rooftop gardens, all of which vary in size. The choice of production methods depends on community conditions and their preference (Grewal and Grewal 2012). The urban farms are micro-farms, kitchen gardens, community gardens, and street gardens (Adams et al. 2014). A typical characteristic of UA is the combination of small and dispersed units creating a supply system that is within the proximity of consumption (Dieleman 2017). It involves both productions for self-consumption and sale with integration of urban economic, social, and ecological systems (Mougeot 2000). UA practices in the city areas mainly consist of community gardens, existing professional farms, innovative indoor farming, rooftop farming, and community-supported agriculture (Prove et al. 2018). Regulatory mechanisms shaping the production, processing, and distribution functions are important policy components of UA (Bailey and Nasr 2000).

Variation in UA as reported by Hodgson et al. (2011) is presented in Table 13.1. Eight non-commercial, four commercial, and one hybrid-

purpose urban farm and gardens are common in different parts of the world. The choice of UA is governed by the purpose of establishing urban farms and gardens and is mainly driven by economic, social, and environmental motives.

Table 13.1 underlines the variation of UA based on the intended purposes, with commercial, non-commercial, and a combination of both, and the food supply chain and ecosystem benefits of UA that vary with the types of practices followed. It nevertheless establishes that UA is multidimensional and multi-beneficial in nature. While further research on the intersection of urban food production and large material and energy regimes (metabolism) is recommended (Goldstein et al. 2016), there is growing body of studies that confirm that growing urbanization is accelerating the implementation of UA in the world. It is seen that, by 2050, the global population will be 34% higher than the present and this growth will concentrate in developing countries, where 70% of people will be living in urban areas. Accordingly, for a need to produce 70% more food by 2050 (Msangi and Rosegrant 2009), UA is increasingly adopted as a complementary approach to other traditional approaches that are aimed at feeding the rapidly growing population and providing recreation services to urban dwellers.

13.4 Benefits and Challenges of Urban Agriculture

Urban Agriculture has several forms that contribute more to food security and environmental and health values than commercial agriculture (Nicholls et al. 2020). Biodiversity restoration, improvement in air quality, and noise reduction are major ecological benefits of UA. Economic development and tourism promotion are its major economic benefits, while physical, health, and aesthetic values are its major social benefits (Ghaleh 2019).

The other benefits of UA are the availability of fresh and quality food, diet improvement, personal satisfaction and enjoyment, money-saving, socialization, exchange of help, self-

Table 13.1 Urban agriculture types and features (Adapted from Hodgson et al. 2011)

Types of urban agriculture/farming practices	Major features
<i>Non-commercial</i>	
Private garden	Food production in front or backyard garden area, including the use of roofs, balconies, fences, walls, basements; typically for self-consumption
Community garden	Small to medium scale, which includes foods and ornamental plants for public or private use and managed by a group of users/members. Products are typically for consumption, education, or sale
Institutional garden	Small to large garden or orchards, often in public or private institutional ownership; typically for educational, therapeutic, or other community service provision. End products are for consumption by a grower, donation to a community, or maybe sold
Demonstration garden	Small gardens on private or public properties, for demonstration only; products are typically donated
Edible landscape	Owned by individual or business and intended for consumption
Guerrilla garden	Food or ornamentals on vacant land are tended by an individual or group. Intended for improving the quality of life in the neighborhood
Hobby beekeeping	Small-scale beekeeping for personal consumption, education, or donation
Hobby chicken keeping	Small-scale production for personal use, sale, or both; undertaken in a residential or public area
<i>Commercial</i>	
Market farm	Small to medium-scale fish, poultry, and small livestock integration with crops with soil-based or soilless techniques
Commercial urban farm	Commercial production of food ornamentals, bee, fish, small to medium animals under horizontal or vertical space using soil-based or soilless systems
Peri-urban farm	Large-scale production of food ornamentals, bees, fish, and other small to medium animals using soil-based or soilless media near the city area or within fringe
Beekeeping	Medium to large-scale commercial production using UA, non-agriculture, and unutilized area
<i>Hybrid</i>	
Hybrid UA	Combination of farms and gardens for personal consumption, education, or donation. Integration of livestock, crops, ornamental, fish, and poultry within the farm is a major feature

sufficiency, and improved neighborhood (Patel 1991). Community gardening can reduce food insecurity, improve dietary intake, and strengthen the family relationship (Carney et al. 2012). Further, UA indirectly benefits communities by providing spaces for civic engagement, cleanses the environment, and improves public health and habitats for pollinators (Nogeire-McRae et al. 2018). UA helps address global warming and fosters sustainability through creating new commons, ecosystem services, reinventing urbanity, and community development through growing

local foods (Mancebo 2018). UA can contribute to the social, economic, and environmental objective of sustainable urban development and increases the efficiency of the national food system (FAO 2007).

Though some benefits of UA for food security, health, and income have been documented in developing countries (Taylor and Lovell 2014), further research is needed on maximizing positive impacts and minimizing negative impacts from it (Nogeire-McRae et al. 2018). However, the capability to increase the

sustainability of urban food systems is contextual and is based on the UA production method, products, and location (Goldstein et al. 2016).

There is much research indicating that UA helps in sustainable urban development, but we have to consider the major economic, spatial, functional, organizational, and institutional challenges like cost, legal issues, space, conflict with other urban functions, and potential health risk of urban foods (Van Tuijl et al. 2018). This suggests that it is a balancing act to address the challenges and major issues while considering the benefits of UA. It is likely that in most cases, there is a trade-off between the economic, social, and environmental indicators. If policy makers and other stakeholders try to increase outcomes from one parameter, it may reduce outcomes from other and vice versa. Thus, balancing the economic, social, and environmental indicators for maximizing benefits through UA is considered as a way forward.

13.5 Wellbeing from Urban Agriculture

Due to the increase in UA initiatives in recent years, the understanding of UA for food security has shifted more toward social, environmental, and economic goals of sustainable urban development (Partalidou and Anthopoulou 2017), creating wider scope for economic, social, and environmental wellbeing research. Human wellbeing is composed of basic needs, economic and environmental needs, and happiness that are like Maslow's pyramid of hierarchy of needs (Summers et al. 2012). The idea of subjective wellbeing in national accounts was first proposed by Diener et al. (2008). Economic indicators have an enormous impact on policy decisions, but they fail to reflect core elements in the quality of life (Diener and Seligman 2018). Societies need to access wellbeing in addition to standard indicators for guiding policy decisions (Diener and Seligman 2018). The main aim of a wellbeing economy is to deliver an equitable distribution of wealth, health, and wellbeing, protecting

resources for the future generation and species (Hough-stewart et al. 2019).

The UA's wellbeing responses are person-centered, geared toward environmental protection and regeneration, positive and long term. The wellbeing aspect of the food system is defined as production within a season, locally grown, a regenerative fair share of resources, and commonality of plant-based diets in production and consumption. Wellbeing depends on social relationships and the environmental balance (Fioramonti 2016). Fioramonti (2016) reported that the wellbeing economy takes a holistic approach and has positive and negative impacts on economic activity. It searches for the linkage of the economy with nature as an interdependent and integrated system (Costanza et al. 2018). Generally, there are different aspects and approaches to measuring wellbeing. In agriculture, poor financial performance can indicate poor wellbeing (Peel et al. 2016).

In addition to direct food production, UA plays ecological and cultural functions that compete with other land uses in the city (Lovell 2010). Engagement in home and community gardening may provide a supportive role for the health and wellbeing of practitioners (Pollard et al. 2018). Exposure to nature through different urban farming promotes health and well-being, the poorest and vulnerable groups' exposure to nature, and offers the low-cost opportunity to promote wellbeing at minimum cost (Capaldi et al. 2015). The experience of working in UA is quantified by commodity production in a capitalistic economy and ultimately turned this practice into a chance of accumulating non-financial capital (Mincyte and Dobernig 2016).

Thus, UA's overall aim is to promote wellbeing through economic, social, and environmental services to people. We should, therefore, analyze UA as a holistic approach rather than financial dimensions of sustainability, which cannot justify UA as it has a low level of realized direct financial benefit. For example, using prime city land for non-agricultural purposes (industrial, commercial, or residential buildings) may get a higher economic return than UA growing

vegetables or flowers. Instead, UA has other social and environmental benefits for the mental, physical, and social wellbeing of urban dwellers.

Understanding of multifunctionality of UA will help develop new systems, institutions, and policies or open space for improvement in the system for maximum wellbeing to the people and society. The major economic, environmental, and social wellbeing parameters related to UA are presented in Fig. 13.1. The scale and acceptance of UA is directly related to and can effectively be measured by the collective analysis of those parameters. The UA research and development work till today focussed on isolated approaches either focussing on economic concepts or social and environmental, but UA is beyond profit and for better understanding, the major wellbeing

indicators of UA should be properly investigated and analyzed.

13.6 Major Wellbeing Indicators of Urban Agriculture

The list of indicators to be investigated for economic, social, and environmental wellbeing measurement from urban farms and selecting appropriate scale and crop mix is presented in Table 13.2. Through the in-depth study of those indicators in the developing world perspective like South Asia, maximum wellbeing promoting scale and UA types can be explored. The study of those indicators not only helps create ecosystem harmony but also helps develop sustainable

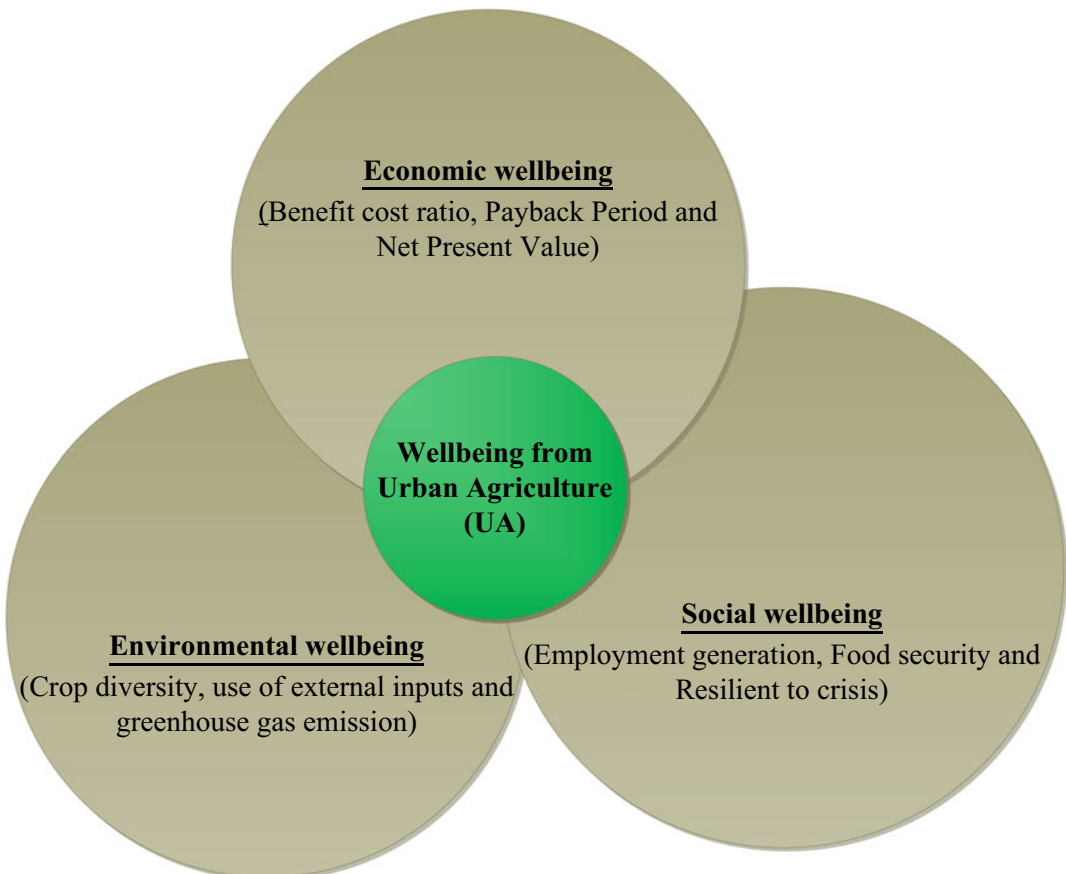


Fig. 13.1 Wellbeing aspects of urban agriculture

Table 13.2 Important indicators of urban agriculture-related to wellbeing

S. no	Wellbeing criteria	Indicators	Measurement methods
1	Economic	Payback Period (PBP), Net Present Value (NPV), and Benefit–Cost Ratio (BCR)	Fixed and variable cost/m ²
			Crop yield/m ²
			Marketable yield/m ²
			Gross return/m ²
			Net return/m ²
			Discount rate
2	Social	Food security	Crop yield/m ²
			Number of consumer/m ²
			The total area under cultivation (ha)
			Population density (Persons/km ²)
			Food supply (kg/person/year)
		Year-round employment	Producer/m ²
			Person-days/year
		Crisis resilience	Food production/m ² /year
			Food supply distance (km)
			Food supply/m ² /year
3	Environmental	Crop diversity	Number of crops grown/m ² /year
			Local crops grown/m ² /year
		Use of external inputs	Manure use/m ² /crop
			Chemical fertilizer use/m ²
			Inorganic and organic pesticide/insecticide use/m ²
			Seeds/seedlings/saplings/m ²
			Irrigation/m ²
		Greenhouse gas emission	Crop types/m ²
			Total and marketable yield kg/m ²
			Supply distance (km)
			Precooling (done or not) and capacity
			Packaging type and material
			Transport type and distance (km)
			Use of machinery and equipment during production and distribution

production technologies based on scale of operation of UA practices.

Those indicators are essential for the identification and promotion of the optimized UA system to meet the economic, social, and environmental needs of the people and the sustainable development of a nation.

13.7 Social Wellbeing from Urban Agriculture

Urban Agriculture can promote social wellbeing through several ways like the encouragement of social participation and sustainable community

development through community-managed space, individual development, social inclusion, and cohesion, strengthening and regeneration of communities (Iles 2005). Besides hedonic value, community bonding and social recreational activities are the major realized benefits from the UA. UA is a major instrument to develop a sustainable food system through the shift of its economic approach to social orientation (Van Tuijl et al. 2018). Urban gardens and farms can create an atmosphere for social and economic investment (Hallet et al. 2017). In the context of developing countries like Nepal, food sovereignty can also be a good social motivator (White 2011) as for most developing countries, and UA is one of the means for providing this.

UA also has the potential to improve the nutritional health of vulnerable people (White 2011). For example, home gardens strengthen family dynamics due to time spent on gardening, harvesting, and preparing food (Gray et al. 2014). Home gardens which are common in rural and urban areas of Nepal at varying scales, also build strong connections between producers with consumers (Mincyte and Dobernig 2016). They also fulfil economic, cultural, and social needs as well as provide a number of ecosystem services (Galhena et al. 2013). As food producers, home gardens help build food resilience through short food chains that can be vulnerable during disruptions like climate change, transport network failure, economic crisis, and shortage of fuel. UA is carried out for economic, recreation, and community building reasons based on country perspective and people's needs. People of wealthier nations treat urban farming as recreation and community building while substance and sale are the main motives of growers from the poorest nations (Hallet et al. 2017).

The underlying preferences and motives of people determine the level of acceptance or rejection of urban grown foods (Sanye-Mengual et al. 2018). Projects that are purely production-oriented and technology-intensive have higher chances of rejection by people (Specht et al. 2016). Thus, we must study the motives and preferences for designing urban farms and gardens for maximum acceptance by the people.

Social inclusion, social capital, and strengthening community are major social benefits of UA (Glover et al. 2005). The highest degree of acceptance can be found from multifunctional UA, which combines commercial, ecological, and social goals, and the success of UA depends upon societal acknowledgment (Specht et al. 2016). Thus, the choice of gardens with multifunctional objectives like a source of food, income, and employment is important for higher social acceptance.

Urban Agriculture reduces social problems like food security, urban poverty, and cost of living and provides recreation for urban people with social and health benefits as the highest motivating factors (Othman et al. 2018). The major social issues like food supply at reduced distance, cost and employment generation are the key interest of urban growers. Besides economic motives, the planning of UA activities should be based on employment, food security, and crisis management potentiality so that it can create maximum satisfaction to the growers and consumers.

13.8 Economic Wellbeing from Urban Agriculture

One of the major interests of urban growers is to maximize profit through better space utilization and product diversification. UA expansion has the potential of providing food and ecosystem services valued up to 80–160 billion USD annually at a global scale (Clinton et al. 2018). Despite the large sum claimed here, there are limited studies on the direct economic benefits of UA like economic gain from household savings, market supply, increased rate of return, and benefit cost-ratio-specific to UA practices.

Moreover, commercial production of food in urban and peri-urban areas has contributed to the development of business opportunities along with local food production and job creation (Cohen and Reynolds 2014). UA has created spaces for business as well as employment opportunities that contribute to the urban economy.

The major motives of UA are the production for home consumption, income, crisis response,

and high price in markets. Major macroeconomic motivations include cost savings to various sectors, especially waste management (Petts 2005). UA has thus direct as well as indirect economic impacts in the long run through food production as well as management of compostable wastes.

Production of horticultural goods such as fruits and vegetables can achieve a yield of 50 kg/m²/year with efficient use of available resources (Orsini et al. 2013). Growers need a method that provides cost-effective crop production and a scalable area to select an optimum mix of crop types (Ward and Symons 2017). Even where the cultivation is in small areas and subsistence, it can provide economic benefit through savings from purchasing food at markets (Oliver 2019). Thus, there is the high economic feasibility of producing foods in urban areas based on yield and resource-use efficiency.

Economic viability and impacts in the urban area are the major criteria of the economic sustainability of UA (Hallet et al. 2017). For low-income families, the cost of maintaining a garden may be more than buying foods due to high investment in fixed structures and special care for breaking the seasonality of production. Thus, future research should investigate cost-effectiveness ability for accessing production (Algert et al. 2016). UA is an important sustainable and scalable approach for food security with good documentation of social, health, and wellbeing benefits, but little has been done on the financial accessibility of food production (Pollard et al. 2017). So major economic parameters like benefit-cost, payback, and return on investment should be studied for different farm sizes to identify optimum production scale for maximum economic wellbeing along with balancing social and environmental factors.

13.9 Environmental Wellbeing from Urban Agriculture

The key global concern at present is sustainable urban development through judicious use of production resources for agricultural activities. Urban food production can improve the

environment by providing opportunities to improve environmental sustainability (Mougeot 2000). Growing food in or near urban areas reduces environmental costs (Depsommier 2011), especially the cost of transportation (Deelstra and Giardet 2000). It reduces greenhouse gas (GHG) emissions and increases carbon sequestration (Kulak et al. 2013) to a greater extent than monoculture-based farming practices. UA can contribute to a low carbon economy and solve the waste problems of urban territories. It can preserve urban ecosystems and can have a better impact on citizens' awareness (Ferreira et al. 2018). Growing own food reduces wastage due to the short supply chain, ultimately reducing GHG emissions from UA (Wise 2014). UA has a substantial role in reducing greenhouse gases generated using agrochemicals, agricultural machinery, and processing and distribution of foods due to reduced distances and low use of external inputs within a limited area.

There is a large variation in the achievable GHG emissions reduction, which can be evaluated at the farm planning and design stage. The largest reductions can be achieved by giving preference to the crops that are conventionally grown rather than growing crops in energy-intensive greenhouses. Care should be taken during the design process to select the most strategic crop types/ species and cultivation techniques (Kulak et al. 2013). The contribution of community farms to reduce waste has also been highlighted since limited packaging is used, household equipment is often reused on-site, and compost production reduces the amount of food waste going to landfills, which can have an impact on GHG emissions (Kulak et al. 2013). However, there is a range of agricultural techniques that is feasible in the context of a community farm and determines their potential impact on GHG emissions. Examples include inter-cropping, polycultures, or multi-cropping, which can lead to higher yields (Rosset 2000) and potentially reduce GHG emissions.

Urban Agriculture is one of the best show-cases of demonstrating good agriculture practices through the adoption of a mixed cropping and low external input agriculture system like organic

farming and natural farming practices. It can provide diversity along with ecosystem services in the cities. UA's biodiversity and ecosystem services can have potentially large societal and environmental benefits for cities, such as enhanced food security, air quality, and water regulation (Lin et al. 2015). So, the major impacts from the use of different types of production inputs, GHG emission rates from production to consumption, and impact of crop diversity should be investigated for ensuring maximum environmental wellbeing.

13.10 Urban Agriculture in Nepal

Urban agricultural practices have greater significance in low-income countries like Nepal for more production and availing safe foods to the consumers (FAO 2010). Small-scale and scattered production units concentrated in or around the major market hubs in different parts of the country is a major feature of Nepalese agriculture (MOALD 2020). The income share from urban agriculture in Nepal is almost 11%, with greater dietary diversity and calorie availability (Zezza and Tasciotti 2010). The UA practices followed in major cities like Kathmandu are mainly motivated by the self-formed social groups and communities.

The kitchen gardening of seasonal vegetables and semi-tall fruits is the most common traditional practice followed by the rural as well as the urban growers of Nepal. At present, farming in urban areas like Kathmandu valley is growing rapidly and is gaining momentum in other densely populated cities of Nepal due to the availability of fertile soil and a high degree of people's engagement as well as huge food demand (Mitchell and Iglesias 2019). Kathmandu Metropolitan City, a local level government, has been promoting rooftop farming since 2012 and has supported more than 500 people with the aim of substituting at least 20% of vegetables from self-production (RUAF Foundation 2013). However, there is no systematic study related to the developmental aspects of UA. As such, there is a limited

understanding of the types of UA in practice, the foods under production, the demand to be met, or the supply currently available in urban areas. Recently, Nepal's provincial and local governments are promoting some of the UA activities like protected vegetable farming and rooftop farming in the major cities. Based on the key informant survey, rooftop vegetable and fruit farming, pot cultivation, kitchen gardening, small-scale protected vegetable farming, small-scale soilless farming, and small livestock integration within available space are the commonly available UA practices in most urban areas of Nepal.

Likewise, some private service providers and international/national non-governmental organizations are supporting UA activities through capacity enhancement, material distribution, and marketing access through a weekly farmers' market in the city areas. To promote UA in Nepal, there is a need to develop a less interrupted food supply mechanism, consider food and environmental services from UA during the city development planning process, and institutional strengthening for better service delivery (Dixit et al. 2014). Home garden, a kind of urban and small-scale homestead farming for food and nutritional security implemented in some places of Nepal through multi-stakeholders' participation is playing a major role in dietary diversity and agrobiodiversity conservation (Gautam et al. 2006). Home garden practices need to be promoted through proper policy and institutional mechanisms (Gautam et al. 2006). The home garden project implemented through Local Initiatives for Biodiversity Research and Development (LIBIRD) in collaboration with Nepal government and local implementing organizations has significantly contributed to on-farm agro-biodiversity conservation and social and economic empowerment of the participating farmers (Anonymous 2019).

UA's economic, social, and environmental impact on overall wellbeing has increased over the year as the UA practice is rapidly increasing. Thus, Nepal needs to quantify the overall impact through proper legal, institutional, and policy mechanism.

13.11 Policy Agenda for Urban Agriculture in Nepal

Unplanned settlements and loss of productive agricultural land within the urban fringe are issues evident in different times in urban areas of Nepal, particularly the Kathmandu Valley. The settlement area in Kathmandu Valley increased rapidly over the previous 53 years, drastically reducing fertile and productive agricultural land (Thapa 2012). Further, the likelihood of increased urbanization of Kathmandu in the coming decade is high, which might cause degradation in the urban ecosystem and environment (Thapa 2012).

Nepal has a National Urban Policy (2007), a National Urban Development Strategy (2015), and a Land Use Policy (2015), which provide a clear land-use classification across Nepal with 11 classes, including agriculture, residential, commercial, industrial, mining, cultural, rivers and lakes, forest, public use, material excavation, and others (MoLRM 2015). However, the rapid loss of productive agricultural land is a pertinent issue due to weak regulatory mechanisms. In the previous three decades, the rate of urbanization in Kathmandu valley has increased by 412%, with a loss of 31% of productive agricultural land (Waseem 2018). Urbanization has created a land shortage for food production and other urban recreational activities used for human wellbeing.

Nepal has no separate policy or planning to foster the UA practices in and around city areas. However, the National Agricultural Policy (NAP) is the central guiding policy for all agricultural practices, including UA. NAP has three broad objectives: increasing production and productivity, marketing mechanism development, and sustainable conservation and utilization of agrobiodiversity (NAP 2004). Based on NAP, the Nepal government has formulated other guiding policies, strategies, and plans, including agro-biodiversity policy (2007), agriculture development strategy (2015–2035), and fifteenth five-year plan (2019–2023), but they neglected UA as one of the potential means for economic, social, and environmental development in the cities.

The urbanization in Nepal is increasing rapidly, and the urban population has increased from 16.8% to 20.2% from 2010 to 2020 (World Bank 2021), and the pace of urbanization is increasing. Rapid urbanization is mainly responsible for the loss of fertile land, which impedes food production and reduces livability in existing urban areas (Haack and Rafter 2006; Toffin 2013). Urbanization creates a wider scope for measures such as UA, which can both feed the urban residents and improve the urban environment and livability. Due to the increased awareness and past campaigns from different stakeholders, including private and non-governmental organizations, the urban farming campaign is gaining rapid momentum in major cities of Nepal. Nowadays, several urban food producers' organizations and farmers' markets are actively operating in major cities like the Kathmandu valley. The current COVID-19 pandemic and the time-to-time sudden food supply blockade in the city areas due to natural calamities in different parts of the country motivated urban residents for agricultural activities in available spaces like rooftops, kitchen garden, and suitable patches of land. Realizing those facts, the Nepal government has initiated some programs like precision and protected farming in nearby city areas and promotion of family and urban farming within major cities. Programs like rooftop farming, urban farming, and kitchen gardening are still in operation through the support from provincial and local level governments. In addition, some community-based private organizations are actively supporting various types of UAs.

However, the anticipated results have not been realized due to the lack of continuity and coordinated approach in program planning and implementation and inadequate monitoring and evaluation mechanisms. Integrating UA into city development plans, policy formulation, and institutionalization through the wider stakeholders' participation are the key identified issues for the sustainability of UA in developing countries (Bryld 2003). Nepal needs urgent actions on the development of a legal framework for UA to be

undertaken and institutional backing and promotion activities to encourage uptake of UA activities.

Urban Agriculture is done under a variety of socio-political conditions so enhancing productivity and sustainability through proper policy environment, access to unused space, supporting and establishing urban farmers' organization, technology demonstration and training, and financial support for increasing productivity and multi-stakeholders' participation for environmental risk minimization are the key for sustainable urban farming (FAO 2007). Moreover, for better food and nutritional security and promote it as a tool of wellbeing, a developing country like Nepal needs a strong and coordinated policy framework and integrated program planning, implementation, monitoring and evaluation approach.

We propose a policy framework for wellbeing promotion through UA for Nepal (Fig. 13.2), based on Sarkar et al. (2019), which was developed for integrating UA in the urban sustainability of Australia.

Nepal has a difficult terrain for long-distance transport and poor infrastructure for fresh produce supply to markets. Therefore, if foods can be produced in or around cities, the country can decrease losses of fresh produce and consumers can have easy access to fresh UA products. Besides, integration of value chain actors within the short supply chain becomes feasible. Jobs and employment opportunities for urban dwellers can be created during input supply, production, and marketing activities. Major cities of Nepal such as Kathmandu, Pokhara, Dharan, and Butwal have limited urban attraction sites like big parks and gardens compared to other South Asian cities. UA can be a good option for tourism and recreation with added economic advantages. UA can be the attraction point for migrant people living in the city. Besides, many migrant workers who gained knowledge on agriculture can use their skills and experiences for sustainable UA activities, thereby creating economic, social, and environmental opportunities by adopting low external inputs dependent on safe production practices at a reduced cost and distance.

The measurement indicators for each wellbeing promotion criteria (Table 13.1) analyze the outcome of UA as the best scale and intervention. Nepal needs a strong and coordinated institutional setup, policy and program framework development, and integration of UA into city development plans for developing a sustainable food supply system. Maximizing wellbeing for people living in cities can only be possible through the integration of UA in the urban planning process. Agriculture is an important component of urban policy and a means to policy objectives (Zeeuw 2016). We must consider major input, technology, and institutional challenges for sustainable urban food production practices based on circular economy principles ('reduce, reuse, and recycle'). UA can be integrated into urban policies, especially in the areas such as land use, food security, health, environment, and social development. The temporal use of vacant land and multifunctional land-use practices may be the possible land-use strategy for Nepal. Similarly, a better access of urban farmers to agricultural research, technical assistance and credit services, and an improved system for input supply and product distribution are other areas of integration in urban policies which can further enhance the social development within communities.

In Nepal, UA does not have an institutional home. Hence, forming a lead agency or an organization for the promotion of UA, enhancing coordination among governmental and non-governmental organizations at federal, provincial, and local levels and urban farmers' associations is of dire need. In a country like Nepal, where most agricultural functions are mandated under local government constitutionally, the capacity building of the local agriculture units, expert support for formulating more efficient policy, and inter-disciplinary functional coordination are of prime importance for promoting UA. Nepal should also integrate UA as a curriculum in the local education system, wherever applicable. The promotion of UA should also get due priority in upcoming national and local level agricultural policies.

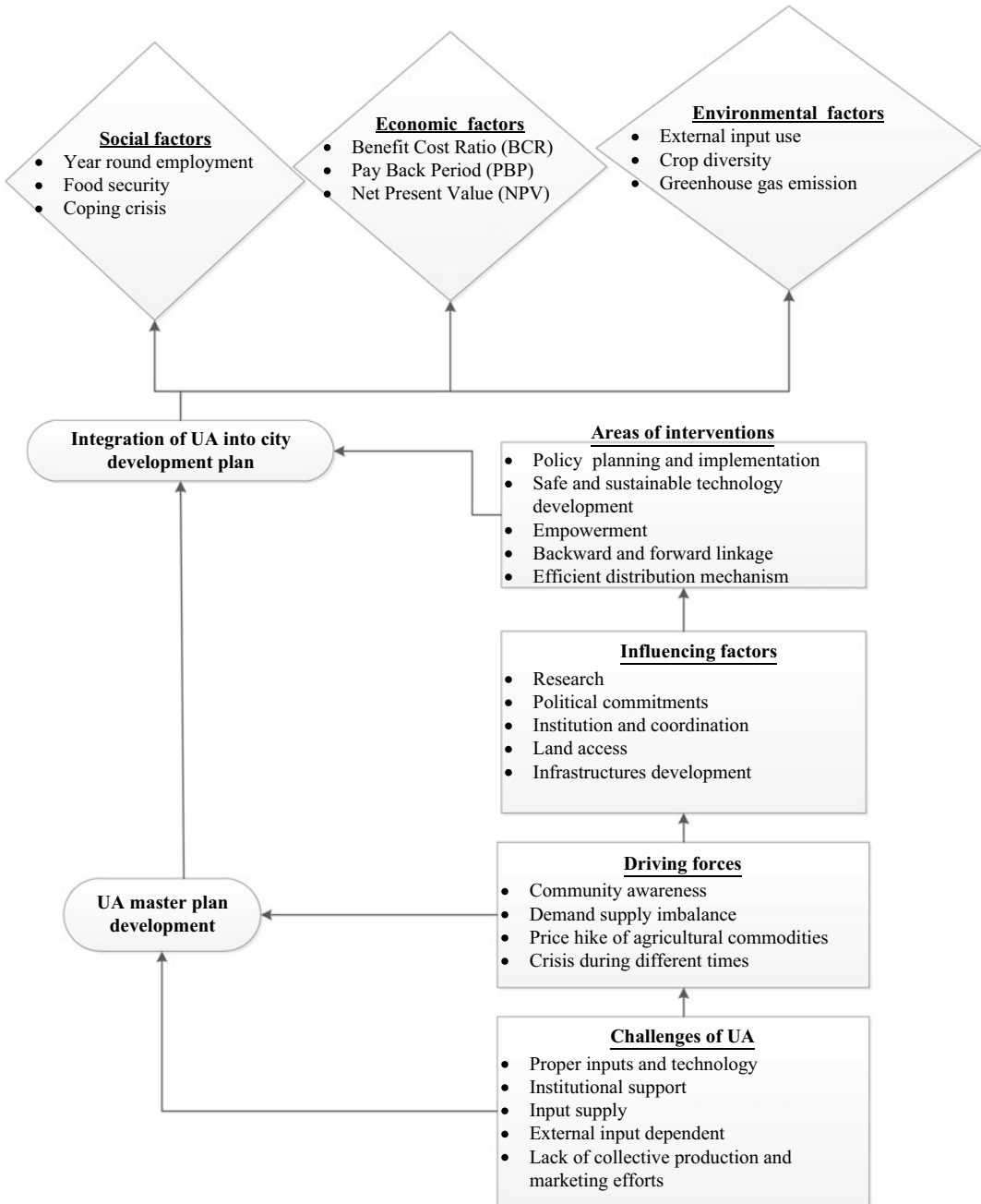


Fig. 13.2 Proposed integration framework for urban agriculture development in Nepal (Adapted from Sarkar et al. 2019)

Nepal needs an Urban Agriculture master plan to integrate UA in a national system in line with city settlement patterns as UA is the major component of sustainable city development,

creating food diversity and quality, food culture, and landscapes (Mason and Knowd 2010). The master plan should cover broad areas like planning, implementation, and monitoring

Table 13.3 Urban agriculture development plan for Nepal

S. no	Key areas	Sub-areas	Suggested lead organization	Support organization
1	Environment friendly and employment centric integrated technology development program	Low external input-based technologies for: • Vegetable production • Fruit production • Floriculture production • Small livestock and small-scale fisheries production • Agroforestry-based urban farming • Decomposable waste collection, enrichment, and utilization	Nepal Agriculture Research Council (NARC)/ Agriculture and other related universities	Federal agriculture and livestock development ministry, provincial ministry, local government (metropolitan, sub-metropolitan, and municipalities)
2	UA Master Plan Development	• Urban settlement plan • Park area development plan • Agriculture area development plan • Livestock area development plan • Waste collection and utilization plan	Metropolitan, Sub-metropolitan, and Municipalities	Federal and provincial ministries/Non-governmental organization/Urban food growers
3	Integration of UA into the city development plan	• UA integration modality • Awareness creation and modality validation • Plan implementation, short-term and long-term impact evaluation	Metropolitan, Sub-metropolitan/Municipalities	Concerned federal and provincial ministries/Non-governmental organizations

mechanisms and technology need assessment with a specific focus on policy formulation, human resources development, adoption of safe production practices, technical empowerment,

sustainable technology development, institutional strengthening and backward and forward linkages to cope crisis and promote urban wellbeing.

Based on the above-proposed framework, the role and responsibilities of the federal, provincial, and local level organizations, research and education institutions, non-governmental organizations and private enablers, and the lead and supporting agencies are presented in Table 13.3. The suggested plan includes crop-specific production technology development through the involvement of research and teaching organizations, master plan preparation through wider stakeholders' participation including growers and enablers, and UA integration mechanism into the city development plan.

Nepal needs to adopt wellbeing approach for better social, economic, and environmental outcomes through UA practices. Institutional and functional linkages among the major stakeholders like government agencies, non-governmental organizations, teaching and research institutions, community-based organizations and individual producers should be strengthened. Government should focus work on institutional and policy reform along with budgetary mechanisms and research/education linkage, while the non-governmental organizations should play an active role in advocacy and implementation arrangements.

13.12 Conclusions and Recommendations

Urban Agriculture is mainly influenced and driven by social, economic, and environmental factors. The motives of farming in urban areas are largely governed by population characteristics, policy, and institutional setup as well as the productive resources available in the nearby area. For a less developed country like Nepal, food production with minimum use of external resources helps in stabilizing the economy and autonomy, thereby increasing the resiliency from the possible risk of environmental problems and impact of climate change in agriculture (Mok et al. 2014), ultimately creating space for sustainability for the long run. Sustainable and diverse food production at low cost is possible from UA by adopting circular economy principles.

Urban Agriculture can play a better role in food supply and human wellbeing, contributing to the sustainable development goal 2 on food and nutritional security, hunger, and sustainable agriculture in developing countries like Nepal. Identification of policy and institutional mechanisms, integration of specific production technology, and marketing mechanism in the city development plan are key agendas that help maximize the economic, social, and environmental wellbeing of the people. The quantification of benefits from the UA should be investigated from economic, social, and environmental indicators rather than only from classical financial analysis. For this, wellbeing approach may be one of the best available holistic options. Further exploratory research is recommended that focus on the current level of UA and growth potentiality, driving factors of UA among current practitioners, and influence of social, economic, and environmental nexus.

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Part II

Livestock and Fisheries

Livestock Contribution to Food and Nutrition Security in Nepal

14

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Abstract

Livestock products are a vital source for achieving food and nutrition security for growing human population in Nepal. Presently, the livestock production system in the country is mostly traditional and subsistence-oriented with low productivity, though it is in transition towards semi-commercial system in some districts. The objectives of this chapter are to assess the status of production, analyse projected domestic production and availability of livestock products for 2029/2030, and identify key production constraints and issues in making Nepal self-reliant in livestock production with reduced import. The major information for the chapter comes from the national literatures on livestock statistics, agricultural census, and published and unpublished research papers and policy documents. Autoregressive Integrated Moving Average (ARIMA) model was used to

predict livestock population and production of primary livestock products for 2029/2030 using data from 1961 to 2019. Analysis showed that the projected growths of livestock population and products are likely to increase in the next 10 years, but the productions are unlikely to meet the nutritional needs of people. Major constraints, gaps, and opportunities for livestock development for ensuring food and nutrition security are assessed, which include low productivity, higher production cost, marketing hurdles, climate change impacts, and institutional and policy issues. To address these issues, livestock development including breed improvements and their promotions, strengthening market infrastructure and support services, technology development and dissemination, and building capacity of institutions and stakeholders including enabling policy environments could be instrumental.

Keywords

Animal source food • Constraints • Food and nutrition security • Livestock productivity • Self-sufficiency

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14.1 Introduction

Food security, as defined by the United Nations' Committee on World Food Security, means that all people, at all times, have physical, social, and

economic access to sufficient, safe, and nutritious food that meets their food preferences and dietary needs for an active and healthy life (World Food Summit 1996). According to this definition, food security involves four pillars: availability, access, utilization, and stability (FAO 2011). The food and nutrition security in terms of availability, access, utilization, and stability are of prime concerns for the people of developing countries in general and Nepal as the food security and food sovereignty are important components of the human rights as envisaged by the Constitution of Nepal (GoN 2015). The continuous rise in population growth, urbanization, and income growth, and changes in preference of Nepalese diet towards animal source food (ASF) appear to be important factors that lead to rise in demand of ASF in future to meet the food and nutrition security. The agriculture development strategy (ADS 2015), which is expected to guide the agriculture sector of Nepal over the next 20 years (2015–2035), has provisioned livestock sub-sector in food and nutrition security programme as a flagship and core programme to address the issue.

The livestock sector plays an important role in the national and regional economics and household food security in South Asia, where its contribution to total agriculture gross domestic product (GDP) ranges from 16% in Sri Lanka to 60% in Pakistan (FAOSTAT 2020). The sector contributes about 26% in agriculture GDP in Nepal (MoF 2019), where the contribution mainly comes from meat, milk, egg, and wool/*pashmina*. This does not include the contribution from manure, draft power, transportation, and other by-products (e.g., fuel) from livestock. The contribution from livestock for ASF comes from diversity within and between livestock species (FAO 2015). The livestock production and consumption of these products has nutritional, social, cultural, and economic benefits. Though, Nepal is a small-sized country, a wide diversity of livestock exists encompassing cattle, buffalo, sheep, goats, pigs, equines, chicken, ducks, turkey, quails, ostrich, rabbits, pigeon etc. (MoAC 2004).

In general, the major chunk of food items comes from cereals including some pulses and

vegetables, having very rarely ASF in people's diet. The inclusion of more ASF such as milk, meat, eggs, and dairy products is necessary to address food and nutrition security as envisioned by the new constitution (GoN 2015). Livestock products (milk, meat, and eggs) are also vital source of nutrition for pregnant mother and children under golden 1000 days (periods from the conception to 2 years of birth of child). According to UNDP around 1 million Nepalese children under 5 years (36%) suffer from chronic malnutrition and 10% suffer from acute malnutrition (MoH 2017). This evidence suggests that the government should have higher priorities to develop the livestock sector to overcome the present gaps of food shortage, malnutrition and make country to be self-reliant in ASF. Increased production and supply of ASF is important to meeting Zero Hunger (Goal #2) and Climate Action (SDG #13) of the UN Sustainable Development Goals by 2030.

The demand of livestock products has been increasing every year due to increase in income, urbanization, and consciousness towards ASF (Paudel and Thakur 2015). Milk and meat are preferred foods in most developing countries of South Asia including Nepal and the demand grows rapidly when incomes increase (FAO 2012). However, the animal production system has not yet become productive, efficient, and commercialized in Nepal. There are several factors and issues affecting this, which must be addressed precisely to make animal production system more efficient, vibrant, and commercialized and eventually sustainable in Nepal. The objectives of this chapter are to assess the status of production, analyse projected production and availability of livestock products for the next 10 years, and identify key production constraints and issues to undertake appropriate measures for making the country self-sufficient in livestock production.

14.2 Data Sources and Methods

The major information for the paper were obtained from the available national literatures on livestock statistics, agricultural census, FAO

statistics, research papers, and policy documents (ABD 2010, 2018; DDC 2018; FAO 2011; MoALD 2020). Data on livestock population by species/types and production and productivity of major animal products (milk, meat, eggs, and wool) were compiled and analysed by ecological regions and provinces. Import and export of key livestock products (meat, and milk) available from official sources was compiled and analysed (TEPC 2019). Autoregressive Integrated Moving Average (ARIMA) Regression model (R Core Team 2013) was used to predict livestock population, human population, and primary livestock products production for the next 10 years (2030) using FAOSTAT data from 1961 to 2019 (FAOSTAT 2020). Information on the production, import and breeds of livestock species was collected from different available sources (ABD 2010; MoALD 2020). The information collected was analysed and used for estimating and projecting contribution of livestock for food security and meeting self-sufficiency for the current and growing population for 2029/2030. Major constraints, gaps, and opportunities are assessed for livestock development to make country self-sufficient in animal sourced food and ensuring food and nutrition security of the population. Due to data limitation, the analysis in the present paper mainly focuses on only one of the four pillars of food security, the first pillar which is the food availability through domestic production and import measures.

14.3 Livestock Population, Distribution, and Their Growth Trends

Nepal is one of the countries in South Asia having the highest livestock population density per unit of cultivated land (FAOSTAT 2020). Nepal has the highest population density (4.3/ha cultivated land) of large ruminants amongst the South Asian countries. A brief status of livestock population and distribution and their projected growth trends and types of livestock breed are outlined below.

14.3.1 Livestock Population and Distribution in Nepal

The distribution of livestock population by provinces in Nepal is presented in Fig. 14.1. According to the latest official statistics of 2018/2019 (MoALD 2020), the total estimated population of large and small ruminants were 12.7 million and 13.1 million heads, respectively in 2019. Similarly the estimated population of pigs and poultry (non ruminants) were 1.49 million and 75.7 million heads, respectively. In 30 high hill / mountain districts, the population of Yak and Chauries (cross between Yak and hill cattle) were 69,588 heads. The estimated population of horses and mules were 59,822 and rabbits (wool and meat type) were 74,645 heads (MoALD 2020).

14.3.2 Livestock Population Trends and Projections

The trend (1961–2019) and projection (2020–2030) of domestic livestock species is presented in Fig. 14.2. Buffalo, goats, pigs, and chicken were steadily increasing over the years, whereas cattle and sheep did not have such trends. The population of sheep was declining in the later years. During last 20 years (1999–2019), the population of cattle, buffalo, goats, pigs, and chicken increased on average by 0.3%, 2.6%, 4.9%, 4.0%, and 16.3% per annum, respectively, whilst the sheep population decreased by 0.3% per annum. The ARIMA model predicts that the population of cattle, buffalo, goats, sheep, pig, and chicken will increase in 2030 that might reach 7.4, 6.1, 18.2, 0.8, 2.0, and 142 million heads respectively (Fig. 14.2). As the country is already having comparatively higher number of livestock species, increasing the productivity rather than absolute number of animals would be desirable in the context of present climate change as livestock are blamed as primary contributors of greenhouse gas (GHG) emissions in the environment (Ghahramani et al. 2020; Maraseni and Cockfield 2011). Therefore, the focus and priorities should be given to research and development activities for better

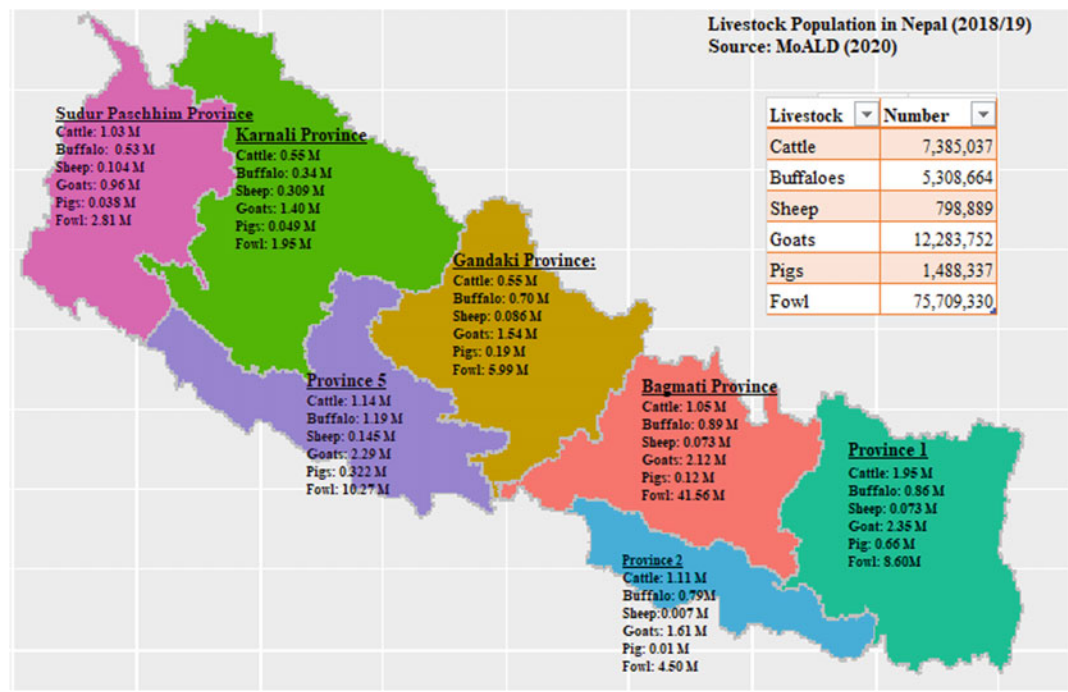


Fig. 14.1 Livestock population distribution across different province in Nepal (2018/2019). *Source* MoALD (2020)

management of the livestock species for improving their productivity.

The population of each of the livestock species is lower than human population except for fowl (chicken), which has 2.6 per person (Table 14.1). The projected livestock population showed that percent increment for each of the livestock species in 2029/2030 is relatively low except for goat, fowl, and pig.

The number of livestock is more in Nepal, but the productivity has been low, and this has made low per capita availability of livestock products (milk and meat) in the country (MoALD 2020). This suggests that the country should focus on high productive livestock rather than a greater number of animals. By doing this the country would not only ensure commercial production system but would also greatly contribute to the environment. This would contribute to addressing at least SDG 2 (Zero Hunger) and SDG 13 (Climate Action).

14.3.3 Livestock Breeds

Nepal has several indigenous and exotic breeds of livestock and poultry raised by the farmers in different ecological regions (Table 14.2). Altogether 25 native breeds/types of different livestock species have been registered so far, which include 7 of cattle, 3 of buffalo, 4 of goat, 4 of sheep, 3 of pig, 3 of fowl, and 1 of horse (Neopane 2006). The history of importation of exotic breeds of livestock for improving production can be traced back to the mid-1900s with importation of cows from UK (in 1961 AD) in the country (NLBO 2019). Later some European cattle breeds, pigs, and poultry were brought to the country (Basnyat 2001). Heifer International should be acknowledged for shipment of these animals (HIN 2000). Since then, live animals and frozen semen import have been taking place primarily for cross breeding to enhance the productivity of native livestock species (ABD 2018).

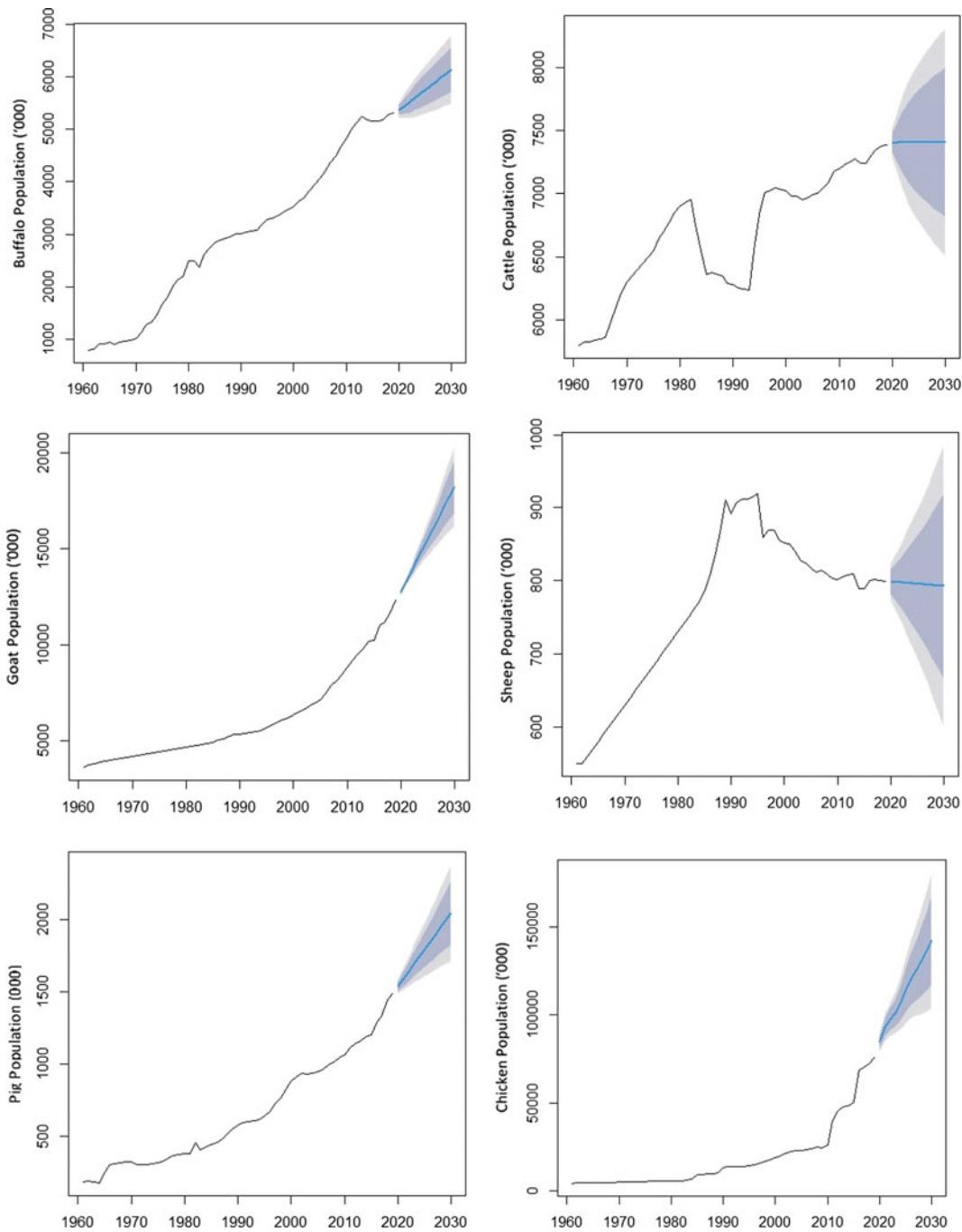


Fig. 14.2 Livestock population trends (1961–2019) and projections (2020–2030). *Source* FAOSTAT (2020)

Table 14.1 Projected livestock population and percent increment in 2029/2030 from current level of 2018/2019

Livestock species	Current livestock population (2018/2019) ^a	Projected livestock population (2029/2030)	% Increment	Ratio of human & animal population (2018/2019)	Ratio of human & animal population (2029/2030)
Cattle	7,385,037	7,406,758	0.3	4:1	5:1
Buffalo	5,308,664	6,136,945	1.5	5:1	5.5:1
Goat	12,283,752	18,247,155	4.8	2.5:1	2:1
Sheep	798,889	792,352	-0.8	25:1	25:1
Pig	1,488,337	2,043,446	3.7	2:1	2:1
Fowl	75,709, 330	142,267,601	8.7	1:2.6	1:4

^a MoALD (2020)

14.4 Productivity, Export, and Import of Livestock Products

Despite large number of livestock population, the country is still not self-sufficient in fulfilling the demand for various livestock products. This has been mainly due to sub-optimal production culminated by poor genetic potential and improper livestock management. Productivity of dairy, goat, and pig meat animals in Nepal is far below the global or Asian average productivity level. The milk productivity of cattle (699 kg/year) in Nepal is half to that of India (1698 kg/year) and nearly 8th times lower than that of China (5632 kg/year) (FAOSTAT 2020). Pig meat productivity in Nepal is half (37.8 kg/animal) to that of China (78.2 kg/animal), whilst goat productivity (11.8 kg/animal) is similar to neighbouring Asian countries but lower than that of China (15.6 kg/animal) and USA (14.7 kg/animal) (FAOSTAT 2020).

14.4.1 Production of Primary Livestock Products

In 2018/2019, a total of 2.2 million MT milk was produced from about 2.4 million milking cattle and buffaloes. Around 14% of total cattle and 26% of total buffalo population have been estimated to be in milking stage. Of the total milk produced, 67% was from buffaloes and remaining 33% from cattle (MoALD 2020). The

contribution of buffaloes in terms of total milk production is gradually declining and that from cattle is increasing mainly due to initiation of dairy cattle farming at commercial scale and increase in the number of crossbred dairy animals mainly cattle with increase in artificial insemination (AI) coverage (MoALD 2020).

The trends of production of livestock products such as milk, meat, and eggs are increasing in recent years. The annual milk production increased by 16.9% during 2015/2016 to 2018/2019 or by average of 5.65% annually. The average annual increase was 7.8% for cow milk and 4.5% for buffalo milk. The increase has been primarily due to increase in number of milking animals and partly by improvement in the productivity. During the same period, the total meat production increased on average by 3.6% annually. The meat production increase per annum was the highest for duck meat (16.3%) followed by pork (7.2%), chicken (4.8%), and chevon (4.3%). The total egg production in the last 3 years increased by 18.5% with average annual increment of 6.15%. The average annual increase in chicken egg production was 6.2 and that for duck egg was 2.6%. Similarly, the wool production in the country during last 3 years has remained mostly static with nominal increase of 0.08% per year.

14.4.2 Productivity of Dairy and Meat Animals

The average annual milk production of cattle and buffaloes together in 2018/2019 was 822 kg with

Table 14.2 Indigenous and exotic livestock breeds in Nepal

Species	Indigenous breeds/Types		Exotic breeds/ crossbred	
	Breed types	Locations	Breed types	Locations
Cattle	Lulu	Manang, Mustang	Jersey	Hills and Terai
	Achhami	Achham, Doti, Bajhang	Holstein Friesian	Hills and Terai
	Khaila	Dadeldhura, Doti, Baitadi	Brown Swiss	Dolakha
	Siri	Ilam, Taplejung	Red Sindhi	Few terai districts
	Pahadi	Across hill districts	Sahiwal	Few terai districts
	Terai	Across Terai districts	Hariana	Terai
	Yak	Mountain districts		
Buffalo	Lime	Hill and Terai districts	Murrah	Terai and Hills
	Parkote	Hill and Terai districts	Surti, Jaffrabadi	Terai districts
	Gaddi	Dadeldhura, Baitadi	Nili Ravi	Research Farms
Goats	Chyangra	Mountain	Jamunapari	Terai districts
	Sinhal	High Hills	Barbari	Western Terai and hills
	Khari	Across hills	Boer	Hills and Terai
	Terai	Across Terai	Sirohi	Hills and Terai
			Beetal	Eastern Terai
			Sannen	Research farms
Sheep	Bhyanglung	Mountain	Merino, Polwarth	Mountain
	Baruwal	High hills	Corriedale	Mountain
	Kage	Hills and valley	Romney Marsh	Mountain and hills
	Lampuchhre	Terai	Border Leicester	Hills
Pig	Chwanche	Hills	Yorkshire, Landrace	Hills and Terai
	Hurrah	Terai	Hampshire, Berkshire	Hills and Terai
	Bampudke	Western Terai	Duroc	Hills and Terai
Fowl	Sakini	Across the country	New Hampshire	Hills and Terai
	Pwankh Ute	Across the country	Australorp	Hills and Terai
	Ghanti Khuile	Across the country	Synthetic breeds, Giriraja	Hills and Terai
Horse			Kadakhnath	Private farms
	Jumli	Jumla district	Arabian	Army Institutions

Sources Neopane (2006), Neopane and Shrestha (2009), Pokhrel et al. (2012), Shrestha (2004)

880 kg for buffaloes and 699 kg for cow (Fig. 14.3). The low annual milk production from cow is particularly due to greater number of indigenous cattle population (MoALD 2020). However, the average 305 days milk production of crossbred cattle in the major dairy pocket areas of the country stands at around 2800 kg, with 3100 kg for Holstein Frisian (HF) derivatives and 2500 kg for Jersey derivatives and great deal of variability amongst individuals (ABD 2010).

Similarly, the potential milk productivity of indigenous buffaloes has not been properly tapped (Shrestha et al. 2005).

14.4.3 Projection Trends of Livestock Products

The projected data based on the past growth rate from 1961 to 2019 from ARIMA model showed

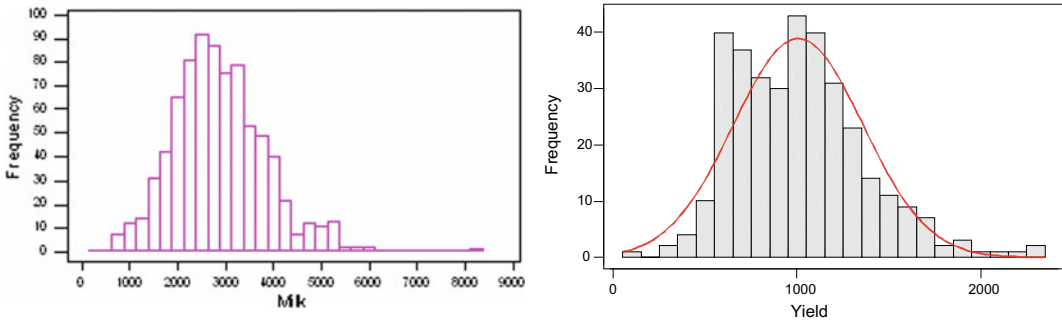


Fig. 14.3 Lactation yield of **a** crossbred dairy cattle, and **b** indigenous buffaloes. 2010 Source ABD (2010), Shrestha et al. (2005)

that growth of total milk (cattle and buffalo) and meat (buffalo, goat, pork, and chicken) is expected to increase rapidly in the next 10 years (Fig. 14.4 and Table 14.3). Per capita availability of milk, meat, and egg (number) in 2030 would be 100.8 kg 13.6 kg, and 80 respectively. This projection (milk and meat) in 2030 corroborates with the projection FAO has made in 2003 for South Asia, though little less in terms of milk (107 kg) but slightly higher in meat (11.7 kg) (FAO 2003).

This indicates that country can likely meet minimum self-reliance in meat and milk products by 2030 with the current population growth rate. This can support self-sufficiency on livestock products as per Government of Nepal plan (NPC 2020). The recent programme of MoALD (The Kathmandu Post 2021) to declare self-sufficiency status for poultry eggs, meat, milk powder and ghee, and fish for improvement in other entities seems to be supported with the growth as projected (Fig. 14.4). However, in the next 10 years,

the income of the population will be projected to increase and demand for meat and milk products may increase significantly (Aryal et al. 2014). In such context, this current project growth rate may not meet increased demand. Similarly, if frequency of disease epidemics (e.g., bird flu) and negative effect of climate change increases, the country may not achieve this projected growth.

14.4.4 Processed Livestock Products

There are few meat processing industries in the country producing processed meat products such as sausages, bacon, ham, dry meat, and pickles. However, there are many milk processing industries in the country with processing capacity varying from 1000 to above 200,000 lit per day. The government-owned Dairy Development Corporation is the largest dairy industry. Presently there are more than 1200 registered primary milk producers' cooperatives in the country

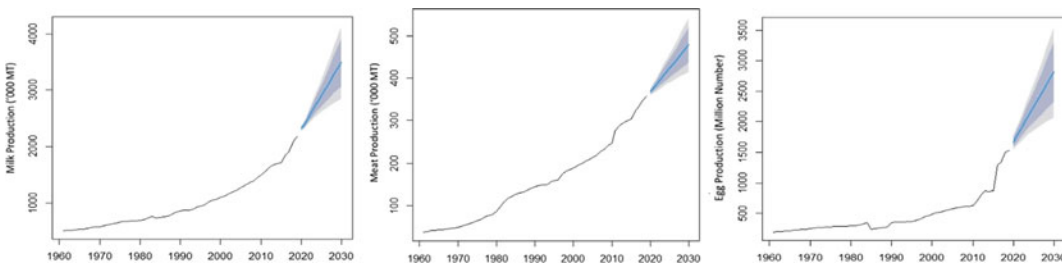


Fig. 14.4 Projected growth of total milk and meat in 2030 using ARIMA model based on past growth rate (1961–2019)

Table 14.3 Milk, meat, and egg production trends over the next 10 years based on last 60 years growth rate

Livestock products	Current livestock production (MT) (2018/2019) ^a	Projected livestock production (MT) (2029/2030)	% increment	Per capita (kg) availability (2018/2019)	Per capita (kg) availability (2029/2030)
Total milk	2,168,434	3,538,275	5.7	74.3	100.8
Chicken meat	62,899	98,820	5.2	NA	NA
Total meat	357,082	477,962	3.1	12.2	13.6
Chicken Egg (no)	1534,680,000	2816,411,000	7.6	53.0	80.0

Source Prediction using ARIMA model from FAOSTAT Data (1961–2019)

^a MoALD (2020)

NA: Not available

through which the raw and chilled milk is channeled into the formal milk market (DDC 2018). Various milk products are produced and marketed by the industry. These include pasteurized standard milk (3% fat and 8% solid not fat), low fat milk, skimmed milk powder, condensed/ evaporated milk, fresh milk drink, curd, yoghurt, *Paneer*, Cheese (*Mozerella*, *Kanchan*, *Yak*), various flavoured ice cream, cream, butter, ghee, etc. The indigenously processed milk products like *Khowa* and hard cheese (*Chhurpee*) are produced at farm level and dairy-based sweets (*Barfi*, *peda*, *rasbari*, *lollipop* etc.) are produced and marketed by the domestic sweet shops/ restaurants.

14.4.5 Import and Export of Live Animals and Livestock Products

With the rise of income, urbanization and increased nutritional needs, demand for livestock and livestock products are increasing and outstripping domestic supply causing increasing reliance on imports. Despite having sufficiently high number of livestock, the country is still not self-sufficient in livestock products. Live animals, particularly goats and buffaloes, worth billions of Nepalese rupees are imported from the neighbouring countries with increasing trends in import (Fig. 14.5). One of the reasons for still importing live goats for meat from India is mainly associated with marketing hurdle within

the country. The production system particularly that of small holders is small scale and scattered that makes collection and bulking somewhat difficult. Traders prefer Indian goats due to their availability at bulk in one place in India. In recent years, the import of live goats has started declining with the introduction of quarantine checks in the border areas.

Different dairy products worth of 243 million US\$ are imported from various countries, main being skim milk powder (SMP) and this is in increasing trend (Fig. 14.5). The volume of imported dairy products has increased by five times in terms of quantity and three times in terms of value from 2007 to 2017 (TEPC 2019). As compared to dairy products, the meat products' import volume and value however are not that alarming.

Export of livestock products from Nepal to other countries are nominal both in volume and value. The value of total live animals and meat products export was US\$ 0.6 million and dairy products was US\$ 0.3 million to various countries during 2018/2019 (TEPC 2019).

14.4.6 Wild Animals Farming as Source of Food

There is potential for domesticating some wild animals for food purpose. Wild pigs have been domesticated to a limited extent for crossing with local pigs or fattening of captured wild pigs, which fetch comparatively higher price in the

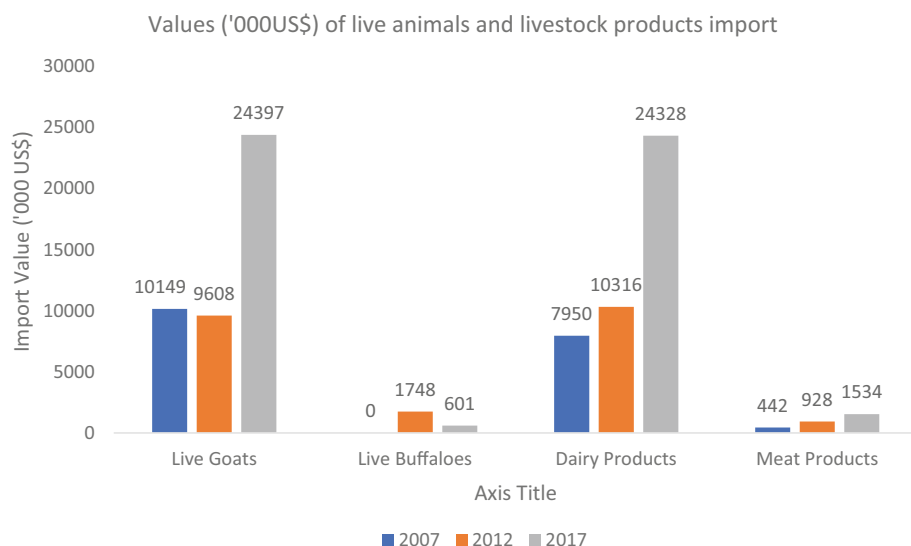


Fig. 14.5 Import trends of live animals and livestock products. Source TEPC (2019)

market (ABD 2010). Authors' observation in the field reveals that some enthusiastic youths have brought *Jungle* fowl from abroad and started commercial farming at some locations in the country. National Park and Wildlife Conservation Rules (1974) of Nepal made a fifth amendment in 2017, and this allowed commercial wildlife farming and sale of the products from wildlife and their body parts by individual firms and institutions that have acquired licenses from the concerned authority. Amended rules to bring the wildlife farming provisions into force were implemented in 2019. However, this couldn't be scaled to large areas though this may be an option for animal source of food in the country.

14.5 Availability of Livestock Products for Food Security

The per capita availability of milk, meat, and egg (number) in 2018/2019 in Nepal was 74.5 kg, 12.3 kg, and 53 respectively. The ministry of agriculture and livestock development in March 2021 declared the country as self-reliant on poultry meat and eggs, goat, milk powder, and ghee (condensed butter) (The Kathmandu Post

2021). Provincial analysis of per capita availability of animal source food reveals the highest for milk (106 kg) and meat (15.5 kg) in *Gandaki* province and egg (133) in *Bagmati* Province, whereas the lowest per capita availability for meat (8 kg) and milk (52 kg) in Province 2 and eggs (16) in *Karnali* province (Table 14.4).

For meat availability, all the provinces except 1 and *Sudur Pashchim* are slightly above the national average. Similarly, for milk availability, province 1, *Gandaki*, *Lumbini*, and *Sudur Pashchim* are above the national average. For eggs, the situation is different as all the provinces except *Bagmati* have the lower availability than the national average.

The per capita availability of milk in Nepal (210 ml/day) is less than that in Pakistan, India, and Bhutan (>250 ml milk/day) but higher than other South Asian countries (<200 ml/day). For meat availability, Pakistan and Nepal are relatively better with 21 and 18.0 kg meat/year respectively than other countries (FAOSTAT 2020). The available evidence indicates that current production of ASF is not adequate to meet the growing population particularly for province 2 and *Karnali* province. Therefore, emphasis should be given for the inclusion of

Table 14.4 Per capita availability (Per capita availability based on production, the import and export from one province to other and from other countries are not accounted for) of animal source food in different province (2018/2019)

Province	Estimated Population (2018/2019) ^a	Production			Per Capita Availability		
		Meat (MT)	Milk (MT)	Egg (No)	Meat (kg)	Milk (kg)	Egg (No)
1	4,979,367	68,738	430,188	245,311	13.8	86.4	49
2	5,933,751	47,358	308,953	110,160	8.0	52.1	19
Bagmati	6,071,338	78,792	397,974	804,543	13.0	65.5	133
Gandaki	2,650,470	40,966	280,612	109,013	15.5	105.9	41
Lumbini	4,985,163	66,437	390,082	189,808	13.3	78.2	38
Karnali	1,668,212	22,876	115,345	26,682	13.7	69.1	16
Sudur Paschhim	2,802,664	31,914	245,281	64,172	11.4	87.5	23
Nepal	29,090,965	357,081	2,168,435	1,549,689	12.3	74.5	53

^aPopulation projection from 2011 to 2018/2019 based on Census data with 1.4% annual increment (CBS 2012). Production data are from MoALD (2020)

ASF in the diet by increased production and better distribution mechanism to improve the nutrition of the growing population.

14.6 Challenges, Constraints, and Issues Facing in Livestock Sector

14.6.1 Low Productivity and High Cost of Production

For commercialization of the livestock sector, efficient production system is very important, and this is constrained by several factors. There has been limited access of livestock owners and entrepreneurs to knowledge and technologies, which makes the sector in subsistence mode even though with higher density of livestock population. The limited availability of feed and fodder for livestock, especially during winter and early summer is the major constraint to livestock productivity in the existing systems (Shrestha et al. 2005). The low level of productivity is attributable to poor genetic potential including inappropriate feeding, health care, and other general husbandry management practices (Neopane and Shrestha 2009; Paudel and Thakur 2015; Rasali 2015). Quality resource centres are lacking or

inadequate and this has made herd productivity improvement over generations difficult. Live-stock seed (i.e., live animals, semen, embryo, etc.) is important but not well-established in the country. Moreover, the country is fully dependent on imported poultry feed (e.g., soybean and maize) and imported genetic materials to sustain commercial livestock sector, which is not only increasing production costs and making less profitable but also risky during economic blockade and pandemics. Cost of production of livestock feed and products is high resulting in less competitive with imported products from neighbouring countries.

14.6.2 Increase Disease and Parasites in Livestock

A high incidence of disease and parasites is an important factor reducing the productivity and increasing the vulnerability of livestock production system (Rasali 2015). Bird flu is a major challenge in the growth of poultry production and marketing. Foot and Mouth Disease (FMD), Peste Des Petits Ruminants (PPR), Swine fever, Haemorrhagic Septicemia (HS), and Black Quarter (BQ) are the most occurring diseases in livestock species (Khatiwada et al. 2010; Poudel

et al. 2020). Mastitis in cattle and buffalo are problems in dairy production (Dhakal et al. 2010). Amongst the parasites in livestock species, the most occurring are liver fluke, paramphistomum, and ascaris (Joshi and Mahato 2013), which reduce the quantity and quality of milk and meat production. In addition, there is a high risks of pathogen spillover from livestock and poultry species to humans due to the lack of sufficient awareness of farmers about zoonosis and disease prevention measures (Poudel et al. 2020). Research capability and limited technologies generation including inadequacy of enabling policy in the sector have constrained the timely control and management of disease and parasites.

14.6.3 Marketing Hurdles and Challenges

Some of the important constraints being faced in the livestock sector are poorly developed marketing mechanism, uneconomic volume for bulking due to scattered production, non-adherence into good husbandry practices and good manufacturing practices resulting into poor quality livestock product marketing, drug residues in meat and milk, and development of antibiotic resistances in livestock species (Nepal et al. 2009; Premi and Aryal 2013). The small-scale scattered production increases the collection cost for the middlemen and traders that affects competitiveness of livestock production in the country. There is a poor value addition, processing, and storage facilities (e.g., cold stores) available for livestock products resulting in poor value chain and marketing. Demand for livestock and livestock products as well as inputs for livestock products are increasing rapidly in the country, but the domestic production is not able to meet this increasing demand due to poor value addition, and production and marketing constraints. Importation of live animals from abroad (in the form of seed) and semen and embryo now days has become very difficult (ABD 2018). Furthermore, currently markets are not being able to efficiently regulate marketing of

quality feed, milk and milk products, meat and eggs, and other livestock products due to absence of appropriate institutions and infrastructural facilities (Gauchan and Shrestha 2017; Nepal et al. 2009). Market hurdles for livestock products exist in the country mainly due to lack of subsidies and economic volume of production (Upreti et al. 2010).

14.6.4 Climate Change Impact

The production and consumption of the livestock products has social, cultural, and economic benefits; however, these food products have a cost to the environment (Herrero et al. 2015). Changes in climate with increasing drought, uncertain rainfall patterns, and increasing temperature have constrained the increasing productivity and profitability of livestock sector. Climate change effects are observed, and their impacts are visible in terms of low production and availability of fodder and forage, enhanced disease and parasite infestation, and others (Chaudhary and Upreti 2012; Khanal et al. 2011; Neopane and Devkota 2015; Neopane et al. 2016). An estimated 18% of human-caused greenhouse gas (GHG) emissions globally comes from livestock (HSUS 2008), and these values for Nepal equal about 23% of total national gross GHGs emission (Bajagai 2012). However, the information on the effect of climate change on the overall productivity of livestock is not available.

14.6.5 Institutional and Policy Issues

The livestock sector is suffering from limited institutional and human resource capacity, poor extension and outreach services which have constrained to reach many smallholder producers (Paudel et al. 2008). In addition, existing national forest and environmental policies are hindering sustainable development of livestock sector (Dhakal et al. 2015). For instance, the current forestry and community forestry policies have restricted the sustenance of traditional transhumance livestock

farming system resulting in decline of transhumance livestock farming and the growth of high mountain livestock development (Aryal et al. 2016; Panday and Gyawali 2013). In most cases agriculture and livestock related policies have not been implemented effectively because of various factors, including limited human resources and implementation capacity, lack of supportive legislation and monitoring and evaluation, poor coordination, and weak planning (Pradhanang et al. 2015). Hence, demand for livestock products, including high value cashmere (*pashmina*) for which Nepal has already established the market and brand name, is largely unmet resulting in huge import from neighboring countries.

14.7 Conclusions and Recommendations

The livestock sector in the country represents mainly of subsistence type with very limited commercial farming and less-developed value chains. The productivity of livestock is low despite the relatively high livestock population against the global average. Specifically, the current production and productivity of livestock is low particularly in *Karnali* and *Sudurpachhim* Provinces and remote hills and mountainous regions, where food insecurity and malnutrition are also the highest. The subsistence type of livestock farming is now slowly converting towards commercialization and modernization particularly in poultry production. Some scattered cases of commercialization with entrepreneurship development are emerging also in dairy cattle and buffalo and piggyery. Even though, projected growth of livestock population and products is likely to increase in the next 10 years, the production of livestock products is unlikely to meet nutritional needs of growing human population in the context of increasing population growth, increase in income growth, urbanization, and increased demand of livestock-based products in the country. Considering the diversity of livestock production system, differential strategies and programmes are required to

make country self-reliant on livestock products and ensure food and nutrition security of the growing population. Focus should be given on decentralization and diversification of production by utilizing rich indigenous breeds based on their suitability to specific ecological regions. Some of the important recommendations are outlined below.

14.7.1 Breed Improvements and Their Promotion

For commercialization of the sector, the productivity of livestock must be enhanced and sustained over the years. This can be possible through use of high yielding and profitable animals based on their performance. Resource centres for supply of livestock seed (live animal, semen, embryo etc.) should be established and strengthened. Use of native breeds of livestock with their improvements should be promoted and this would be more economical if cares are taken. For example, several native breeds' meat products (e.g., Sakini chicken, mountain goats) appear to be expensive than exotic breeds meaning that they have value for money. Improvement and promotion of native species and breeds and integration of livestock with crop and agroforestry would be a better adaptation strategy (Joshi and Shrestha 2004; Neopane and Devkota 2015). Promotion of native breeds, their value addition, and smallholder commercialization can be an effective sustainable development strategy for the country to meet increasing demands of native livestock products particularly amongst high end consumers in urban areas. The success of small holder commercialization in dairy cattle and meat goat has been demonstrated in the country (KUBK 2019). Special focus should be given to locally adaptive mountain goats and sheep breeds in mountainous region particularly in *Karnali* province and piggyery (particularly black colour pigs) in Province 1. Khari goats across the hills throughout the country should be strengthened using selective breeding for enhancing their genetic improvement.

14.7.2 Strengthening Market Infrastructure and Market Support Services

Improvement of market infrastructure and support services are suggested with the development of cooperatives, market centres, cold stores, and reducing the role of middlemen for farmer's profitability, and availability of quality and hygienic ASF for the consumers. For this, strengthening human resource and institutional capacity is essential that supports building capacity of farmers, entrepreneurs and other stakeholders (including R&D professionals), market institutions and their legal framework, and support services for livestock production, agribusiness innovation and marketing (Premi and Aryal 2013). Adequate investment on rural infrastructures and markets is essential to increase farmers' access to inputs, adoption of improved technologies, and farmer-market linkages. Financing and credit policy with soft and easy loans for agricultural machineries and commercial agriculture in rural areas is suggested (Gauchan and Shrestha 2017). Implementation of insurance schemes covering all livestock commodities to minimize risks in livestock farming is essential for commercialization of livestock husbandry.

14.7.3 Technology Development and Dissemination

With growing urbanization, increase remittance income, and dietary changes, the demand for high value dairy and meat products is increasing. This necessitates increased investment in R&D for the livestock sector focusing on suitable technologies for feed and nutrition, husbandry management, and post-harvest research for processing and marketing of livestock products. Development and dissemination of new modern and climate smart technologies are essential to control disease and parasites in animals and forages/fodder, improve productivity, adapt to changing climate, and reduce market vulnerability (Devkota et al.

2011; Khanal et al. 2011). Priority should be given to develop and disseminate cost-effective technologies for feed production (e.g., quality protein maize and soybean for feed) that are currently being imported from foreign countries. The research capacity on climate change is inadequate and needs enormous amount of improvement to develop livestock breeds, climate smart technologies, and practices that help in adaptation and mitigation. The increasing GHG emission from livestock implies that the country requires to improve breed quality of livestock animal for higher productivity by raising livestock in a sustainable manner (Chaudhary and Upreti 2012; Neopane and Devkota 2015; Upreti 2011). Public and private sectors collaboration and partnership for livestock research and development should be put in place.

14.7.4 Promotion of Local Production Systems and Practices Including Organic Farming

Technology development and support services must be adequately targeted to local production system utilizing niche areas including organic farming and use and improvement of native breeds amongst resource-poor smallholder farmers in the hills and mountains (Neopane and Devkota 2015; Shrestha 1995). The organic livestock farming that utilizes diverse native animal genetic resources will promote the biodiversity as it is based on native breeds and local practices. The organic farming operating in the country uses several products from livestock species and breeds and this contributes to the promotion of animal genetic resources. For livestock production, areas for niche commodities should be identified and promoted that have comparative advantages in specific ecologies such as yak and Chauri, and sheep and *Chyangra* in the higher hills and the high mountains, and sheep, goats, chicken, and pigs in the lower mid hills and Terai (Neopane and Devkota 2015). There is a need to be focussed on the productivity enhancement of native livestock breeds through organic ecological

production system in the country based on the comparative advantages.

14.7.5 Building Capacity of Institutions and Stakeholders

Presently, livestock sector in the country is receiving less attention by policy makers and planners in budget allocation, investment, and capacity building. The human resources and institutional capacity of livestock sector should be strengthened to increase productivity, promote business innovation, and enhance product quality standard. Enhancement of capacity of livestock farmers, agro-entrepreneurs, R&D professionals and their community and market based-institutions, and technology development and provisions are critical to support economic volume of production and marketing. Increased support for sustainable livestock production system supporting small-scale farmers with assurance of equal access to land, technology, and markets is essential (UNDP 2020). Increased laboratory facilities and capacity building for the isolation and characterization of field strains of pathogens and production of different types of vaccines using the latest technologies are essential for veterinary vaccine production (Poudel et al. 2020). Similarly, capacity building of national research farms and centres in maintaining breeding animals and connecting this to performance recording system would be necessary. Capacity building of local government institutions for extended AI services and establishing national herd registration systems with Pedigree Performance Recording System (PPRS) and formulating national breed and technology certification mechanism must be in place.

14.7.6 Enabling Policy Environments

Enabling policy environments in terms of suitable policies, institutions, market systems, and public support services are vital to increase productivity, profitability, and sustainability of

livestock production to ensure food and nutrition security systems. Effective implementation of current livestock and agricultural related policies and the arrangement of institutional set up are required to improve production and timely delivery of quality inputs, feed, and support services. Access to new technologies, agricultural credit, and public support system is crucial for expansion of improved technologies, practices, and adoption of market-oriented production systems. The major support services currently used in livestock production include research and extension promotional activities, price and transport subsidy on quality inputs mainly feed, forage seed and machineries, quality assurance services and regulation, and information support services. Livestock policies and programmes also need to prioritize on production of livestock feed in addition to livestock products to reduce escalating imports by developing and disseminating suitable improved varieties of feed and breeds of livestock and delineating special zones and production pockets.

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Land and Livestock Ownership and Household Food Security in Nepal

15

Prem Bhandari

Abstract

Do land and livestock ownership play a role in addressing household food security in Nepal? This chapter empirically investigates the associations between agriculture—specifically the land and livestock ownerships and food security—in Nepal. Although over two-third of the households rely on agriculture for livelihood, slightly over one-half (52%) of the households are food insecure. More importantly, while a large proportion of holdings in Nepal own at least some land and animals, the presence of a large fraction of food-insecure households raise the above question. Using the sustainable livelihood (SL) framework, which has been widely used to assess the factors influencing various livelihood outcomes including food security, this chapter investigates the issue at the household level using the nationally representative 2016 Nepal Demographic Health Sur-

vey (NDHS) data. This data provides unique opportunity to examine the question. The results based on the multilevel regression (binary logistic and OLS regressions) show that the ownership of both land and livestock are significantly and positively associated with household-level food security, adjusting for other factors such as age, gender, and education of the household head, household size, a household's wealth status and geographical location of a household. Indeed, at the household level, the ownership of land and livestock reduced the food insecurity problem. The evidence, in general, suggests that while agriculture is important in addressing the food insecurity challenge in the country, it's not sufficient and a household's access to other capital assets such as education, wealth status, and geographical location of a household are equally important for solving the problem. As Covid-19 is still evolving, the post-Covid-19 effects on food security is beyond the scope of this chapter. Overall, any policy that provides the ownership of land and animals to the households will help lessen food insecurity problem in the country.

Keywords

Assets · Food security · Land · Livestock · Ownership · Sustainable

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15.1 Introduction

Food security is one of the global challenges. Globally, one-in-four people (1.9 billion) are moderately or severely food insecure (Roser and Ritchie 2019). According to the World Bank (2021), the year 2020 marked the most severe increase in global food insecurity and it is expected that this will have significant impact on vulnerable households in almost every country. Nepal is not an exception. The most recent mVAM Household Livelihoods, Food Security and Vulnerability Survey (2020) reported that 20.2% of households had inadequate food consumption and 4.7% of households had poor dietary diversity (Government of Nepal and WFP 2020). Slightly over 43% of children between the age of 6 and 23 months of age could not meet the minimum recommended dietary diversity. As the Covid-19 is evolving, its effect on food security will be further worsened worldwide over time.

Nepal, an agriculturally-based country, is one among the most food-insecure countries in the world. Based on the Global Food Security Index (GFSI), in 2021, Nepal ranked 79 out of 113 countries with a GFSI of 53.7. The affordability score was reported at 48.3, the availability score was 65.4 and the quality and safety score was 53.7 out of 100 (Economist Impact 2021). Nepal's average energy intake increased to 2536 kilocalories/person/day in 2010/2011 from 2350 kilocalories (kcal) per person per day in 2005–2007 (WFP et al. 2013).¹ The Global Hunger Index (GHI) is improving and is at 19.1 in 2021 as compared to 22 reported in 2017 (von Grebmer et al. 2021). In 2015, about one-quarter of the Nepali population was still below poverty line (GoN 2015). In 2010/2011, of the Nepal's

75 districts, 38 were characterized as food-insecure districts (GoN 2012). Among them, two districts were self-sufficient for less than three months only, three districts were food secure for 3–6 months, 14 were food secure for 6–9 months and 19 districts were food secure for 9–12 months.

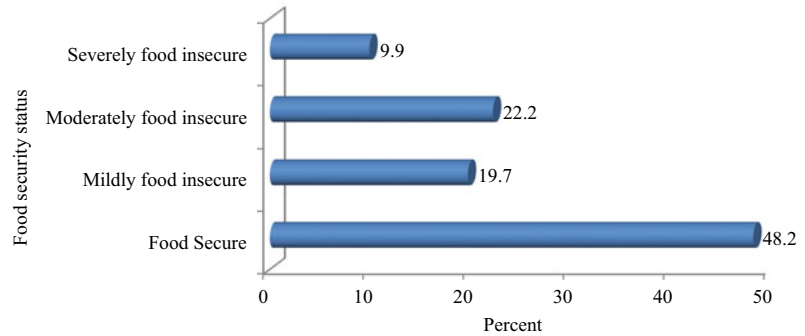
According to the 2016 Nepal Demographic and Health Survey (NDHS) (Ministry of Health, Nepal; New ERA; and ICF 2017) that used the Household Food Insecurity Access Scale (HFIAS) for measuring food security, nearly half (48.2%) of the households were food secured (Fig. 15.1). In total, 19.7%, 22.2%, and 9.9%, respectively, were mildly, moderately, and severely food insecure. Specifically, the severely food-insecure households reduced from 16% in 2011 to 10% in 2016. However, the mildly food-insecure household increased from 12 to 20%. These numbers suggest that Nepal continues to struggle from food insecurity problems and requires serious attention and concerted efforts to overcome food insecurity challenge.

The Government of Nepal (GoN) aims to eradicate poverty, end hunger and all forms of malnutrition *by ensuring access to safe, nutritious, and sufficient food all year round the year for all people by 2030 through its sustainable development goals (SDGs) programs* (Government of Nepal 2015). More importantly, the 2015 Constitution of the Federal Democratic Republic of Nepal has recognized “*the right to food as a fundamental right*” of its citizens (Kaphle et al. 2020; NHRC and FAO 2017). Nepal requires concerted efforts to meet the challenge of food insecurity problem and meet SDGs by 2030.

Evidence shows that the ownership of land and livestock are among the key factors associated with food insecurity in Nepal (FAO 2011; Little et al. 2006; Maharjan and Khatri-Chhetri 2006; Subedi and Dhital 2007). In Nepal, the average size of operational holdings (actual area cultivated) is only 0.5 hectares and 95% of the holdings are operated by small farmers who have less than 2 hectares of land (Central Bureau of Statistics 2013). On the other hand, *livestock keeping* is also an integral part of farming in

¹ A moderately active adult man (18–50 years of age) requires about 2400–2800 kcal of energy intake and a moderately active adult woman of this age requires about 2000–2200 kcal of energy intake. Source: Institute of Medicine. Dietary Reference Intakes for Energy, Carbohydrate, Fibre, Fat, Fatty Acids, Cholesterol, Protein, and Amino Acids. Washington (DC): The National Academies Press; 2002. <https://health.gov/dietaryguidelines/2015/guidelines/appendix-2/>.

Fig. 15.1 Distribution of households (percent) by food insecurity, Nepal. *Source* Ministry of Health, Nepal; New ERA; and ICF (2017)



Nepal. Animals are kept for food (meat, milk, egg, manure, animal power, and other food products), employment, and income to farm families. Thus, the ownership of land and animals is considered a key to address food insecurity problem of households (FAO 2011). It is reported that a total of 3354 thousand holdings owned some types of livestock (Central Bureau of Statistics 2013). For example, among these holdings, 68% of them reported that they owned cattle, 50% holdings had a buffalo, 70% had a goat, 3% of them had a sheep, and 13% of them had a pig.

Overall, this chapter examines the associations between the land and livestock ownership—the access to productive assets—and household-level food security in Nepal. This investigation is important because a large majority of households still rely on agriculture to meet food demand and the relationships between food security and the ownership of productive capitals such as land and livestock have not been empirically assessed, previously. This chapter utilizes the sustainable livelihood (SL) framework (e.g., Bebbington 1999; DFID 1999) to empirically investigate the theoretical relationships among interest variables. This framework has been widely used to assess the factors influencing various livelihood outcomes including food security. Specifically, the goal is to empirically investigate the associations using the nationally representative household-level data from 2016 Nepal Demographic Health Survey (NDHS) (Ministry of Health, Nepal; New ERA; and ICF 2017). The findings from this research will be important guide to the newly formed

federal and provincial governments in designing and perusing food security policies.

15.2 The Concept, Dimensions, and Measurement of Food Security

Food security is a multidimensional concept. Thus, measuring the concept per se is not an easy task. There were already over two hundred definitions of food security in 1996 (Maxwell 1996) and there is no doubt that this number has multiplied over time. The most commonly used definition of food security is offered by the World Food Summit (1996), which is defined as: “*Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life.*” This definition has acquired the broadest acceptance (Smith et al. 1993).

There are four dimensions of food security: availability, access, utilization, and stability (FAO 2006; Napoli 2010/2011) (Fig. 15.2). The first three dimensions, food availability, accessibility, and utilization are the physical dimensions and stability is the temporal dimension (Napoli 2010/2011). The nutritional status, the ultimate outcome, is determined by food utilization, which depends upon the accessibility of food, which is determined by its availability. The availability of food does not always translate into accessibility due to inadequate income or low purchasing power. In addition, the accessibility of food does not guarantee its proper utilization

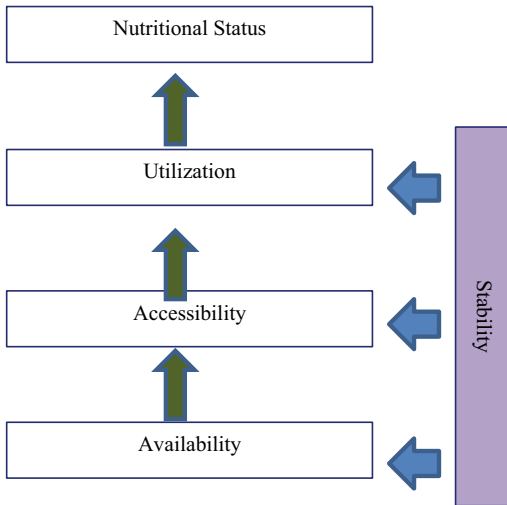


Fig. 15.2 Dimensions of food security framework. 2011 Source Adapted from Napoli (2010/); also, Bhandari et al. (2020)

by a household. The sustainable utilization, accessibility, and availability of food are greatly influenced by factors such as weather, conflict, unemployment, disease and so on also known as the stability dimension. Thus, the stability dimension influences other three components of the food insecurity framework over time. This chapter primarily focuses on the *accessibility* of food security.

This chapter uses the *Household Food Insecurity Access Scale (HFIAS)* developed by Food and Nutrition Technical Assistance (FANTA) of USAID (Coates et al. 2006, 2007). The measurement instrument consists of nine items that measure occurrence and frequency of food access.

In HFIAS, the nine items are grouped into three domains of food insecurity access: (a) anxiety and uncertainty about household food supply, (b) insufficient quality that includes variety and preferences of food types, and (c) insufficient food intake. These items are measured in a scale of 0–3 (0 = never, 1 = rarely, 2 = sometimes, and 3 = often).

The first domain is also known as “anxiety domain” is *anxiety and uncertainty about household food supply*. This domain is measured by asking “In the past 12 months, how frequently

did you worry that your household would not have enough food?”.

The *second domain* is *insufficient quality* which measures whether a household experienced having limited choices in the type of food that a household eats during a specific period. The following *three* items measure this domain. In the past 12 months,

- How often were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?
- How often did you or any household member have to eat a limited variety of foods due to a lack of resources?
- How often did you or any household member have to eat some foods that you really did not want to eat because of a lack of resources to obtain other types of food?

The *third dimension* is *insufficient quantity*, which measures whether a household had to cut the amount of food due to a lack of resources. The following five items measure this domain. In the past 12 months.

- How often did you or any household member have to eat a smaller meal than you felt you needed you felt you needed because there was not enough food?
- How often did you or any household member eat fewer meals in a day because of lack of resources to get food?
- How often was there with no food to eat of any kind in your household because of lack of resources to get food?
- How often did you or any household member go to sleep at night hungry because there was not enough food?
- How often did you or any household member go a whole day and night without eating anything because there was not enough food?

The type and number of occurrence indicators and time frame may be modified depending upon the context. Using the aforementioned indicators, the HFIA scale is calculated, which is the sum of the frequency of occurrence of items during the

past reference period.² The summated scale ranges from 0 to 27 for nine items (0–21 for seven items). The higher number in the scale refers to a greater level of food insecurity and vice versa. This scale is used for food security groupings—food secure, mildly food insecure, moderately food insecure, and severely food insecure (Coates et al. 2007; NDHS 2011). The *household hunger scale (HHS)*, is another proxy indicator of food access, also known as the household food deprivation scale (Ballard et al. 2011). The HHS originates from HFIAS and is based on the response to three items about perceptions of a household on varying degrees of hunger by the number of times a household has experienced hunger within the past 30 days prior to the survey. The frequency of occurrence is measured as: never (0 times) = 0 score; rarely/sometimes (1–10 times) = 1 score; and often (more than 10 times) = 2 score.

15.3 The Sustainable Livelihood Framework and Food Security

15.3.1 The Concepts

According to Chambers and Conway, a *livelihood* comprises the capabilities, assets, and activities required for a means of living. The concept of “livelihood” has been widely adapted by many (e.g., Bhandari et al. 2020; Morse et al. 2009; Morse and McNamara 2013). Similarly, for them (p 7), a *livelihood is sustainable* when “it can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation.” This concept began during the 1992 Earth Summit held in Rio (Morse and McNamara 2013) that led to the Agenda 21 (Agenda for the 21st Century). The aim of Agenda 21 was that everyone must have the “opportunity to earn a sustainable livelihood.” A number of frameworks have been

developed to study sustainable livelihoods. A few examples are: DFID livelihood model, CARE livelihood model, Oxfam livelihood model, IFAD livelihood framework, and IMM livelihood framework (Acharya et al. 2012).

15.3.2 The Sustainable Livelihood Framework

This chapter utilized the sustainable livelihood framework (SLF) developed by DFID (1999) to empirically investigate the associations between land and livestock ownership and food security while controlling for other livelihood assets. This SLF is comprehensive and is widely used to examine the links between various dimensions of livelihood such as livelihood assets and livelihood outcomes including food security (DFID 1999). The framework (Fig. 15.3) is discussed in detail in Bhandari et al. (2020).

There are five components in DFID’s livelihood framework: (a) vulnerability context, (b) livelihood assets, (c) transforming structures and processes, (d) livelihood strategies, and (e) livelihood outcomes. Each of these components is interconnected and the livelihood outcomes are directly or indirectly determined by the first four prior components.

15.3.2.1 Vulnerability Context

This component includes various external factors that influence a household’s (individual’s) access to assets and livelihood opportunities. These factors are (i) shocks (e.g., weather, human and health shocks, conflict, economic and environmental shocks); (ii) trends (e.g., population, resources, economic, and technology trends); and (iii) seasonality (e.g., price, production, health, and employment opportunities). These trends are external to the system and affect livelihood outcomes and the availability of and the access to assets.

15.3.2.2 Livelihood Assets

This component includes various capitals that directly or indirectly influence livelihood outcomes. These assets or capitals are: *Human*

² Recall period may vary—“in the past 30 days” or “in the past 12 months” depending upon the context.

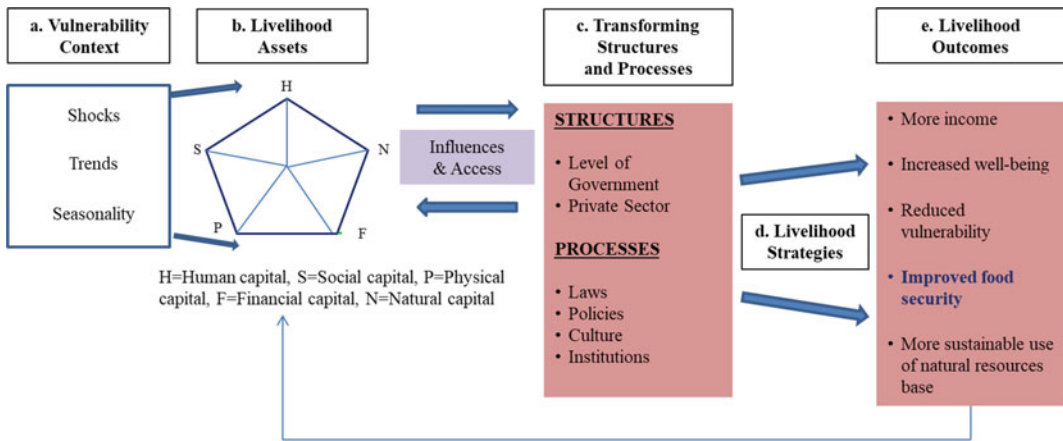


Fig. 15.3 Sustainable livelihood framework. *Source* Adapted from DFID (1999)

capital (H in Fig. 15.3) comprises the amount and the quality of labor available, skills, knowledge, and health that together enable individuals or households to pursue different livelihood strategies to achieve their livelihood objectives. *Natural capitals* (N in Fig. 15.3) are resource stocks such as land and land quality, topography, flora and fauna, water, air, and environmental services from which livelihoods are derived. *Financial capitals* (F in Fig. 15.3) are economic resources that include both flows as well as stocks and contribute to both consumptions as well as production. *Physical capitals* (P in Fig. 15.3) are the basic infrastructures and producer goods essential for supporting livelihoods such as transportation, road, market, water supply, schools, banks, cooperatives, employment centers, community development programs, communication, health and sanitation, and many other nonfamily services (Ahmed et al. 2008; Bebbington 1999; DFID 1999). Finally, *social capital* (S in Fig. 15.3) refers to various “social resources upon which people draw in pursuit of their livelihood objectives” (DFID 1999: Sect. 2.3.2). According to DFID (1999), social capital resources are developed through (i) networks and connections that increase people’s trust and ability to work together and expand their access to wider institutions; (ii) membership of formalized groups which is often a reflection of adherence to mutually-agreed or commonly

accepted rules, norms and sanctions; and (iii) relationships of trust, reciprocity, and exchanges that facilitate cooperation and may provide the basis for informal safety nets.

15.3.2.3 Transforming Structures and Processes

This component comprises of institutions, organizations, policies, and legislations that facilitate the application of livelihood capitals and shape livelihood outcomes. The structures or institutions/organizations help create, implement and enforce legislation.

15.3.2.4 Livelihood Strategies

Livelihood strategies are various options for pursuing livelihood goals. The greater the diversity of livelihood strategies, the higher the household’s resilience to the shocks, trends, and seasonality conditions within the vulnerability context.

15.3.2.5 Livelihood Outcomes

The aforementioned components directly or indirectly influence the fifth component of the framework—livelihood outcomes. These outcomes are the outputs such as increased income, greater well-being (e.g., self-esteem, physical security, empowerment, etc.), reduced vulnerability, greater food security, and/or improved environmental sustainability.

15.3.3 Nepal's Agricultural Context

Nepal is an agriculturally-based country. Agriculture is subsistence, however, remains the major source of income and employment for the majority of households. Nearly two-third of households make their livelihood from agriculture, which absorbs about 60% of the labor force for employment. According to the 2016 Nepal Demographic Health Survey, agriculture provides jobs for both women (70%) and men (33%). Farmers have been commonly practicing mixed farming—which includes a number of crop varieties such as cereals, vegetables, fruits, and fodder crops for animal production. In addition, farmers keep animals such as cattle, buffalo, goats, sheep, pigs/swine, chicken ducks, and other birds. Production of a variety of crops and animals even in a small scale may increase the dietary diversity of household members.

According to the sustainable livelihood framework, both land and livestock are natural capitals and are crucial for sustaining livelihoods of people. Both of these capitals are economic as well as social resources as the access to and ownership of these resources provide employment and income. In addition, the ownership of land is an important criterion in defining one's position in the socio-political-economic class hierarchy (Blaikie et al. 2000; De Janvry 1981). The ownership of this vital resource increases control over other resources such as earned income from land, political power, and access to other institutions, for example, banks.

cultivated) is only 0.5 hectares. 95% of holdings are operated by small farmers who have less than 2 hectares of land, covering 72% of the cultivated area. Of the total holdings, 85% of them owned at least some land. The proportion of holdings who owned less than 2 hectares of land was 95% (58% of the holdings owned less than 0.5 hectares of land, which was only 21% of the total owned holding). This evidence shows that an overwhelming majority of owned holdings are small and marginal.

Livestock keeping is an integral activity of farm households. Animals provide food (meat, milk, egg, animal power, and other food products), employment, and income to farm families. Farm households may sell animals and earn incomes. Therefore, the ownership of livestock is a key to address food insecurity problem of households (FAO 2011). In Nepal, the 2011/2012 national sample census of agriculture 3354 thousand holdings reported having different types of livestock. Among these holdings, 68% of them reported that they owned cattle, 50% of holdings had a buffalo, 70% had a goat, 3% of them had a sheep, and 13% of them had a pig. Evidences suggest that households with large livestock size are less vulnerable to food insecurity, especially in times of drought when crops fail (FAO 2011; Little et al. 2006). Animals are important source of financial, economic, and social capitals in times of need and therefore, are important elements of food security assets.

Subedi and Dhital (2007) noted that small-holdings, marginal land for agricultural production, weather-dependent cultivation, and poor technology/technical know-how of farmers are some of the key factors influencing food insecurity in the country. Similarly, Maharjan and Khatri-Chhetri (2006) found that food secure households have significantly higher amount of total land, and have higher percentage of irrigated land as compared to food-insecure households. Maharjan and Khatri-Chhetri (2006) further reported that food security increases with the increase in number of total livestock holdings. Using the nationally representative 2016 Nepal Demographic Health Survey data, this

15.4 Theoretical and Empirical Review

15.4.1 The Ownership of Land and Livestock and Food Security in Nepal: A Review

In Nepal, 3831 thousand holdings reported some land (Central Bureau of Statistics 2013). The average size of operational holdings (actual area

chapter empirically investigates: *Does the relationship between the ownership of land and animals hold true even after adjusting for other theoretically known confounding factors?*

15.4.2 Other Potential Factors of Food Security: A Review

There are many other potential factors that are theoretically known to influence both the outcome and explanatory variables.

15.4.2.1 Human Capital and Food Security

Human capitals are education, skills, knowledge, health, and the amount and quality of labor availability that together enable individuals or households to pursue various livelihood strategies (DFID 1999). *Education*, an important human capital, enhances knowledge and skills, which will strengthen capability to initiate production-oriented agriculture, agri-business or increases rewarding employment opportunities. This will ultimately help increase a household's overall income, which may be used to overcome food insecurity problem. Evidences suggest that education is negatively associated with food insecurity, malnutrition, and hunger (Beyene and Muche 2010; Iftikhar 2017; Sseguya 2009).

Household size. The availability of quality labor at home may also influence productive activities in the household. Thus, the household size may influence both consumptions as well as production. Garret and Ruel show evidence of a negative association between household size and food security in Mozambique. Maharjan and Joshi (2011) also found a negative association between family size and food security in Nepal.

Sex and age of household head. According to the 2011 Population Census of Nepal, nearly 26% of households are headed by females (CBS 2012). As nearly two-third of households are engaged in agriculture, gender of a household manager may have an important influence on

household food security. Similarly, *age of the household head* could be another important factor to have an effect on household food security. Evidence suggests that elderly managers may be less likely to engage in production-enhancing activities using modern farm inputs (Bhandari 2006). Thus, age of the manager may have a negative influence on household-level food security. Another way round, elderly managers could utilize knowledge and experience to solve food insecurity problems (Beyene and Muche 2010).

15.4.2.2 Financial Capital and Food Security

Financial capitals such as savings, cash, bank deposits, and remittances may be invested to achieve livelihood outcomes. Thus, the access to financial capitals may reduce food insecurity problem of a household. A household may purchase farm inputs such as chemical fertilizers, pesticides, and improved farm implements, and use them on their farms. Thus, a *household's wealth* such as the ownership of home or land or other assets can be an important indicator of financial/economic capital. Regmi et al. (2015) provide evidence that the earned incomes were used to improve households' food security in Bangladesh.

15.4.2.3 Social Capital and Food Security

Social capitals are various "social resources upon which people draw in pursuit of their livelihood objectives" (DFID 1999: Sect. 2.3.2). These resources are the networks and connections developed by an individual, a household, or a community through membership, relationships, reciprocity, and exchanges that facilitate cooperation among individuals or households. Social capital is important at times of financial hardship, food shortages, or severe illnesses to overcome adverse events (Liverpool-Tasie et al. 2011). In Uganda, Sseguya (2009) found that households with social capital significantly reduced food insecurity.

15.4.2.4 Physical Capital and Food Security

Physical capitals are basic infrastructures such as transportation, road, market, schools, banks, cooperatives, employment centers, communication, health and sanitation, and other nonfamily services (Ahmed et al. 2008; Bebbington 1999; DFID 1999). The access to such infrastructures and services may improve a household's food security status. For example, a household's proximity to the urban center where most infrastructures are available, or the location of a household in the Terai region or those in the remote provinces may experience differential account of food security (Bhandari 2019; Bhandari et al. 2020).

15.5 Methods

15.5.1 Data

This chapter used the nationally representative Nepal Demographic Health Survey (NDHS) data collected in 2016. The NDHS was designed to collect information and provide estimates of key population and health indicators for the country as a whole. The research design is multilevel in nature and used multi-stage sampling procedure to identify samples. The detailed procedure for sampling and data collection is provided in the NDHS 2016 report (Ministry of Health and Population (MOHP) [Nepal], New ERA, and ICF International Inc. 2017). This survey utilized recently revised political division of the country considering seven provinces, 75 (not 77) districts, and 217 municipalities. Altogether, in the first stage, a total of 383 wards (199 rural and 184 urban) were selected. A total of 11,490 households, 5520 in urban areas, and 5970 in rural areas were selected. Three questionnaires were administered—the Household Questionnaire, the Women's Questionnaire, and the Men's Questionnaire. The data utilized here comes from the household questionnaire that collected information from 11,490 households and contains detailed information on household-level food security reported by a household member.

15.5.2 Measures

Measurement of outcome and explanatory measures and controls is discussed below.

15.5.2.1 Outcome Measures

Measures of Food Insecurity. As discussed earlier, HFIAS includes three domains of food insecurity: (a) anxiety and uncertainty about household food supply, (b) insufficient quality which includes variety and preferences of food types), and (c) insufficient food intake. The NDHS (2017) included these items to measure food security. Each item was measured whether a household experienced that item in the past 12 months or not. Each item was measured in ordinal scale with four responses 'never, rarely, sometimes, and often'.

The household food security scale was measured as follows. First, a food insecurity index was calculated which is the sum of the frequency of occurrence during the past 12 months. As each of these items is measured in a scale of 0–3 (0 = never, 1 = rarely, 2 = sometimes, and 3 = often), the summated index or the scale ranged from 0 to 27. Higher number in the scale represents a greater level of food insecurity. Next, the three domains as presented earlier were also separately created. First, each response item whether a household experienced or not was recoded. The response was dichotomized as "0" if a household did not experience in the past 12 months vs. "1" if a household experienced the item as rarely, sometimes, or often. For example, (a) anxiety and uncertainty about household food supply were coded 0 vs. 1, (b) insufficient quality that includes variety and preferences of food types was coded 0 vs. 1, and (c) insufficient food intake was coded as 0 vs. 1.

15.5.2.2 Explanatory Measures

Land and livestock ownership are the two major explanatory variables. *Land ownership*—the measure of a household's access to and ownership of land at the time of survey—was measured as whether a household owned any land (coded 1) or not (coded 0). Similarly, the ownership of *livestock* was separately measured as the

ownership of cattle/buffalo, cow/bulls, goats, chicken, and pigs each coded as yes (=1) or no (=0).

15.5.2.3 Controls

The effects of several households and geographic controls theoretically known to influence a household's food security are measured as: *Household size* was measured as the number of persons in a household. *Age of the household head* is measured in years. *Gender of household head* was coded as male (=0) and female (=1). *Education* of a household head was measured as no education, primary (grade 1–5), secondary (grades 6–10), and higher (11 plus). A household head with no education has been considered as the reference category. A household's *wealth index*, a composite index (NDHS 2016), was measured in quintiles and is coded as: lowest quintile, second quintile, third (middle) quintile, fourth quintile, and fifth (highest) quintile. The lowest quintile is used as the reference category. Geographic controls included a households' location by *ecological regions* which were grouped into three categories—mountain, hill, and the Terai. The Terai region is the “bread basket” or the “granary” of the country and thus, used as the reference category. *Rural–urban location* of a household was another geographic measure and rural location is considered as the reference category. Similarly, location of a household by *province* was also controlled. There are seven provinces. Province six lies in the far-western-northern region of the country which has among the lowest socio-economic development indicators. Thus, this province is considered as the reference category.

15.5.3 Analytic Strategy

First, descriptive statistics of the measures were calculated (Table 15.1). Second, bivariate analysis between outcomes and explanatory variables was performed (Table 15.2). Next, as the data was multilevel in nature, several multivariate

models using the multilevel modeling (hierarchical linear modeling) techniques were estimated. These multilevel procedures take into account of clustering of households by geographic clusters (Garson, 2013). Before running the multilevel modeling, the statistical significance of the intercept component is examined for each model. If the intercept component is statistically significant, the intraclass correlation coefficient (ICC) is also statistically significant implying that a multilevel modeling approach is appropriate and needed for the analysis (Garson 2013).

The first outcome measure, household food security scale is a continuous measure (model 1 in Table 15.3). Thus, a multilevel Ordinary Least Square (OLS) regression model was estimated using *lmer* function of R (also PROC MIXED SAS). The results are presented as unstandardized regression coefficients. For continuous independent variables, a positive regression coefficient is interpreted as—a unit increase in an independent variable increases the outcome variable by ... points and vice versa. Similarly, for categorical independent variables—a positive regression coefficient is the unit greater than the reference category and a negative regression coefficient is the unit lower than the reference category.

For dichotomous outcomes that measured household-level food insecurity, multilevel logistic regression models were estimated using the *glmer* function of R (also SAS GLIMMIX) (models 2–4 in Table 15.3). The results are presented as odds ratios for easy and clear interpretation. According to Liao (1994: 16), the odds ratios are “the odds of having an event occurring versus not occurring, per unit change in an explanatory variable, other things being equal.” The values of odds range from 0 to infinity. For continuous independent variable, “an odds ratio greater than 1 indicates that the odds of being ... increases when the independent variable increases; and an odds ratio of less than 1 indicates that the odds of being ... decreases when the independent variable increases” (Menard 1995: 49).

Table 15.1 Descriptive statistics of measures used in the analysis ($N = 11,040$ households)

Measures	Descriptive Statistics		
	Mean	SD	Min–Max
<i>Outcome measures</i>			
Overall food insecurity (score)	3.79	4.70	0–27
Anxiety and uncertainty about food supply (Yes = 1)	0.09	0.28	0–1
Insufficient quality (Yes = 1)	0.53	0.50	0–1
Insufficient food intake (Yes = 1)	0.22	0.41	0–1
<i>Explanatory measures</i>			
Land ownership (owns = 1)	0.80	0.40	0–1
Animals ^a : Owns cattle/buffalo (=1)	0.31	0.46	0–1
Owns cow/bulls (=1)	0.45	0.50	0–1
Owns goats/sheep (=1)	0.52	0.50	0–1
Owns chicken (=1)	0.39	0.49	0–1
Owns pigs (=1)	0.09	0.29	0–1
<i>Household wealth status</i>			
Wealth index (lowest quintile = 0)	0.25	0.43	0–1
Second quintile	0.21	0.41	0–1
Third (middle) quintile	0.19	0.39	0–1
Fourth quintile	0.19	0.39	0–1
Fifth (highest) quintile	0.17	0.38	0–1
Household size (numbers)	4.44	2.28	1–38
Gender of household head (Female = 1)	0.33	0.47	0–1
Age of household head (years)	46.00	14.80	15–95
Education of household head (Ref: No education)	0.40	0.49	0–1
Primary	0.23	0.42	0–1
Secondary	0.26	0.44	0–1
Higher	0.11	0.31	0–1
Ecological regions: Terai (Reference)	0.44	0.50	0–1
Mountain	0.08	0.28	0–1
Hill	0.48	0.50	0–1
Rural–urban: Urban (Reference)	0.63	0.48	0–1
Rural	0.37	0.48	0–1
Federal provinces: Province 6 (Reference)	0.13	0.34	0–1
Province 1	0.15	0.36	0–1
Province 2	0.15	0.35	0–1
Province 3	0.15	0.36	0–1
Province 4	0.14	0.34	0–1
Province 5	0.15	0.36	0–1
Province 7	0.13	0.34	0–1

^aOnly a fraction of household own horses, ducks, and yak. Therefore, these households are excluded from the analysis

Table 15.2 Mean comparisons between land and livestock ownership and food insecurity in Nepal, 2016 ($n = 11,040$)

Measures	a. Overall food insecurity (score)	b. Anxiety and uncertainty about food supply (Yes = 1)	c. Insufficient food quality (Yes = 1)	d. Insufficient food intake (Yes = 1)
<i>Land ownership</i>				
Owens ($n = 8835$)	3.64	0.08	0.53	0.20
Does not own ($n = 2205$)	4.38***	0.13***	0.54	0.27***
<i>Cattle/buffalo</i>				
Owens ($n = 3368$)	3.79	0.07	0.56	0.21
Doesn't own (7672)	3.79	0.09***	0.51***	0.22
<i>Cow/bulls</i>				
Owens ($n = 4938$)	4.46	0.09	0.61	0.25
Doesn't own (6102)	3.25***	0.08**	0.46***	0.19***
<i>Goats</i>				
Owens ($n = 5751$)	4.10	0.08	0.59	0.23
Doesn't own (5289)	3.45***	0.10***	0.46***	0.20**
<i>Chicken</i>				
Owens ($n = 6750$)	2.56	0.09	0.58	0.23
Doesn't own (4290)	4.16***	0.09	0.49***	0.21**
<i>Pigs</i>				
Owens ($n = 10,047$)	3.77	0.10	0.57	0.23
Doesn't own (993)	4.01	0.08	0.52	0.21

t-test results: $^+p < 0.10$, $^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

For categorical independent variables, “an odds ratio greater than 1 indicates an increased chance of an event occurring versus not, and an odds ratio less than 1 indicates a decreased chance of an event occurring versus not occurring” (Liao 1994:15). AIC (Akaike information criterion) is used as the goodness-of-fit measure and the Null (intercept only) and the model AIC values within each model are compared. The lower AIC values as compared to the Null values are the better fitting models (Garson 2013).

15.6 Results and Discussion

15.6.1 Descriptive Results

Table 15.1 presents the descriptive statistics of the measures used in the analysis. Based on the table, the average household-level food insecurity scale

(score) is 3.79 which ranged from 0 to 27 (0 being food secure and 27 being highly food insecure). Nearly one-half of the households (41% with 0 score) reported that they were food secure. This proportion decreased from 2011 results which were 48% (with 0 score). By food security domains, only nine percent of the households reported that they experienced anxiety and uncertainty about food supply in the past 12 months. On the other hand, slightly over half (53%) of the households reported that they were worried about insufficient quality supply—limited choices in the variety of foods and 22% of them reported insufficient food intake (quantity) in the past year due to a lack of resources.

Eighty percent of the households reported that they owned some farmland. 31% of households owned cattle/buffalo, 45% owned cow/bulls, 52% owned sheep/goats, 39% owned chicken and only nine percent owned pigs.

Table 15.3 Multilevel models estimating the associations between land and livestock ownership and food insecurity, controlling for other factors in Nepal, 2016 ($n = 11,040$)

Measures ^a	a. Overall food insecurity (score) (model 1)	b. Anxiety and uncertainty about food supply (odds ratios) (model 2)	c. Insufficient food quality (odds ratios) (model 3)	d. Insufficient food intake (odds ratios) (model 4)
<i>Explanatory variables</i>				
<i>Natural capital:</i> Land ownership (owns = 1)	-1.33***	0.44***	0.59***	0.46***
Animals: Owns cattle/buffalo (=1)	-0.66***	0.58***	0.78***	0.68***
Owns cow/bulls (=1)	-0.50***	0.70***	0.86**	0.76**
Owns goats (=1)	-0.39***	0.59***	1.04	0.76***
Owns chicken (=1)	-0.25**	0.80*	0.94	0.79***
Owns pigs (=1)	-0.05	1.23	0.94	1.05
<i>Human capital:</i> Household size (numbers)	0.09**	1.04*	1.04***	1.05***
Gender of household head (Female = 1)	-0.25**	0.80*	0.94	0.80***
Age of household head (years)	-0.01*	1.00	1.04***	1.00
<i>Education of household head (No education, 0, Reference)</i>				
Primary	-0.69***	0.74***	0.78***	0.69***
Secondary	-1.26***	0.50***	0.52***	0.48***
Higher	-1.96***	0.24***	0.30***	0.26***
<i>Financial/Economic capital: Wealth index (lowest quintile = 0, Reference)</i>				
Second quintile	-2.67***	0.31***	0.35***	0.36***
Third (middle) quintile	-4.09***	0.19***	0.20***	0.18***
Fourth quintile	-5.33***	0.10***	0.10***	0.08***
Fifth (highest) quintile	-6.56***	0.04***	0.04***	0.03***
<i>Geographic controls</i>				
Ecological regions: Terai (=0; Reference)	0.07	1.38	1.00	1.14
<i>Mountain</i>				
Hill	0.03	1.27	1.17	1.20
Rural–urban: Urban (=0; Reference)				
Rural	-0.20	0.87	0.89	0.84+

(continued)

Table 15.3 (continued)

Measures ^a	a. Overall food insecurity (score) (model 1)	b. Anxiety and uncertainty about food supply (odds ratios) (model 2)	c. Insufficient food quality (odds ratios) (model 3)	d. Insufficient food intake (odds ratios) (model 4)
<i>Federal provinces: Province 6 (=0; Reference)</i>				
Province 1	−1.47***	0.91	0.49***	0.77
Province 2	−0.87*	0.90	0.85	0.86
Province 3	−1.30***	0.90	0.57***	0.84
Province 4	−1.58***	0.58*	0.40***	0.63
Province 5	−0.78*	1.22	0.78	1.19
Province 7	−0.65*	1.15	0.71*	0.96
Intercept	10.77***	0.11	3.27***	1.46***
ICC (Null)	0.21	0.16 (Null = 0.19)	1.13 (Null = 0.23)	0.16 (Null = 0.22)
AIC	61,422.55 (Null = 63,741.64)	5465.20 (Null = 6203.85)	12,134.06 (Null = 13,921.13)	9292.40 (Null = 10,659.86)
Pseudo- <i>R</i> -square (total)	37% (Null = 21%)	40% (Null = 19%)	40% (Null = 23%)	41% (Null = 22%)

^aFor model 1, the outcome is HFIAS score, a continuous measure that ranges from 0 to 27. Outcomes for models 2–4 are binary coded (food insecure = 1 and food secure = 0)

+*p* < 0.10, **p* < 0.05, ***p* < 0.01, ****p* < 0.001

The average number of family members was 4.44. 77% of households were headed by a male. The average age of the household head was 46 years. Nearly 40% of the household heads did not have any formal schooling. 23% of them had primary level of schooling, 26% had secondary level of schooling and only 11% had higher level of education. One-fourth (25%) of households belonged to the lowest wealth quintile, whereas 17% of the households belonged to the highest wealth quintile.

By geographic regions, 44% were from the Terai region, 48% from the hills, and only 8% were from the mountain. Only 37% of households were from the rural areas.³ The households were proportionately distributed by province.

Food insecurity score of households that did not own any agricultural land was significantly greater (4.38 vs. 3.64) than those households that owned any land (Table 15.2). Similarly, a greater proportion of households that did not own land

reported that they experienced anxiety and uncertainty (column b), insufficient food quality (column c), and insufficient food intake (column d) as compared to those who owned land. The association between livestock ownership and food insecurity, however, slightly varied by type of animals. For example, the food insecurity score was significantly greater for those who owned cows/bulls and goats, whereas this score was as expected (lower) among chicken and pig owners. Also, the results for three specific domains varied. While these bivariate results are inconclusive, the adjusted results that control for the effects of other confounders are discussed below.

15.6.2 Multivariate Results

15.6.2.1 Land Ownership and Food Security

Results from Table 15.3 show that the households that owned land had significantly lower HFIAS scores (regression coefficient −1.33; *p* ≤ 0.000, model 1) as compared to the households that did not own any land controlling for all other factors.

³ The country now has 263 municipalities, and 59% of the total population lives in urban areas. Thus, the 2016 NDHS results are based on the updated urban–rural classification.

Similarly, the results for specific domains also support this finding. The households that owned land had significantly lower odds of experiencing anxiety and uncertainty about food supply (odds ratio = 0.44; $p \leq 0.000$, model 2, column b) in the past 12 months as compared to the households that did not own any land, adjusting for all other factors. The results are as similar and as expected for insufficient food quality (model 3, column c) and insufficient food intake domain (model 4, column d).

15.6.2.2 Livestock Ownership and Food Security

As hypothesized, the ownership of animals in general reduced the HFIAS score (food insecurity score) as compared to those households that did not own animals. Specifically, the ownership of cattle/buffalo, cow/bulls, goats, and chicken significantly reduced HFIAS score whereas the ownership of pigs was statistically not significant, adjusting for all other factors. These results are consistent with the 2011 results (Bhandari et al. 2020). Most results are statistically significant. Overall, these results provide strong evidence that the ownership of land and livestock is associated with the food insecurity problem in Nepal.

15.6.2.3 Other Factors Influencing Food Security

The results from Table 15.3 (models 1–4) further show that the access to other assets also plays important role in addressing food insecurity challenge in Nepal. Among human capital, for example, education of the head of the household is significantly correlated with the household-level food insecurity. Adjusting for other factors, a household head with a higher level of education significantly helped reduce the food insecurity situation of the household as compared to the households with heads with no education. The results were consistent across all three domains of food security (models 1–4). Similarly, as expected, other things remaining the same, the household size has a positive influence on household food insecurity. Likewise, the odds of eating insufficient quality or a limited variety of

foods also increased by 4% and the odds of eating limited quantity of food by household members increased by 5% with the increase of one household member, net of all other factors. Contrastingly, male-headed households were significantly more likely to be food insecure as compared to the households headed by a female. Although the *age of the household head* was found to be significantly but negatively associated with the food insecurity scale, a one-year increase in a household head's age significantly increased the odds of limited variety of foods intake. A *household's wealth* is negatively associated with the food insecurity status.

Evidences suggest that there is no significant difference in food insecurity status of households by ecological regions. Also, there is no difference in rural–urban food insecurity. However, the provincial-level differences in overall food insecurity are clear. The households in province 6 (Karnali Pradesh) reported significantly higher level of food insecurity as compared to the households of other provinces, net of other factors. The provincial-level differences in food insecurity of households, however, varied by specific domains.

Overall, the results for these other factors in a theoretically expected direction provide confidence in the findings and conclusions obtained. Evidences show that the ownership of land and livestock are significantly associated with a household's food security status. The land and livestock owner households are relatively food secure as compared to those that do not own any land or livestock. While the ownership of land and livestock (specifically the cattle and buffalo) consistently and significantly reduced food insecurity in all three domains, the ownership of goats and chickens in the household reduced food insecurity related to domains (b) anxiety and uncertainty about food supply, and (d) insufficient quantity of food intake only. However, the ownership of pigs was not significantly related to household food insecurity. This could be because only a small fraction of households raise pigs. These findings suggest a broad picture of the relationships between the ownership of land and livestock and food insecurity. From a

policy perspective, the ownership of capital assets such as land and livestock requires serious attention to solve the challenges of food insecurity in Nepal. Since food insecurity is more of a geographically driven problem, the provincial governments should be more attentive in designing province-specific food security policies and programs in the country.

However, there is variation in the amount of land and number of animals owned by households as discussed earlier. For example, the proportion of holdings that owned less than 2 hectares of land was 95% (58% of the holdings owned less than 0.5 hectares of land, which was only 21% of the total owned holding). In this situation, the size of the owned holding may have important implications in solving food insecurity problem. Similarly, according to the 2011/12 national sample census of agriculture, 3354 thousand holdings reported having some type of livestock. Among these holdings, 68% of them reported that they owned cattle, 50% of holdings had buffalo, 70% had goats, 3% of them had sheep, and 13% of them had pig. In this case also, this chapter does not provide evidence of the relationship between the size of land holding and the size of livestock holding and food insecurity due to limitation of data. Thus, a further investigation is necessary to examine these issues.

The results associated with other controls in a theoretically expected direction provide confidence in the conclusion. For example, the evidences showed that the level of education reduced food insecurity in a household. Interesting to note that the female-headed households reported that they were relatively more food secure than the male-headed households. This finding is in contrary to the general expectation that female-headed households are relatively more vulnerable to food security than the male-headed households (e.g., Maharjan and Joshi 2011; Mallick and Rafi 2008). There could be several reasons. In developing countries, women spend much time in agriculture and contribute to production. In addition, agriculture has been feminized due to male out-migration and the households with a female head may have been

working hard to reduce food insecurity. Or, it could be due to the remittances received by migrant-sending households from the out-migrants. This may perhaps imply that empowerment of women may enhance food security status of a household. While this is not the focus of this paper but it may be an important agenda for future research. Similarly, as expected, a household's wealth status was closely associated with food insecurity. Although remittances have become important sources of household income more recently, a further investigation is needed to examine the significance of remittances in addressing food insecurity problem. In addition, there is provincial-level variation in household-level food insecurity. The households in the far western region of Nepal, in provinces 6 and 7 and province 2 in the south-eastern Nepal are the most food insecure as compared to those that are located in 1, 3, 4, and 5 provinces.

15.7 Conclusion and Policy Implications

Food insecurity has been a chronic problem in Nepal. This has been further exacerbated by Covid-19 more recently. Nepal's subsistence-oriented agricultural base has been the major backbone to address food insecurity in the country. However, the agriculturally-based economy is at the crossroad. A large number of farmers are small and marginal in nature and farming is mixed type with some crops grown and animals kept by households. The production out of this small-scale farming is just for sustaining their livelihoods. Although many factors shape a household's food insecurity situation (Bhandari et al. 2020), less is known about whether the ownership of productive assets such as land and livestock plays a role to alleviate household food insecurity. A few studies that examined these issues previously were either focused at the micro-level and were not nationally representative (Maharjan and Khatri-Chhetri 2006), or the study examined these issues in general (e.g., Bhandari et al. 2020) than specifically as presented here. This chapter provides

empirical evidence of the association between land and livestock ownership and household-level food insecurity using the nationally representative 2016 Nepal DHS data.

Given the evidence as discussed earlier, an important recommendation is that the policy-makers should understand the multidimensionality of food insecurity situation in the country while designing policies to address the food insecurity challenge. While the provision of ownership of land and animals, the production assets of most small farmers in Nepal, is important policy measure to be focused, the ownership of land and animals alone, however, are not sufficient conditions to address the challenge of food insecurity. Other factors such as household size, education, gender of the household head, household wealth that includes assets other than land and animals, and geographical location of a household should be carefully considered while designing policies to reduce food insecurity problems in the country.

While this paper fills important gaps in the existing literature using the nationally representative household-level data, there are several limitations. One of the limitations is its cross-sectional nature of data. Thus, the results are rather associations and conclusions should be taken cautiously. In addition, the evidence is at the country level. Provinces and geographic niches in Nepal are diverse and there are socio-economic and cultural differences among households in terms of caste-ethnicity and the access to various capitals. This variation may have influenced on food habits of people as well as on food insecurity. The analysis has failed to control some of these factors. More importantly, this data was collected in 2016 when Covid-19 was not in sight. As Covid-19 is still evolving, it is expected that the food security situation worldwide as well as in Nepal will be adversely impacted. This post-Covid-19 effect, which is going to shape almost every aspect of economy (and life of people) including the future scenario of food security, is beyond the scope of this chapter. Thus, these conclusions should be considered rather cautiously. Despite the fact, this chapter makes an important contribution through empirical

evidence to framing post-Covid-19 food security policies at the time when the constitution of Nepal 2015 has expressed state's commitment to food security enshrining the right to food as fundamental right of every individual. This knowledge will be an important basis to eradicate poverty (SDG 1: No poverty), end hunger (SDG 2: Zero hunger), malnutrition (SDG 3: Good health and well-being), and inequality (SDG 10: Reducing inequality) by ensuring access to safe, nutritious and sufficient food all round the year for all people by 2030. Nepal, however, requires concerted efforts to meet the food insecurity challenge and meet SDGs by 2030.

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Sustainable Livestock Production Safeguarding Animal and Public Health in Post-COVID Nepal

16

Santosh Dhakal and Surendra Karki

Abstract

Agriculture and livestock sectors remain one of the mainstays of Nepalese economy and contribute nearly one-fourth to the gross domestic product. Livestock sector, particularly poultry and goat farming, is continuously growing in Nepal. Milk, meat, and egg production have substantially increased over the past decade. Livestock production can be catalytic in achieving Sustainable Development Goals (SDGs) of ending poverty and reaching to zero hunger in Nepal. Nepal is being self-reliant on various livestock products as this industry has been gradually shifting from traditional subsistence farming to commercialization. Nevertheless, Nepal is heavily dependent on import of raw materials and animal health supplies. Emerging and

reemerging infectious diseases pose severe impact on the sustainable development of livestock sector. Importantly, more than 60% of emerging diseases are zoonotic. Thus, prompt identification and management of infectious diseases in animals are not only important for welfare and health of animals but also to protect public health. The coronavirus disease 2019 (COVID-19) pandemic negatively impacted all aspects of livestock sector including production, processing, transport, sales, and consumption in Nepal. The objective of this study is to review the current trend of livestock production, its contribution to achieve SDGs, zoonotic diseases of importance, and the impact of COVID-19 on livestock sector in Nepal. Methodology followed included review of the published research and review articles, and reports from the governmental and relevant non-governmental organizations available online. This pandemic has reemphasized the importance of interconnectedness of animal-human-environmental health. To prevent future epidemics or pandemics and to safeguard veterinary and public health from emerging and reemerging pathogens, institutionalization, and implementation of One Health, a collaborative, multidisciplinary, and multisectoral approach is necessary. This article provides recommendations for the sustainable development of livestock sector to protect both animal and human health in Nepal.

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Keywords

COVID-19 · Infectious diseases · Livestock production · One Health · Zoonoses

16.1 Introduction

Livestock sector is an integral part of Nepalese agricultural practices. In Nepal, animals are raised for food (meat, milk, eggs), manure, draught purpose, to get raw materials for industries, and as a source of income (Poudel et al. 2020a). Livestock-derived foods are reliable sources of nutrients and micronutrients which help in reducing nutritional deficiencies in the developing world (Randolph et al. 2007). Globally, livestock sector accounts for 20–24% of total agricultural gross domestic product (GDP), provides 34% of protein intake and 18% of dietary energy, and acts as an essential source of income for over 600 million households (FAO 2020a). In Nepal, 60–70% of its population is associated with agricultural practices which is intertwined with livestock farming (FAO 2020b). The contribution of agriculture sector to national GDP is around 27.1% while that of livestock sector alone is 11.5% (Poudel et al. 2020a). Despite heavy dependence in agricultural sector, Nepal remains as one of the food-insecure countries. It is estimated that more than 4.6 million people in Nepal are food insecure with higher proportion of rural population being affected due to higher food prices (USAID 2019). Besides, malnutrition and micronutrient deficiencies among children, pregnant and lactating women is widely prevalent. An estimate by World Food Program of the United Nations shows that nearly 40% Nepalese children below 5 years of age are stunted and 10% suffer wasting due to acute malnutrition whereas approximately 1.4 million pregnant and lactating women were malnourished and 48% suffered from anemia (USAID 2019). This huge proportion of food insecurity and malnutrition is probably linked with cereal crop-based food habits of Nepalese population. Access to livestock products such as

milk, meat, and eggs would be helpful to mitigate the problem of malnutrition in Nepal.

As the world's population is expected to reach around 9.7 billion by 2050, the Food and Agriculture Organization (FAO) estimates that the demand for livestock products will also increase tremendously in coming decades (FAO 2020a). In Nepal, the estimated population is 30.4 million, and the average annual population growth rate is around 1.35% (www.cbs.org.np). With increasing population, their shift toward urban areas, and rising per capita income (USD 1191 currently), the demand for livestock products is also increasing in Nepal and is expected to further increase in the coming years. To fulfill this increased demand for livestock-derived foods and to achieve the sustainable development goals (SDGs) of ending poverty and reaching to zero hunger, sustainable development of livestock sector is of utmost importance.

Nepalese livestock industry faces a myriad of challenges. A major hindrance to livestock sector development is the frequent outbreaks of bacterial, viral, and parasitic diseases along with the lack of effective breeding policies and availability of quality feeds. Besides the economic losses to the farmers in the livestock sector, several pathogens of animal origin can spill over into the human population leading to larger outbreaks (Tomley and Shirley 2009). Thus, effective management of livestock sector and successful prevention and control of livestock pathogens are highly necessary for sustainable livestock production and the protection of both animal and human health. The interconnectedness of animal-human-environmental health calls upon a unique public health strategy, known as one health approach, which combines the efforts of multi-sectoral professionals including human health, animal health, and environmental health (e.g., climate change, disruption in ecosystem, and changes in animal-human interface) to reach a common goal of health for all (Mackenzie and Jeggo 2019). The ongoing pandemic of coronavirus disease 2019 (COVID-19) has severely affected livestock sector due to disruption in the supply chain. In Nepal, dairy and poultry sectors were notably affected resulting in losses of

millions of dollars due to the disruption in supply chain, reduced market demand, and lack of infrastructure to preserve perishable livestock products owing to the prolonged lockdown imposed to control the pandemic (FAO 2020c). This pandemic has once again highlighted the need for one health approach to deal with emerging and reemerging pathogens which affect not only the human-animal-environmental health but also overall economy including the livestock industry. In this article we have reviewed the trend of livestock production and productivity in Nepal, discussed the contribution of livestock sector to achieving SDGs, summarized the important zoonotic diseases of animal and human health concern, explained the impact of COVID-19 on livestock industry, highlighted the importance of one health approach, and provided recommendations to tackle animal and human health challenges in the future in a sustainable manner. Information included in this article are collected from the published research and review articles, and reports from the governmental and relevant non-governmental organizations available online.

16.2 Status of Livestock Production and Challenges in Nepal

Population of cattle and buffalo is almost stagnant in the last 10 years; sheep population has gradual decrease; pig population is growing slowly; while the population of goats and chicken are rapidly increasing in Nepal (MoALD 2020). The tremendous increase in chicken population is attributable to the commercialization of poultry industry and an investment of millions of rupees from the private sector (Poudel et al. 2020a, 2021). As foreign employment opportunities lured many youths to out migrate, many returned with skills and capital and their first choice of self-employment was commercial poultry farming (Kaphle 2000). Goat industry is not as commercialized compared to the poultry industry but involvement of cooperatives, farmers' groups, and women's group have contributed to the growth of this sector following sound

investment from the public sector. The growth rate of chicken meat production in Nepal in the last decade was more than 280% while the growth rate of milk and overall meat was accounted for 44.9% and 43.6%, respectively (Table 16.1). Despite these progresses, Nepal imported live animals and livestock and fish products worth of NRs 6003.6 million (USD 51.75 million) while exported animal and animal products worth of only NRs 207.7 million (USD 1.79 million) during mid-July 2020 to mid-March 2021 with the total trade deficit of NRs 5795.8 million (USD 49.96 million) (Table 16.2). The huge trade deficit shows a great scope for increasing the production of livestock and fisheries to meet the growing demand.

One of the major challenges of livestock farming in Nepal is heavy reliance on inputs, such as feed ingredients (maize and soya), biologicals, and veterinary medicines (Karki et al. 2021). The feed composition for livestock in Nepal mainly comprises of crop residues, grains and grain by-products, and green fodder which are seasonal in nature (Osti 2020). It is estimated that the supply of dry matter, crude protein, and metabolizable energy in the animal feed in Nepal is deficit by 30–40% than the requirements which leads to the lower animal productivity (Osti 2020).

Likewise, there is a high incidence of major animal diseases, such as Foot-and-Mouth Disease (FMD) in cloven-footed animals, Pest-des-Petits Ruminants (PPR) in goats and sheep, Classical Swine Fever (CSF) in pigs, and High and Low Pathogenic Avian Influenza (HPAI and LPAI) and Newcastle disease in poultry (Poudel et al. 2020a). However, the coverage and quality of animal health services is insufficient.

16.3 Policy Status and Gaps

The Government of Nepal put forward National Agriculture Policy in 2004 with a vision to transform subsistence farming into commercial and competitive enterprises (Pradhanang et al. 2015). However, this policy has become obsolete due to the change of governance structure to

Table 16.1 Trend of major livestock products produced in Nepal from 2009/10 to 2018/19 (MoALD 2020)

Livestock products	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17	2017/18	2018/19	Increase in 10 years (%)
Milk production (Mt)	1,495,897	1,556,510	1,622,751	1,680,812	1,700,073	1,755,725	1,854,247	1,911,239	2,092,403	2,168,434	44.96
Meat production (Mt) ^a	248,573	277,625	287,930	295,167	298,244	303,401	322,059	332,544	346,179	357,081.6	43.65
Buff	162,213	167,868	172,414	175,132	173,906	174,012	175,005	180,080	185,180	188,574.3	16.25
Mutton (Mt) (Sheep meat)	2691	2722	2720	2721	2656	2658	2684	2714	2754	2762.728	2.67
Chevon (Mt) (Goat meat)	49,851	52,809	53,956	55,578	59,053	60,906	65,583	67,706	70,802	73,914.35	48.27
Pork (Mt)	17,066	17,923	18,277	18,709	19,269	20,135	23,509	24,535	28,214	28,578.84	67.46
Chicken (Mt)	16,527	36,085	40,346	42,810	43,133	45,458	55,041	57,268	60,122	62,899.1	280.58
Egg (Chicken) ('000)	629,793	691,070	788,310	874,194	859,515	865,947	1,294,166	1,338,312	1,498,024	1,534,680	143.68
Fish (Mt)	24,869	26,941	29,999	31,221	37,427	41,481	48,543	55,842	58,432.6	62,725	152.22
Wool production (Kg)	579,631	586,232	587,017	587,834	586,848	586,731	588,348	594,312	594,639	589,738	1.74

^a Meat production from minor contributors including ducks not included

Table 16.2 Livestock products imported and exported in Nepal (Mid-July 2020 to Mid-March 2021)

SN	Description	Import values (NPR, 000)*	Export values (NPR, 000)*	Trade balance (NPR, 000)*
1	Live animals	1,106,461	0	−1,106,461
2	Meat and edible meat offal	18,544	5470	−13,074
3	Fish and crustaceans, mollusks, and other aquatic invertebrates	1,174,858	0	−1,174,858
4	Dairy produce; birds' eggs; natural honey; edible products of animal origin	1,331,869	68,744	−1,263,125
5	Other animal originated products	32,079	41,663	9584
6	Meat, fish or crustaceans, mollusks, or other aquatic invertebrates	43,321	0	−43,321
7	Raw hides, skins, and leather	38,707	77,869	39,162
8	Wool, fine or coarse animal hair; horsehair yarn and woven fabric	2,257,804	14,011	−2,243,793
	Total	6,003,642	207,757	−5,795,885

That asterisk is to indicate the monetary values

* Values are in thousands (in Rupees) (1 USD = NRs 116)

Data source Department of Custom, Government of Nepal <https://www.customs.gov.np/page/fts-fy-207778>

federal system with three tiers of government: federal, provincial, and local. Likewise, the Government of Nepal has put forward a 20-year Agriculture Development Strategy (ADS) 2015–2035, including livestock sector, with a vision to develop a self-reliant, sustainable, competitive, and inclusive agricultural sector that drives economic growth, and contributes to improved livelihoods and food and nutrition security leading to food sovereignty (MoALD 2016). This strategy is expected to accelerate growth of agriculture sector through four strategic components, governance, productivity, profitable commercialization, and competitiveness. However, Nepal embarked into the federal structure of governance after this strategy was developed due to which there is a need to align this strategy as per the new federal system of governance in Nepal. The Breeding Policy (2011) aims in improvement of animal breeds to increase productivity. However, an efficient and systematized implementation mechanism to conserve the indigenous breeds and to exploit genetic resources for breed improvement is lacking (Pradhanang et al. 2015). In 2021, Government of Nepal has also endorsed Dairy Policy (2021) with an aim to increase the per capita milk

availability to 91 L (MoALD 2021). Another major act, existing in the livestock sector in Nepal, is the Animal Health and Livestock Services Act, 1999 and its regulation, 2000. Quarantine services were established in Nepal as per the provision of this act. This act provides authority to the Department of Livestock Services to restrict movement of livestock and products from areas where outbreaks of infectious diseases have occurred. Besides, there is another act named, Animal Slaughterhouse and Meat Inspection Act, 1999 and its regulation, 2001 which was enacted for meat inspection to safeguard public health. However, even after 22 years of its enactment, this act has not been effectively implemented. In addition, the criminal code of the Government of Nepal also has some provisions related to animals such as prevention of cruelty against animals and prohibition of carelessness, abandonment, and bestiality. Likewise, Government of Nepal endorsed the Bird Flu Control Order, 2008 to facilitate the timely control and containment of highly pathogenic avian influenza in Nepal. However, there is a lack of comprehensive act to guide the control of infectious livestock diseases in Nepal (Karki et al. 2021). In 2013, the government of Nepal

introduced Crops and Livestock Insurance Directives which facilitated implementation of livestock insurance program. However, the adoption rate of this effective risk-management tool is low in Nepal indicating the need of awareness generation among farmers for its success (Devkota et al. 2021). Likewise, Government of Nepal has endorsed a “One Health Strategy 2019” with an objective to promote one health in Nepal through multisectoral coordination and collaboration, joint disease surveillance and laboratory services, capacity building of stakeholders, preparedness and response, and communication and advocacy (MoALD 2019). However, the lack of institutional arrangement and dedicated funding is impeding its effective implementation. Overall, there is lack of effective policies in breeding, nutrition, and animal health while existing acts and regulations are also not effectively implemented (Karki et al. 2021).

16.4 Livestock Sector Development and Sustainable Development Goals

The United Nations (UN) has put forward 17 sustainable development goals (SDGs) for 2030 with an aim to promote peace and prosperity for people and planet by ending poverty and other deprivations (<https://sdgs.un.org/goals>). The Government of Nepal has integrated SDGs into its developmental frameworks, developed roadmaps, and established needed institutional setups (HLPF 2020). Livestock sector development directly contributes to several SDGs (Fig. 16.1) including, 1 (no poverty), 2 (zero hunger), 3 (good health and well-being), and 13 (climate mitigation by reducing GHG emissions) (FAO 2018; Smith 2017). All these SDGs are unlikely to be achieved without the interventions in the livestock sector (Smith 2017).

Around 17% of Nepal's population is estimated to be living below the international poverty line (\$1.9/person/day) (NPC 2020). Due to the COVID-19 pandemic, between 1.6 and 2 million jobs are disrupted within the country

while thousands of migrant workers have lost their foreign employment (Subedi 2021). Therefore, even more families are likely to be pushed below the poverty line in post-COVID Nepal. Livestock sector is the fastest-growing agriculture sub-sector. The demand for livestock products in Nepal is already unmet (Table 16.2) and owing to the population growth, higher income, and urbanization, the national and global demands are expected to increase in the future. Thus, livestock sector can be catalytic in providing employment opportunities and be the source of income generation helping people sustain their livelihood and come out of poverty (SDG 1). The Government of Nepal will require employment opportunities within the country to absorb thousands of returned migrant workers and livestock sector can be one prominent option for that. Livestock sector is already contributing tremendously to the economic growth of Nepal which can be boosted with increased production and commercialization of value-added products (SDG 8). The Agriculture Development Strategy (2015–2035) of Nepal also envisions such a transformation of subsistence to commercial farming (NPC 2020). More than 33% of women in Nepal are engaged directly in agricultural activities, which is greater than in other industries (CBS 2019). Through proper training and by providing resources for livestock production, the quality of life of women, underprivileged and marginalized people can be improved (SDG 5), “*leaving no one behind.*”

The Global Food Security Index and Global Hunger Index scores for Nepal are 46 and 20.8, respectively (NPC 2020). Over 4.6 million people in Nepal are food insecure. The prevalence of undernourishment, stunting, and malnutrition are 8.7%, 31.6%, and 10%, respectively. Likewise, 24.3% of children below age 5 years are underweight and 52.7% are anemic. Among women of reproductive age, the prevalence of anemia is 40.8% (NPC 2020). Lack of dietary diversity, due to unavailability of food varieties or associated cost, is one of the major factors responsible for malnutrition and other nutritional deficiencies (Arimond and Ruel 2004; Arimond et al. 2010). Foods of animal origin (e.g., meat, milk, eggs)

Fig. 16.1 Sustainable development goals (SDGs) to which livestock sector can have direct impact (Smith 2017; FAO 2018).



are rich sources of easily bioavailable macronutrients (carbohydrates, proteins, and fat) and micronutrients (vitamins and minerals) (Varijakshapanicker et al. 2019). Animal-origin foods also provide vitamins and minerals which may not be supplemented by plant-based foods. Compared to plant-origin foods like rice and millet, animal-source food, e.g., eggs, offers more easily digestible pool of amino acids (Shivakumar et al. 2019). Stunting represents chronic undernutrition and inclusion of egg or milk in the diet is shown to be associated with reduced stunting rates and better child growth in many countries (de Beer 2012; Iannotti et al. 2017; Shivakumar et al. 2019). A 3-year longitudinal impact assessment study in Nepal also showed that milk consumption was associated with better height and weight gain in children (Miller et al. 2020). A randomized controlled trial in Burkina Faso showed that behavioral changes strategy including integrated nutritional and agricultural training to mothers and gifting of chicken to increase egg consumption among children significantly decreased severe acute

malnutrition, including wasting, underweight, and mortality (McKune et al. 2020). In Nepal, organizations including Heifer International are practicing livestock gifts and are supporting people with livestock production and disease management. There will be high chance of consumption of balanced diets including animal-source foods when people have access and ownership to it. Thus, sustainable livestock development can provide a foundational support to achieve food security, i.e., the availability, access, use, and stability, and SDGs (2, 3, and 12) in Nepal.

The association of sustainable livestock production with SDGs is often complex as there can be positive, negative, or mixed interactions (Mehrabani et al. 2020). The positive interactions are described above, but it can negatively impact the climate as this sector is responsible for nearly 13% of global greenhouse emissions (SDG 13) (Mehrabani et al. 2020). Likewise, six out of 10 emerging human infectious diseases are of animal origin which can negatively affect the goal of achieving *good health and well-being* (SDG 3).

However, by increasing productivity per animal the greenhouse gas emissions can be successfully reduced (SDG 13) and through proper management of livestock diseases both animal and human health can be safeguarded (SDG 3) in Nepal and elsewhere. Therefore, effective breeding interventions and strengthening animal health systems through public–private partnership need to be the part of sustainable livestock production system in post-COVID Nepal.

16.5 Major Zoonotic Diseases and Their Importance for Animal and Human Health in Nepal

The global burden of zoonotic diseases, i.e., diseases that are transmitted from animals to humans, was already alarming before the COVID-19 pandemic (Jones et al. 2008; Machalaba et al. 2015). Thirteen major zoonotic diseases out of more than 200 known zoonoses result in more than 2.4 billion cases and 2.2 million human deaths across the world annually, with the major burden being centered in developing countries (ILRI 2021). Nepal is considered one of the hotspots for zoonotic disease transmission because of its wider biodiversity and intimate wildlife-domestic-human interactions (Grace et al. 2012). There are several endemic and emerging zoonotic diseases that are affecting human and animal lives in Nepal (Gautam et al. 2021). In April 2021, multisectoral stakeholders involving humans, animals, food, and wildlife in Nepal have prioritized 10 zoonotic diseases, viz. influenza, rabies, coronavirus, leptospirosis, brucellosis, salmonellosis, zoonotic tuberculosis, leishmaniasis, cestodiasis (cysticercosis/neurocysticercosis), and toxoplasmosis, as the priority zoonotic diseases of Nepal from one health perspective.

Rabies is one of the oldest known endemic zoonotic diseases in Nepal. Around 50–100 people die of rabies annually in Nepal (Devleeschauwer et al. 2016), which is gradually decreasing compared to rabies-associated deaths during the 1970s (Pantha et al. 2020). Livestock are also affected by rabies and it is estimated that

200–400 animals die from it annually (Pantha et al. 2020). A study conducted in 2013 showed a wide genetic diversity of the rabies virus in Nepal with co-circulation of three different phylogenetic groups, namely Indian subcontinent clade, and two different Arctic-like sub-clades within the Arctic-related clade (Pant et al. 2013).

It is estimated that 30,000 to 40,000 new active cases of tuberculosis (TB) are reported in humans in Nepal annually (Adhikari et al. 2019). Studies conducted in the livestock population of Nepal have shown the presence of bovine tuberculosis in the cattle population of Nepal. For example, a study conducted in Chitwan indicated that 15% of 100 cattle and buffaloes tested were positive for bovine tuberculosis (Pandey et al. 2012). In another study, Jha et al. (2007) isolated *Mycobacterium bovis* in 16% ($n = 5/32$) of cattle and 17% ($n = 6/36$) buffaloes in samples collected from the western part of Nepal (Jha et al. 2007). A recent study from Nepal involving TB patients and cattle indicated that exposure to infected cattle and other socio-demographic factors were responsible for development of TB in humans (Gompo et al. 2020b). However, the exact contribution of bovine tuberculosis to the overall burden of human Tuberculosis in Nepal is not known.

Highly pathogenic avian influenza (HPAI) was confirmed for the first time in 2009 in Nepal in birds in Jhapa district, the eastern part of Nepal (Gompo et al. 2020a). More than 250 outbreaks of HPAI H5N1 outbreaks have been confirmed in Nepal and reported to the World Organization for Animal Health from 2009 to 2020 (OIE 2021). In 2021, nine outbreaks of HPAI have already occurred (as of August 22, 2021) in backyard birds, ducks, turkeys, and layers birds but the circulating strain this year is H5N8 compared to H5N1 in previous years (OIE 2021). One person died from HPAI H5N1 infection in 2019 in Nepal (WHO 2019). In recent years, outbreaks of low pathogenic avian influenza (LPAI) H9N2 which has a zoonotic potential, have increased substantially in Nepal (Gompo et al. 2020a).

Brucellosis, a bacterial disease, is also considered one of the major zoonotic diseases in

Nepal. In a seroprevalence study conducted among pregnant women in Kathmandu, 11.25% ($n = 9/80$) were positive for Brucellosis (Thapa and Maharjan 2018). Likewise, 18.08% ($n = 66/365$) individuals were seropositive for Brucellosis in a study conducted in Chitwan, Nepal (Nepal et al. 2016). In livestock population, brucellosis is commonly detected. In a recent study conducted in Rupandehi, Nepal, 15% sheep ($n = 12/80$) and 1.1% goats ($n = 3/277$) were seropositive for *Brucella* spp. (Gompo et al. 2021). Similarly, 12% ($n = 28/233$) animals tested were seropositive for Brucellosis in Kailali district with variation across the species, cattle 32% ($n = 16/50$), buffalo 13.4% ($n = 9/67$) and goats 2.6% ($n = 3/113$) (Pandeya et al. 2013).

Among the parasitic zoonoses, neurocysticercosis is considered to have the highest burden in Nepal with an estimated disability-adjusted life year (DALYs) of 14,268 (95% CI: 5450–27,694) followed by congenital toxoplasmosis (DALYs 9255 and 95% CI: 6135–13,292) between 2000 and 2012 (Devleesschauwer et al. 2014). Other potentially endemic parasitic zoonoses include trichinellosis, toxocariasis, diphyllbothriasis, foodborne trematodosis, and taeniosis (Devleesschauwer et al. 2014). Besides, alveolar echinococcosis, dirofilariasis, cutaneous leishmaniasis, gnathostomiasis, angiostrongyliasis are reported sporadically (Devleesschauwer et al. 2014).

The burden of vector-borne diseases is also high in Nepal. Japanese encephalitis (JE), a mosquito-borne viral disease, was first detected in Nepal in humans in 1978 and is annually detected in low land (Terai) Nepal (Ghimire and Dhakal 2015). A total of 1823 JE cases were reported from 2007 to 2015 in Nepal with a case fatality rate of 6.6% (Pant et al. 2017). This disease has been reported from 63 out of 77 districts of Nepal and is gradually expanding from low land to hills and mountains together with the expansion of vectors (Pant et al. 2017). Pigs contribute as an amplifying host in JE transmission. Pigs tested from four districts of Nepal showed that nearly 17% ($n = 67/454$) of pigs tested were seropositive for the JE virus (Thakur et al. 2012). Studies conducted among

pig farmers from Kathmandu, Morang, Rupandehi, and Kapilvastu districts showed that despite years of sufferings from JE and governments efforts of awareness generation and vaccination, the knowledge and practices relevant to on-farm risk reduction were very low (Dhakal et al. 2014, 2012). This, in general, reflects the low level of awareness about zoonotic diseases among public in Nepal.

16.6 COVID-19 and Its Impact on Livestock Sector in Nepal

Nepal reported first case of COVID-19 in January 2020. As of 29th August 2021, total number of Real-time Polymerase Chain Reaction (RT-PCR) positive cases reached 759,222, of which around 1.4% (10,714) died (MoHP 2021). To manage COVID-19 pandemic, the Government of Nepal imposed nationwide lockdown and travel restrictions. It also carried out several other activities including development of guidelines for quarantine; establishment of quarantine centers throughout the country; dissemination of information for awareness generation toward social distancing, hand hygiene, and use of mask; increased its COVID-19 testing and contact tracing capabilities; and designated hospitals for COVID-19 management (Dhakal and Karki 2020; Sharma et al. 2021; Basnet et al. 2021). Nepal launched the first phase of vaccination on 27th January 2021 and as of August 29, 2021, more than 4 million people were fully vaccinated (MoHP 2021; WHO 2021). Procuring more doses of vaccines and vaccinating the rest will be a daunting task ahead for the Government of Nepal.

COVID-19 pandemic has affected all sectors of human life and economy, including the livestock sector. While the actual global impacts of COVID-19 on livestock sector are yet to be estimated, it is observed that livestock value chains are disrupted, and all aspects of animal production, processing, transport, sales, and consumption are affected negatively (Fig. 16.2) (FAO 2020d). There has been no evidence that food animals or food products are involved in the

transmission chain of SARS-CoV-2 (Dhakal and Ghimire 2020; Salajegheh Tazerji et al. 2020). Even the experimental infections of pigs, chickens, and ducks with SARS-CoV-2 resulted in no successful establishment of the infection (Khamisse et al. 2020; Salajegheh Tazerji et al. 2020). However, dissemination of misinformation about the link of animal products with transmission of SARS-CoV-2 to humans resulted in abandonment of agricultural products and reduced consumption of animal products including meat and eggs in many countries including Nepal (Dhakal and Ghimire 2020; FAO 2020d).

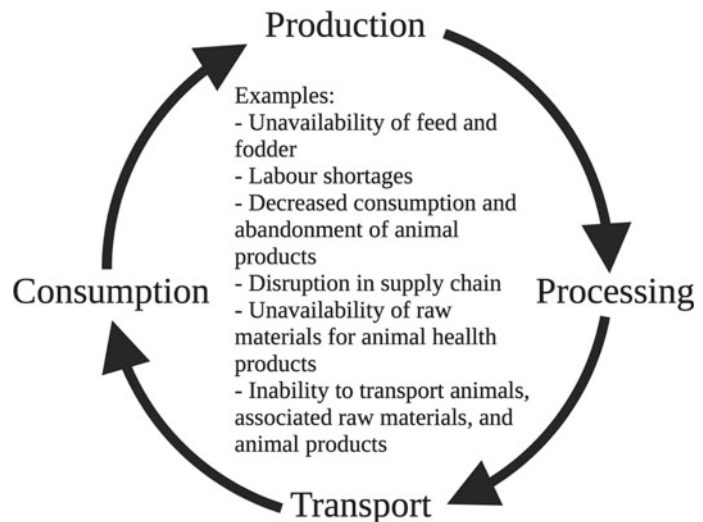
The requirement for social distancing, limitations for mass gatherings, requirement of additional personal protective equipment, unavailability of public transportations, closure of businesses, and lack of sufficient storage facilities for the fragile animal products were some of the many unprecedented outcomes of the COVID-19 pandemic. This resulted in huge economic burden to the livestock sector through labor shortages, unavailability of raw materials, and inability to transport or sell animal products (FAO 2020d).

Dairy industry is one of the worst-hit livestock industries due to the restrictions put down by the government to control the COVID-19 pandemic. During the initial months of lockdown, the market for milk and milk products in Nepal was decreased by around 60% leading to a loss of

over 20 billion Nepalese rupees (THT 2020). This could be a great hindrance to the dairy sector development in Nepal which has observed a noticeable growth in recent years with the average increase in milk production from cattle and buffalo sources being 8.2% and 2.9% per year, respectively during the period of 2008/9 to 2017/18 (Poudel et al. 2020a). As the market demand reduced during the pandemic, farmers were able to sell only half of the 6.2 million liters of milk produced daily (THT 2020). The closure of hotels and restaurants and absence of social and cultural events resulted in reduced market demand for dairy products which was further affected by the difficulty in long-distance transportation (THT 2020). With the unavailability of alternatives such as making powder milk, farmers were compelled to even dump milk and face tremendous economic losses (THT 2020).

Poultry industry is another booming industry in Nepal that gives employment to thousands of Nepalese and contributes to around 4% in the national GDP (Poudel et al. 2021). The past decade (2008/9 to 2017/18) observed impressive (19.5% per year) increase in chicken population with 26.1% and 14.4% per year increase in chicken meat and egg productions (Poudel et al. 2020a). During the pandemic, poultry industry suffered from lack of market and unavailability of feed; cold storage were not available;

Fig. 16.2 Impact of COVID-19 in different aspects of livestock industry in Nepal. Adapted from FAO (2020d)



transportation of birds, feed, meat, and eggs became difficult; the price for chicken was reduced significantly; and consumers were refrained from consuming poultry product owing to the misinformation that it may transmit SARS-CoV-2 (Ghimire 2020; Prasain 2020). Hatcheries and farmers were even compelled to destroy chicks and eggs (Ghimire 2020; Prasain 2020). Thus, COVID-19 pandemic is likely to have negative impact on the continued growth of poultry industry in Nepal. In Bangladesh, 12–15 million liters of milk were unsold resulting in a loss of \$6.7 million per day while around \$1.35 billion were lost by the poultry industries within a 15-day period (Rahman and Chandra Das 2021). Likewise, production of poultry feeds and day-old chicks and sale of medicines were reduced by 30–50% during the pandemic (Rahman and Chandra Das 2021). In India, the demand for dairy products was reduced by 25–30% with subsequent decline in price during the early months of COVID-19 (Biswal et al. 2020). Similar declines in demand and price were observed for poultry products (Biswal et al. 2020).

In summary, the COVID-19 pandemic severely affected all aspects of production, processing, transport and consumption of animal and poultry products in Nepal as it did in neighboring SAARC countries, including India and Bangladesh (Biswal et al. 2020; Rahman and Chandra Das 2021). Further study is necessary to estimate the overall burden of COVID-19 pandemic in the Nepalese livestock sector. Nonetheless, the government of Nepal should come up with suitable post-pandemic policy which will provide stimulus packages or subsidies to the farmers that are severely affected due to the COVID-19 pandemic.

16.7 One Health Approach and Its Importance to Tackle Animal and Human Health Challenges

Emerging infectious diseases (EIDs) are predominantly (>60%) zoonotic (transmitted from animals to humans) in nature, and over 70% of

those originate in wildlife (Jones et al. 2008). The emergence and spread of these zoonotic pathogens are determined by various socio-economic, environmental, and ecological players including human population density; urbanization; wildlife richness; intensification of agriculture; international travel and trade; and the interaction between humans, wild animals and domestic animals (Jones et al. 2008; Machalaba et al. 2015; Mackenzie and Jeggo 2019). The influenza pandemic of 2009, caused by swine-origin influenza virus, is one example of successful spillover of pathogens from domestic animals to humans (Mena et al. 2016). Though the intermediate animal host involved in SARS-CoV-2 transmission are not yet clearly understood, experimental infection of macaques, genomic resemblance with pangolins, and infection of domesticated minks refer to possible involvement of intermediate animal host during spillover of this virus from bats in wilderness to humans (Poudel et al. 2020b; Salajegheh Tazerji et al. 2020). The way in which humans and animals share pathogens and the interconnectedness of humans, animals, and their ecosystem in pathogen maintenance or spread calls for a holistic approach of EID research (Caron et al. 2012).

One Health approach is very relevant for South Asia, including Nepal, which is a hot spot for many EIDs (McKenzie et al. 2016), as this holistic approach will make optimum use of limited resources for early detection and management of EIDs through collaboration at local, national, and global levels (Mackenzie and Jeggo 2019). The major zoonotic diseases (described above) have tremendous burden on human and animal population in Nepal which cannot be controlled efficiently without the coordinated efforts from veterinary and public health sectors (KC et al. 2020). Control of rabies in humans is possible only when it can be controlled in wild and domestic animals. Likewise, influenza in humans can be prevented in a sustainable manner only when avian and swine influenza are prevented (KC et al. 2020). Several efforts have been taken through governmental or non-governmental organizations in Nepal to promote OH approach

(Acharya et al. 2019). The successful launching of Avian Influenza Control Project (ACIP 2007–2011); Zoonotic Disease Control Project (ZDCP 2012–2014); and antimicrobial resistance (AMR) project funded by The Fleming Fund are some of the examples (Acharya et al. 2019). There are different organizations working on zoonotic diseases, often independently, from human and animal health departments in Nepal which need to work together to solve the health problems in a sustainable manner (Acharya et al. 2019).

The COVID-19 pandemic has reemphasized the importance of OH approach and its implementation in Nepal and worldwide (Amuasi et al. 2020; KC et al. 2020; Poudel et al. 2020b). The experiences gained by the veterinary sector from periodic outbreaks of infectious diseases, such as avian influenza, and the laboratories and infrastructures thus developed were handy when the country was facing scarcity of PPE and diagnostic facilities (Gautam et al. 2020; Kaphle 2020). Five different veterinary laboratories were used early on the pandemic for COVID-19 diagnosis, namely—(1) National Avian Disease Investigation Laboratory, Chitwan; (2) Veterinary Laboratory, Biratnagar; (3) Veterinary Laboratory, Surkhet; (4) Veterinary Laboratory, Dhangadi; and (5) Veterinary Laboratory, Janakpur (Gautam et al. 2020; Kaphle 2020). This highlights that scientific research and development work in veterinary and public health sector in Nepal should go hand on hand using OH approach so that we can tackle the health issues of wildlife, domestic animals, humans, and environment more effectively.

16.8 Conclusions and Recommendations

In last decade, livestock industry has gained momentum in Nepal. Poultry, dairy cattle, swine, goat, aquaculture, and game birds are the trends for Nepal. Financial support and subsidies from the government have attracted youngsters, women, and returned migrant workers in this movement. By providing employment opportunities to thousands and investment in billions,

livestock industry has been instrumental in progressing Nepal toward achieving sustainable development goals of the UN, especially in the poverty alleviation and zero hunger. While livestock are integral part of the livelihood, they are also a source of disease spillover events. With increased interconnectedness of wildlife, domestic animals, and humans, the emergence or re-emergence of economically important and zoonotic pathogens is predictable. Research and investments in isolation by animal health, public health or environmental health sectors cannot provide a comprehensive solution to these emerging and reemerging health problems. COVID-19 has clearly exposed the lack of coordination among governmental organizations and scarcity of infrastructures for testing, tracking, and treatment in Nepal. This experience needs to be considered as an opportunity to strengthen the animal-human-environmental health research and capacity building. To achieve sustainable development of livestock sector in Nepal and to safeguard both animal and human health (Fig. 16.3), we put forward the following recommendations:

- Effective policies on breeding, feeding, and animal health need to be formulated for sustainable livestock production. Conservation and improvement of local breeds should be promoted, as they are hardy and adjust well with the prevalent husbandry practices of Nepal. In addition, exploration of other genetic resources, that fits well with Nepal's husbandry practices, is necessary for breed improvement to increase livestock productivity.
- Nepal is heavily reliant to foreign countries in feed ingredients, mainly maize and soya, available feed resources are seasonal in nature, and animal feed is deficit in nutritional constituents. Therefore, government should implement strategies, such as making efficient use of barren and uncultivated lands for all year-round production of fodder and proper storage of excess feeds, and promotion of high-yielding varieties of maize and soya, to overcome the problem of nutritional deficit and increase animal productivity. Then only

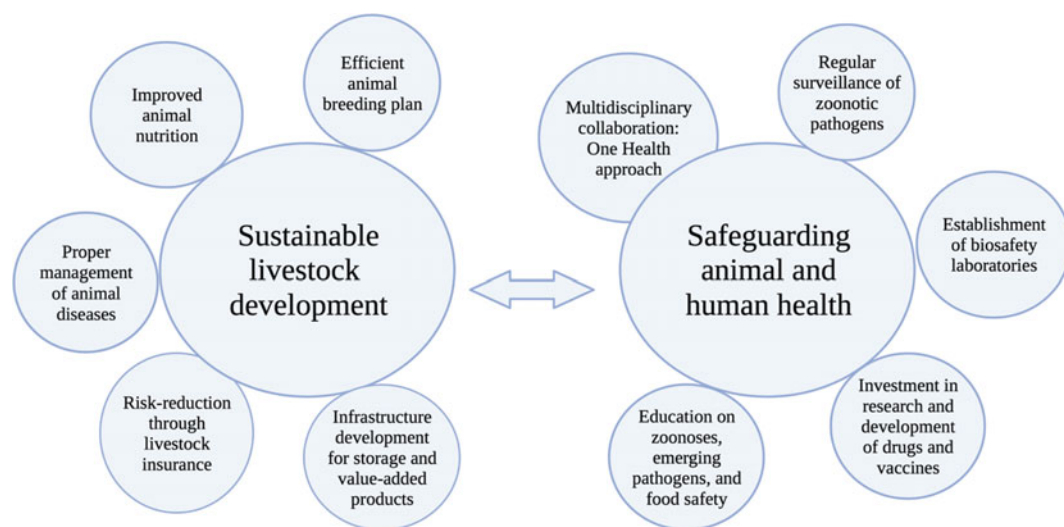


Fig. 16.3 Roadmap to achieve sustainable livestock development in post-COVID Nepal safeguarding animal and human health.

Nepal in true essence can be self-sufficient in livestock industry.

- Veterinary health sector is as important as public health sector. Therefore, coverage of wildlife and animal health services throughout the country needs to be improved and upgraded. Veterinary laboratories should be equipped with molecular diagnostic facilities for timely and precise surveillance of pathogens, and effective regular treatments. Sustainable veterinary medicine needs to be promoted to focus on herd health management and prioritize disease prevention (Lin et al. 2003).
- Increasing the coverage of livestock insurance policy is necessary to reduce the risk of diseases and natural disasters. Development of policies, including stimulus packages and subsidies, for unprecedented emergencies like the COVID-19 pandemic is also necessary.
- Investment in infrastructure such as cold chains and powder milk plants in public-private partnerships in strategic locations of Nepal needs to be considered to preserve perishable livestock products during low market demand time as observed during COVID-19 lockdown period.
- Investment is utmost important for establishment of pharmaceutical and biological companies within the country that independently or in collaboration with international partners can play a leading role in the fight against common major livestock diseases and the emerging and reemerging pathogens of animal and human health importance.
- Consumer awareness is key, as food safety-driven market will force producers to maintain certain regulatory standards during livestock production. Strong government legislation regarding this and its enforcement would be pivotal.
- Strict implementation of existing livestock acts and regulations, including the Animal Slaughterhouse and Meat Inspection Act (1999) is necessary. Umbrella act to control infectious diseases of livestock is recommended to safeguard both animal and public health.
- Prioritization of pathogens of importance at wildlife-human-animal interface is necessary to continue research and development in their surveillance to prevent future epidemics or pandemics.
- An institutional setup for effective implementation of one health policy needs to be established where experts from different sectors work under the same umbrella. Relevant

ministries including the Ministry of Agriculture and Livestock Development and Ministry of Health and Population should take such initiatives.

- In the budget of fiscal year 2020/21, Nepal government put forward the concept of Center for Disease Control (CDC) and Food and Drug Administration (FDA). As in other countries, health authorities like this should have representation of all stakeholders including veterinary science, public health, microbiology, and others to achieve all-round development in health sector.
- Establishment of biosafety laboratories in different provinces is necessary which will be compatible to perform research and development work on highly infectious pathogens of animal-human interface, including avian and swine influenza, tuberculosis, and coronaviruses.
- To prepare next generation of experts to tackle future disease outbreaks, veterinary and public health curricula need to be updated with inclusion of sufficient theoretical and practical information on zoonotic diseases, epidemics and pandemics, and their preventive measures.

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Changes in Transhumance Systems in Nepal: Analysing Socio-ecological Impacts Using Driver-Pressure-State-Impact-Response Framework

17

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Abstract

Globally, small-scale agricultural systems form the main livelihood option for billion plus people and play an important role in food security. However, such agricultural systems have been undergoing unprecedented changes due to multiple change stressors. Previous studies have indicated that the transhumance systems in northern mountainous areas of Nepal are jeopardised but there is a limited understanding of the nature and extent of the actual changes in the systems. This chapter uses a Driver-Pressure-State-Impact-Response (DPSIR) framework to analyse the socio-ecological impacts of transhumance systems in Nepal. The analysis revealed that the driver of changes to the transhumance systems comes

from different spatial scales (global, national and local levels) affecting households' labour dynamics (resulting in labour shortage) and flexibility (due to access restrictions for live-stock movement). Although transhumance systems play an important role to the livelihood, food security and ecosystem services, these systems showed a declining trend in Nepal. The loss or decline in the transhumance systems can result in decreased crop production, increased livelihood vulnerability, reduced food security, changed vegetation composition and altered ecosystem services. These impacts are directly related to various sustainable development goals (SDGs) including no poverty (SDG 1), zero hunger (SDG 2) and biodiversity (SDG 15) suggesting an important contribution of long-standing transhumance systems in achieving SDGs. Moreover, findings of this chapter provide a comprehensive knowledge and understanding for making important policy decisions on transhumance including whether to encourage or discourage transhumance systems in the mountainous areas of Nepal, the entire Himalayas and other parts of the world having similar geographical, socio-economic and political settings.

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Keywords

DPSIR framework · Livelihood · Nepal ·
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Transhumance

17.1 Introduction

Small-scale agricultural systems form the main livelihood options for billion plus people around the world and play an important role in global food security. The sustainability of such agricultural systems generates multiple benefits and helps in achieving various sustainable development goals (SDGs). Small-scale agricultural systems are important for SDG-2 (zero hunger) as they contribute to end hunger, improve nutrition and enhance food security (Gil et al. 2019; Wong et al. 2017). Those small-scale agricultural systems often have a long history and persist in a unique configuration of environmental, social-cultural and institutional settings. However, such long-standing social-ecological systems (SESS) are facing a range of challenges from the global social and environmental change (Abel et al. 2006; Young et al. 2006) and many SESSs might collapse by the end of this century due to rapid change in human and biophysical processes (Ostrom 2007). Among others, historically practiced pastoral systems are examples of SESSs subjected to significant forces of change and are at greater risk for their sustainability (Ayantunde et al. 2011; Steinfeld et al. 2006).

Transhumance is a form of pastoralism in which livestock are moved between fixed points to utilise the seasonal availability of grazing resources (Ayantunde et al. 2011; FAO 2001; Nyssen et al. 2009). As they have permanent residence, transhumant herders move around pastures but always return to their permanent residence for some part of the year. Transhumance is considered as one of the adaptive strategies developed by the mountain people for the optimum utilisation of low-productive mountain pastures (Körner et al. 2005). It is practiced by the people from the settled communities in combination with arable agriculture (Jones 2005; Aryal 2015). Pastoral systems (including transhumance) have been constrained globally in recent decades (Dong et al. 2011), with major factors being shortages of labour

(Banerjee 2009; Namgay et al. 2014), agricultural intensification (Bhasin 2011) and changes in land-use policies (Bassett 2009; Fu et al. 2012). Other compounding pressures come from the socio-political and economic changes associated with globalisation (Poudel 2020; Hodges et al. 2014) and climate change (Gentle and Thwaites 2016; Rayamajhi and Manandhar 2020).

In the Himalayan Mountains, the transhumance involves upward movement of livestock with the onset of summer and downward movement of livestock when approaching to the winter. Transhumant herders follow a seasonal calendar to utilise grazing resources distributed at different altitudes (Aryal et al. 2014). Transhumance systems form a main livelihood strategy for the people living in high Himalayas and is embedded with the culture and traditions of mountain communities. Moreover, the products from the transhumance systems contribute for the food security of mountain communities. There are indications that the transhumance systems in Nepal Himalayas have been threatened by various factors (Poudel 2020; Banjade and Paudel 2008; Bhusal et al. 2018; Tiwari et al. 2020) and are undergoing rapid transformations. However, there is a limited understanding of the nature and extent of these change pressures and its socio-economic and environmental impacts. Therefore, this chapter aims to: (i) analyse the drivers of change and socio-ecological stressors to the transhumance systems, (ii) analyse current trends of transhumance systems, (iii) identify possible impacts from the changes to the livelihood and ecosystems and (iv) discuss possible responses of transhumance systems under different scenarios.

This chapter uses a Driver-Pressure-State-Impact-Response (DPSIR) framework to the transhumance systems in Nepal and in doing so, this chapter applies a systems thinking approach to analyse the socio-ecological impacts from the current trend in transhumance systems. The evidence compiled from local and regional case studies and observations is important in

developing a comprehensive picture of changes in a social-ecological system (Magliocca et al. 2018). The findings from the studies using such comprehensive approach can be helpful in developing strategies to achieve sustainable development goals (SDGs). The chapter is based on the analysis of data, information and findings from previous studies in Nepal and the Himalayan region. Relevant literatures from other parts of the world are also referred to in analysing socio-ecological impacts. This chapter is organised into six sections. Following this introduction section, sect. 17.2 defines the transhumance and discusses its key features. Considering transhumance system as a social-ecological system (SES), sect. 17.3 introduces DPSIR framework used in this chapter. Section 17.4 details the drivers of change, pressures, state, impacts and response of the transhumance system. Section 17.5 summarises key findings using DPSIR framework. The last section (sect. 17.6) presents conclusions and some policy implications.

17.2 Key Features of Transhumance System

17.2.1 Transhumance as a Type of Pastoral Systems

Grazing-based production, i.e. pastoralism has four categories, based on the degree of movement: (i) nomadism, (ii) transhumance, (iii) agro-pastoralism and (iv) enclosed system and ranching (FAO 2001). Movements of nomads are opportunistic and follow pasture resources in a pattern that varies from year to year whereas transhumance refers to the regular movement of herds between fixed points to exploit seasonal availability of grazing resources (Ayantunde et al. 2011). In transhumance, livestock is moved seasonally between fixed points to utilise availability of grazing resources (FAO 2001; Aryal et al. 2014). Agro-pastoralists are settled pastoralists who cultivate sufficient areas to feed their families from own crop production. While livestock is still valued property in agro-pastoral

system, their herds are on average smaller than other pastoral systems and graze within a finite area around their village which can be reached within a day. Enclosed system or ranching includes livestock production whereby the animals are kept on large but enclosed expanse.

17.2.2 Components of Transhumance System

The transhumance system has three components: rangelands (land), livestock and herders (labour or people) (Brower 1990). Rangelands include grasslands, scrublands, woodlands, etc. Climatically determined rangelands occur in areas where the availability of soil water is below the requirements of trees. Savannah and shrub steppes are examples of climatically determined rangelands. Rangelands differ from the pastures in the sense that natural vegetation grows in the rangelands whereas plants are established by human beings in pastures. Rangelands are often the common property of several owners (Crépin and Lindahl 2009) and are managed principally with extensive practices such as managed livestock grazing and prescribed fire rather than seeding, irrigating and using fertilisers. The importance of rangelands is higher in transhumance systems than in other livestock production systems as grazing is the predominant method of livestock feeding. Livestock includes various types of domesticated animals. Livestock herders play a key role in developing and sustaining rangelands (Dong et al. 2007; McVeigh 2004). Moreover, herders' traditional knowledge on plant-animal-environment relationships is important in transhumance systems (Fernandez-Gimenez 2000).

17.2.3 Seasonal and Recurring Movement of Livestock: A Key Feature of Transhumance

Seasonal movement of livestock is a key feature of transhumance. Livestock mobility in transhumance can be understood from different perspectives. From the local knowledge system or

from the herder's perspective, it is rational to move livestock in the areas having suitable climate and grazing resources (Adriansen 2006). Therefore, livestock mobility is an adaptive response of herders as grazing resources are distributed over larger spatial areas. When grazing resources are distributed over a large area and the productivity is low, it is uneconomical to use those lands for other purposes. In this situation, the mobility offers more flexible and adaptive utilisation of resources (McAllister et al. 2006) and helps to convert low-quality plant resources into high-quality animal products. From the scientific knowledge system perspective, the mobility is ecologically rational in arid and semi-arid ecosystems to avoid overgrazing and rangeland degradation (Adriansen 2006). Moreover, mobility provides a recovery period for vegetation in the grazing areas (Bruegger et al. 2014).

17.2.4 Livestock Production and Transhumance in Nepal

Three traditional livestock management systems were described by Pariyar (2008) and FAO (2005) in Nepal. They are (i) transhumance; (ii) sedentary; and (iii) stall feeding. The transhumance systems are common in the northern mountainous areas of Nepal (Pariyar 2008; FAO 2005). In transhumance, animals move seasonally in an annual cycle according to their requirement and grazing resource availability at different altitudes (Aryal et al. 2014). Herds of yaks, *chauri* (female crossbreed of yak/nak and cow/bull), cattle, sheep, goats and horses seasonally move from one place to another. Rangelands at higher altitudes are only accessible in summer (July–September) season. Therefore, herds are moved to low-lying areas in the winter (December–February) season.

The integration of crops and livestock production is a key feature of the transhumance systems in Nepal (Aryal 2015). The livestock and crop production complements each other in transhumance deriving mutual benefits. In one hand, the use of agricultural by-products by the

livestock helps to lessen the severity of winter bottleneck when there is severe shortage of feeding resources. In the other hand, the use of livestock manure in the agricultural field allows circular resource flow and reduces external input for crop production (Erenstein and Thorpe 2010). Moreover, the mixed strategy implies diversified livelihood, balanced nutrition, food security and reduces risks from systemic threats such as climate change (Wright et al. 2012).

17.3 Transhumance as a Social-Ecological System

As noted earlier (in Sect. 17.2.2), the transhumance consists of rangelands, livestock and herder and is a dynamic social-ecological system (SES). The rangelands or pastures are the resource systems (ecological system); individual livestock, pasture or rangeland are the resource units; transhumant herders are the users and customary rules and institutions, indigenous knowledge, state rules and organisations constitute the governance systems when conceptualising transhumance systems in Ostrom's SES framework (Ostrom 2009). Being a complex SES, individual units/components are invariably interconnected in transhumance and the disturbance to one unit/component could have a cascading effect to others at the systems level. Even though the transhumance systems were evolved as a main livelihood strategy for mountain communities, there were limited expectations/demands (eg. livestock grazing, collection of wild vegetables, fruits and medicinal plants) in the past from the mountainous rangelands of Nepal. However, there are changes in the social-economic and other circumstances of local people mainly under the influence of globalisation. Moreover, different and often competitive interests for the use of mountainous rangelands have been emerging in recent decades. The demands from rangelands have changed from subsistence-oriented to multi-functionality. Government policies have tried to accommodate multi-functionality of rangelands such as through the promotion of tourism and biodiversity conservation.

A systems thinking approach is required to examine the complex SES such as transhumance and uncover cascading impacts of disturbance in one unit to other units and the whole system. The Driver-Pressure-State-Impact-Response (DPSIR) framework (Fig. 17.1) which is a variant of the pressure and release (PAR) model by Blaikie and Brookfield (1987) and was subsequently refined and improved in the Wisner et al. (2004) provides a simple and transparent framework to integrate socio-economic factors with natural sciences. Moreover, this interdisciplinary framework provides a useful tool to uncover the state and cause-effect relationships (Bell 2012), Van Mai & To, 2015). Therefore, this chapter uses the DPSIR framework to analyse major drivers of change in transhumance systems, current state of transhumance systems (or major changes) and likely impacts from those changes in a meaningful way.

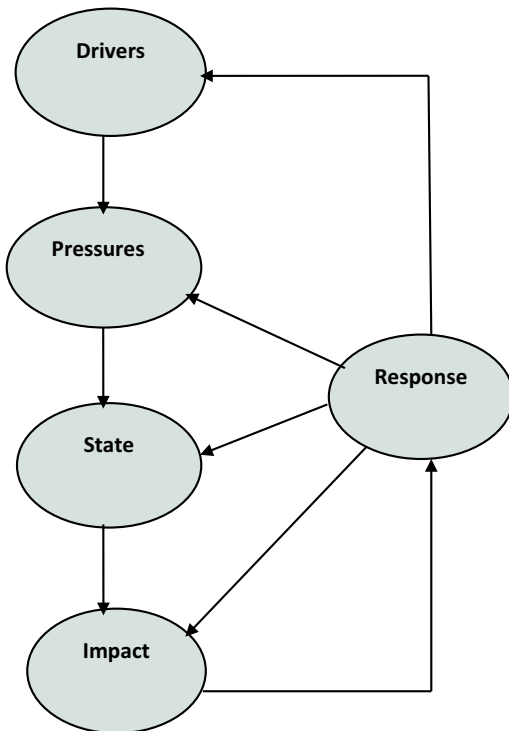


Fig. 17.1 Driver-Pressure-State-Impact-Response (DPSIR) framework. *Source* Adopted from EEA (1999)

17.4 DPSIR Framework to Analyse Transhumance Systems in Nepal

17.4.1 Drivers of Change to the Transhumance Systems

There are various drivers of changes to the transhumance systems in Nepal. These drivers are classified as global/regional, national and local.

17.4.1.1 Global/Regional Level Drivers

Globalisation

The northern mountainous areas of Nepal remained relatively isolated from the external world for long time due to inaccessibility and closed socio-political systems. However, the globalisation has breached such isolation increasing the flow of people, ideas, knowledge, technology and money by various degrees. The globalisation has manifested in different ways such as migration, tourism, education and associated changes in socio-economy and livelihood (Rhoades 1997). The transhumance system in Nepal is affected by both emigration and immigration. The migration of young people was induced by the labour demand in other countries which has created a shortage of herders for transhumance systems. Globalisation has heightened emigration to unforeseen levels where the migration has tripled since the 1980s (Hoermann and Kollmair 2009). Overseas migrants from Nepal are largely attracted by employment opportunities in the Gulf countries as their booming construction and farming sectors offer employment opportunities for unskilled workers.

In some areas such as Langtang, Khumbu and Annapurna, there is an increase in the number of tourists offering alternate employment opportunities and attracting local people towards tourism business. The growth of tourism has affected transhumance in different ways (Padoa-Schioppa and Baietto 2008; Sherpa and Kayastha 2009).

First, the increasing tourism has offered additional livelihood options whereby many families switched their profession from animal husbandry to tourism-related business. Second, it has created labour shortages for the family because tourism attracted labour for mountaineering, guiding and portering. Third, tourism has diversified the livelihood options and income sources and thus reducing the livelihood dependency on traditional systems. The integration into market economy altered the way local people interact with the landscape such as from herding and farming to tourism (Spoon 2011). Labour migration for off-farm jobs is driven by the growing penetration of wider market economy (a primary part of globalisation) in which earning cash is a necessity for accessing education and healthcare. Fourth, tourism has changed the purpose and demand of livestock rearing. The demand for female livestock such as *naks* and *chauri* which were reared for dairy products decreased whereas the demand for male livestock such as yak and *jokpyo* which can be used to carry baggage of the tourists has increased in Khumbu of Solukhumbu District (Stevens 1993).

In addition to tourism and labour migration, education has also played an important role in changing transhumance systems. Schools were established even in rural and mountainous regions of Nepal after the implementation of the National Education System Plan (NESP) in 1971. Governmental and non-governmental organisations had run and are still running many campaigns and awareness-raising activities to enrol children in schools after 1980 (MoE 2015). This has changed the attitude of people and they started to send their children to school. The increase in school enrolment has also changed the labour dynamics in the households (Poudel 2020) and it has gradually decreased the involvement of young people in the transhumance.

Climate change and variability

Climate change and climate variability can affect all three components (livestock, rangelands and herders) of transhumance systems directly or indirectly. The Inter-Governmental Panel on

Climate Change (IPCC 2021) has predicted that the nature of precipitation in higher Himalayas will change whereby there will be increasing rainfall instead of snowfall. The study by (Aryal et al. 2016) has revealed that the majority of transhumant herders across multiple sites in Nepal have perceived decreased amount of snowfall and fast melting of snow in the rangelands that can cause soil moisture deficit ultimately affecting the quality and quantity of grasses in the rangelands. The impacts of climate change to the rangelands could be more complex as it has the potential to alter the competition between plants, growth habits, productivity and plant-animal interactions (IPCC 2014) and decrease rangeland quality (Klein et al. 2014). Decreasing rainfall can lead to the drying of water resources (springs, rivers) and reduced water availability in the rangelands. The drying of water resources can lead to the abandonment of rangelands which can enhance grazing pressure in other rangelands.

It has been reported that the growing season can advance and there can be changes in the phenology of plants in the Himalayas (Wester et al. 2019; Shrestha et al. 2012a, b; Xu et al. 2009). Majority of the transhumant herders have perceived early onset of summer season, early growth in greenery and early flowering/maturing of grasses. These changes can alter the timing of grass production and the quantity and quality of grasses in the rangelands. The early maturity of the grasses in the rangelands can extend the duration of grass shortage because this time is followed by the winter season. As the seasonal movement in transhumance is mainly guided to adjust with the temperature and grazing resources at different altitudes (Aryal et al. 2014; Aryal 2015), the transhumant herders might have to make decisions in an environment of greater uncertainty with these changes. If herders respond to the early onset of summer and greenery moving up slope earlier, this can affect other agricultural activities such as planting and harvesting crops and ultimately disturb their seasonal calendar. Such changes in the calendar of local people might also have implications for the ecosystem and ecosystem management

(Franco 2015). At the same time, the increase in temperature and changing precipitation can increase the encroachment of shrubs and trees in the grasslands (Naito and Cairns 2011; Zomer et al. 2014).

Regional tension and closure of border

The political change in Tibet and border close between Nepal and China has affected movement of livestock and marketability of livestock products across the border in various sites in Nepal. Nepalese herders from Khumjung in Solukhumbu were using rangelands across the border for centuries (Bauer 1990). The governments of Nepal and China agreed in 1959 to close the border with Tibet by 1988 (McVeigh 2004). The reasons for sealing the border were the Sino-India war and incursion of Chinese into Tibet. The sealing of the border curtailed cross-border activities of herders in Khumjung (Bauer 2000), Manang (Poudel 2020), Doplá, etc. The effects from the border sealings on Himalayan transhumance and trade have been reported by many scholars in Indian Himalayas (Bhasin 2011; Negi 2007) and Nepalese Himalayas (Bauer 2004; Gurung 2008). The increased livestock pressure leading to rangelands degradation due to border closure has also been reported in some areas (Oli 2008) whereas increased inbreeding in livestock due to reduced gene flow between livestock populations has been reported in other areas (McVeigh 2004). In Eastern Nepal, some rangelands are getting intense pressure after the establishment of Singhalila National Park in Darjeeling (India) which restricted grazing and the Indian herders started to bring their yaks to rangelands of Nepal due to the open border (Oli 2008).

17.4.1.2 National-Level Drivers

State conservation policies and practices

One of the national-level drivers of changes to the transhumance systems in Nepal is state conservation and forest management policies. The government of Nepal has executed different schemes of protected areas such as National Parks, Conservation Areas and Wildlife Reserve

and most of them are in the mountainous region. The protected areas differ in terms of access restriction to resource use and participation of local people in their management. The introduction of protected areas such as national parks in mountains has restricted access to the transhumant herders which has compromised the flexibility of transhumant herders affecting operational freedom, access and mobility (Aryal 2015; Banjade and Paudel 2008; Seeland 2000; Tiwari et al. 2020). In addition, Nepal has exercised different types of forest management such as community, collaborative, national and religious forests. The forest management policies such as community forestry policies which are well-acknowledged for devolution of power to the local people in forest management has also brought unintended outcomes for transhumance systems at local level. This is mainly due to the dominance of local elites in forest management introducing grazing ban or entry fees for grazing (Banjade and Paudel 2008; Bhusal et al. 2018).

Political instability and conflict

A decade (1996–2006) long political conflict between Maoist cadres and the State's military in Nepal has been identified as another driver of change for transhumance systems in Nepal. Insurgents tried to take strategic advantages from mountain terrains using them as refuge (UNEP-WCMC 2002). Herders from the far western Nepal using Khaptad National Park in Summer season were reported to be suffered from both the State's military as well as Maoist's cadres (Aryal 2015). They were often suspected as spies by the opponents' side and there was no secure environment to move with livestock and stay in jungle and rangelands. The political instability has also accelerated overseas labour migration (Malla and Rosenbaum 2017), again affecting households' labour dynamics. Now, the political conflict is over and the country is in a new political regime. However, it is uncertain whether the traditional system will recover and to what level. Although the number of livestock increased with the stabilisation of the conflict, the number of goats increased at a faster rate than other livestock types in Majhigaun of Bajhang

district (Aryal 2015) suggesting that there could be changes in herd composition even if they recover. Some changes could be irreversible because the systematic change in traditional systems could be associated with the socio-economic and cultural transformation of the communities (Marini et al. 2011).

17.4.1.3 Local-Level Drivers

Local biophysical conditions

The higher Himalayas in general are more fragile, inaccessible, marginal and diverse (Jodha 1998). The terrain is rugged with steep slopes and soil is poorly developed. The rangelands are less productive and the grazing resources are scattered over larger spatial areas across different ecological zones. Due to these features, the physical hardships are greater in higher Himalayas and socio-economic processes were evolved to adjust with those mountain features (Jodha 2005; Banskota 2000). The transhumance-based livelihood needs to deal with those biophysical characteristics and the people of younger generation often see this livelihood option more difficult. Therefore, as an alternate livelihood option become available, they prefer to practice other livelihood leaving transhumance systems.

In addition to pre-existing biophysical and ecological factors making the livelihood of mountainous communities harder, there are other stressors becoming inevitable in recent decades. Due to climate change and climate variability, there is a declining access to water along transhumance routes and rangelands (Aryal et al. 2014; IPCC 2014). This has either forced people to abandoned grazing lands that were previously used or demanded more labour to fetch water to their temporary stables used in transhumance. The changing precipitation pattern from snowfall to rainfall means that the rangelands in high mountains remain dry for longer period of time which is likely to reduce forage production and quality which has been reported by previous

studies (Paudel and Andersen, 2013, 2010). The decline in forage quantity and quality can pose additional burden to transhumant herders and their families as they have to travel more with livestock or spent more time in the collection of grazing resources.

Poverty

Poverty is another underlying factor for the changes in transhumance systems in Nepal. The Himalayas is a home for growing numbers of rural poor whose livelihood is based on direct utilisation of natural resources (Sandhu and Sandhu 2015). Nepal is a least developed country and poverty is widespread. Poverty is even more deeply rooted in the remote mountainous areas (Pyakuryal et al. 2010). Poor people are likely to have larger families, lack investment capital and face insecure property rights (Hazell and Wood 2008). The people practicing transhumance in the Himalayas own limited land and food is not enough to feed their families. When an alternate income source is available, poor people who are seeking alternative livelihood options tend to switch their professions readily.

17.4.2 Actual Pressure from the Drivers of Change

The drivers of change that were identified in previous section (in Sect. 17.4.1) have resulted different pressures to the transhumance system in Nepal. The actual pressures from those drivers of change are shortage of labour due to changed labour dynamics, movement restriction and reduced flexibility, decreased quality and quantity of grazing resources, drying of water resources and low or decreased livestock production. The labour migration (both internal and external) and tourism are responsible for changing households' labour dynamics and creating acute labour shortages for the transhumance systems.

17.4.3 Current State or Trend of Transhumance Systems

There are studies from different parts of Nepal which indicate that the transhumance systems are in declining trend. Based on focus group discussion with the transhumant communities, Aryal (2015) has reported recent changes and trends in the transhumance systems in Solukhumbu, Dolakha and Bajhang district (Table 17.1) of Nepal. The major changes reported are smaller number of families practicing transhumance, changes in herd size and composition, changes in movement pattern (due to abandonment of distant rangelands), diversification of households' income and reduced dependency in transhumance. The number of goths (temporary stables) used by transhumant herders in the Khaptad National Park has reduced (Fig. 17.2) from above 450 (in 1988) to less than 250 (2011) in 23 years (KNP and BZ Management Plan 2005; Aryal 2015).

17.4.4 Possible Impacts of Current Trends in Transhumance Systems

17.4.4.1 Social Impacts

The social aspects which are likely to be impacted from the decline or loss of the transhumance systems in Nepal are on livelihood, crop production and indigenous knowledge and culture.

Effect on livelihood

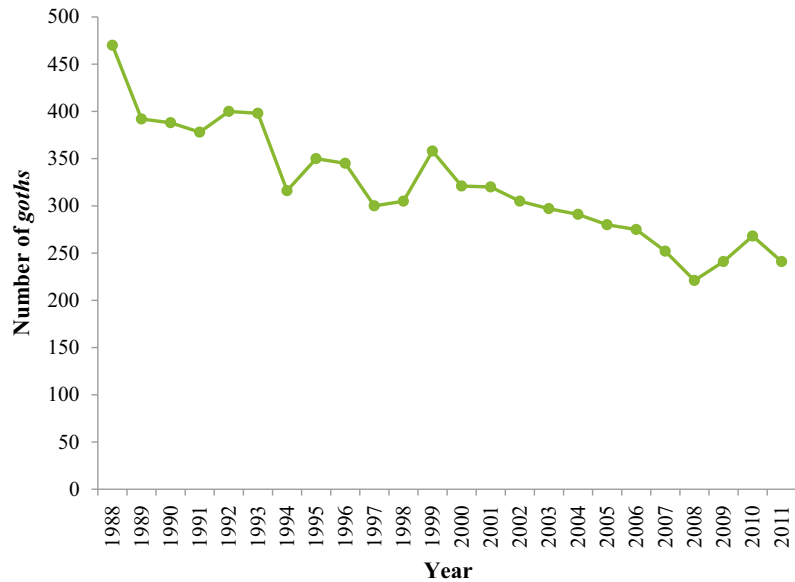
In the mountainous areas of Nepal where agricultural production is low and poverty is high (Pyakuryal et al. 2010), livestock production provides an important livelihood option (Malt-soglou and Taniguchi 2004). Moreover, the transhumance is the main livelihood strategy for people who lack formal education, technical skills and capital (money) and cannot switch to alternate livelihood options. The loss or decline of transhumance systems, therefore, affects the livelihood of these marginal people.

Table 17.1 Major changes in transhumance

Changes in	Site (district)		
	Khumjung (Solukhumbu)	Kalinchok (Dolakha)	Majhigaun (Bajhang)
No of families practicing transhumance	Decreased	Decreased	Decreased
Herd size	Decreased for many families but increased for few families	Decreased	Decreased
Herd composition	Nak/ <i>chauri</i> before tourism, Yak/ <i>jokpyo</i> after tourism	Number of <i>chauri</i> heavily decreased	Before conflict cattle, goat after conflict
Grazing areas	Few herders reach to distant rangelands	Distant rangelands at high elevation are abandoned and grazing areas at lower elevation are restricted due to CF	No change
Purpose of rearing livestock	Changed from livestock products to livestock as means of transport	Almost same (except no wool is produced from goats and sheep)	Almost same (but preference of goats is to generate cash)
Dependency on transhumance	Decreased	Decreased	Decreased
Involvement of young generation in transhumance	Decreased	Decreased	Decreased

Source Adopted from Aryal (2015)

Fig. 17.2 Number of *goths* (temporary stables) used for transhumance inside Khaptad National Park (KNP). Source Adopted from DNPWC (2013), Aryal (2015)



Effect on agriculture

As noted earlier, crops and livestock production are integrated in the transhumance systems of Nepal deriving mutual benefits for both productions (Aryal et al. 2018). This indicates that the loss or decline of the transhumance system is likely to reduce crop production. The crop production is highly dependent on livestock production in high mountains of Nepal. In remote mountainous areas where there is no or limited access to the alternate means of crop production (eg. chemical fertilisers, tractors), livestock provides the only source of manure and draught power. Moreover, livestock products (milk, butter, cheese, hardened cheese, meat) supplement the diet of people in Nepal (Broaddus-Shea et al. 2020) and are important source of protein for the people who are involved in transhumance and their families. Therefore, the loss or decline of transhumance systems can increase the livelihood vulnerability and food insecurity for transhumance communities. This indicates that the sustainability of the transhumance systems can contribute to achieve several sustainable development goals including zero hunger (SDG 2), no poverty (SDG 1), sustainable cities and communities (SDG 11) and life on land (SDG 15).

Loss of traditional knowledge and culture

In high Himalayas including Nepal, the transhumance itself was evolved as a culture of local people (Namgay et al. 2013). The loss of transhumance systems come with social costs such as accelerating loss of customary lifestyles, traditional knowledge and ancestral culture (Stevens 1993). The loss of such knowledge and culture might be irreversible as they are linked to broader process of social transformation (Marini et al. 2011). Due to interactions with nature and transmission of knowledge and experiences for generations, transhumant herders possess knowledge about local agro-ecological conditions, plants and animals (Spoon 2011). Their knowledge and experiences are useful in herd and grazing management. The losses of transhumance systems mean loss of such traditional knowledge. The loss of such knowledge primarily affects people who depend on the same land as in the past, but traditional methods, knowledge and social institutions no longer exist.

17.4.4.2 Ecological Impacts

Loss of biodiversity

The role of livestock grazing in relation to the high Himalayan biodiversity is a highly

debatable issue among local resource users and conservationists. There is no or little support from policymakers for transhumance grazing in the Himalayan region because policy decisions are often based with the consideration that the livestock grazing is detrimental to rangeland ecology and biodiversity (Rao et al. 2003; Roder et al. 2002). Policymakers of Nepal also assume that rangelands are degraded and grazing is the main reason for such degradation (Miller 1995; Pande 2004). However, there are recent studies (Sharma et al. 2013; Aryal et al. 2015) indicating that some level of grazing is desirable in the Himalayan rangelands to reduce shrub encroachment and maintain biodiversity.

Previous studies from the Himalayan region (Shrestha et al. 2005; Shrestha et al. 2012a, b) suggest that snow leopard (endangered and iconic species for conservation focus in higher Himalayas) prey on both wild and domestic ungulates. Those studies also indicate that there is a diet overlap and competition between domestic livestock (such as sheep, goats and yak) and wild ungulates (blue sheep and Himalayan Tahr) and usually suggest reducing number of domestic livestock. However, Bauer (1990) reported that utilisation patterns between wild ungulates and livestock differs. Historic land-use practices such as grazing increase the heterogeneity, proportion of early succession plant species and availability of forage and browsing for wild ungulates (Siebert and Belsky 2014). However, there is no studies on how the absence of domestic livestock will directly affect food availability for blue sheep and Himalayan Tahr which are major prey species for snow leopard that have the highest conservation focus in higher Himalayas. However, there are indications that the abandonment of grazing in Himalayan rangelands will proliferate shrub encroachment (Sharma et al. 2013) which can change the grass availability for those herbivores. Furthermore, the Himalayan rangelands are of particular concern due to high endemism (Salick et al. 2009) and an increase in shrub cover can threaten endemic species (Brandt et al. 2013).

The conservation of agro-biodiversity and indigenous livestock breeds is important to

benefit mountain region (Inam-ur-Rahim et al. 2013). The decline or loss of traditionally practiced production systems for any reason lead to the decline in agro-biodiversity. The loss of transhumance means the loss of native breeds of livestock that are well adapted to the higher altitude. During transhumance, herders collect and use various wild but edible plants, fruits and mushrooms which are consumed by themselves or sold along the transhumance route. The transhumance also complements crop production in various ways and the decline or loss of transhumance can result in loss of local races and varieties of crops. The local livestock breeds and crop varieties might have different cultural and social values and meanings. Therefore, the loss of these local resources can have negative impact on culture and customary practices of mountain communities in addition to the reduced gene pool and decreased production.

Changes in vegetation and land use

Himalayan rangelands are cultural landscapes subjected to human use for centuries and the abandonment of traditional practices such as transhumance might alter the vegetation and land use. Predicting future vegetation and land-use dynamics in the absence of livestock in the Himalayan rangelands is one of the important scientific and management challenges. Some studies (Nautiyal and Kaechele 2007; Sharma et al. 2013) have indicated that the shrub and bush cover is likely to increase in the Himalayan rangelands after grazing abandonment which is also the case in other mountains (MacDonald et al. 2000; Poyatos et al. 2003). As vegetation responds differently to different types of livestock; changes in livestock composition as seen in some areas can also affect vegetation (Kerven et al. 2012). Furthermore, the increase in temperature and change in rainfall patterns due to climate change may compound with the declining herding patterns to affect vegetation dynamics and the land use (Sturm et al. 2001). If increasing number of local people abandon distant rangelands and begin to graze their livestock in the nearby communal lands (forests or rangelands) or private lands, it is likely that the grazing

pressure in the nearby areas will increase leading to their degradation (Sneath 1998).

Loss of ecosystem function and services

The decline or loss of transhumance systems might affect ecosystem function and services in the mountain landscape. The changes in species diversity and vegetation composition as discussed in previous section could alter ecosystem functions (Archer 2010; Chapin et al. 2000). The increase in shrubs can increase the extent of fire in the rangelands which may affect endangered species. Changes in vegetation in the high Himalayan rangelands may alter the provision of ecosystem goods (grass, food, medicinal plants and genetic resources) and aesthetic and spiritual values. For example, the increase in shrub cover due to grazing abandonment can reduce grass production in the rangelands which can again affect livestock production ultimately affecting livelihood of herders (Beyene 2010; Solomon et al. 2007). The increasing tourism in the mountainous area of Nepal is also an example of soaring consumption of aesthetic values of mountain landscapes which can be altered with the change in vegetation.

17.4.5 Likely Future Responses of Transhumance Systems

The societies are changing in response to various change stressors described above and it cannot be guaranteed that the dynamic social-ecological systems (SESs) remain as they were in the past or as they are in the present. The future of transhumance systems is likely to depend on how practitioners (transhumant herders) and policy-makers perceive recent changes and current trends in the transhumance systems. It is likely that the state's policy decisions can influence the responses of herders. In the situation where government policies promote other livelihood options, it will further discourage transhumant herders to practice transhumance systems. This policy decision will complement other drivers of changes resulting current declining trend and will

accelerate the declining trend. However, other forms of land use (e.g. monoculture or specialised enterprise) may not provide the same level of diversity and stability in mountains because of the cold and harsh climatic conditions where short crop growing seasons demand livelihood diversity and stability in food security. Transhumance complements the farming systems in multiple ways through income and livelihood, diet and cultural institutions (e.g. rituals, festivals) that can provide more robustness and flexibility required to make a living in cold and harsh climatic conditions of mountains where crop growing season is limited. In the situation where government chooses to wait and see (do nothing), the transhumance systems could continue to decline in the current pace in response to multiple drivers of changes and change pressures. Transhumance systems may cease but other forms of pastoralism can continue with the change into a more sedentary form of livestock production. In the situation where state policies create a competitive position whereby transhumance herders can improve income and living standards from transhumance systems compared to other livelihood options available, it will encourage local people to continue some level of transhumance.

17.5 Summary or Key Findings Using DPSIR Framework

Key findings from the review and analysis are presented in the DPSIR framework (Fig. 17.3). The drivers of change to the transhumance system are classified into different scales; global/regional, national and local. The broader scale global drivers of change are globalisation (migration and tourism), climate change and international relations resulting opening and closing of borders. State public policies, economy and conflict are identified as national-level drivers. The biophysical conditions and poverty are local-level drivers. The drivers at different scales have created different pressures to the transhumance system in Nepal. The actual pressures are shortage of labour, access restriction

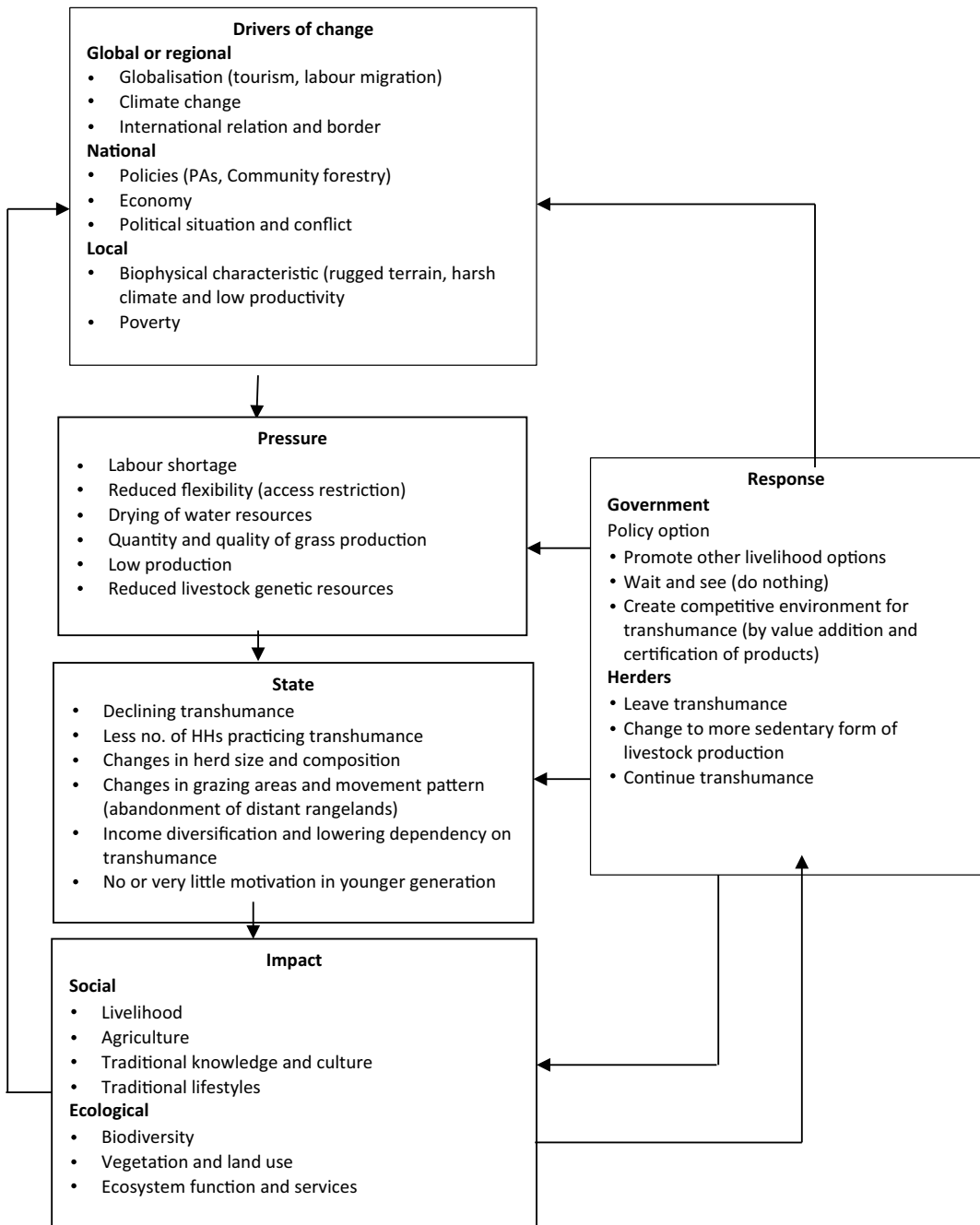


Fig. 17.3 Driver-Pressure-State-Impact-Response (DPSIR) framework for transhumance systems

leading to reduced flexibility, decline in quantity of quality of grazing resources, drying of water resources, inbreeding and reduced livestock production. The transhumance systems in Nepal are showing declining trend. The people of

young generation are less engaged in transhumance and the distant rangelands are abandoned. Moreover, local people are diversifying households' income and the dependency on transhumance has also decreased. The current trend of

decline in transhumance systems might have various social and ecological impacts. The social impacts from the decline in transhumance system might be on livelihood, crop production, food security and indigenous knowledge and local culture. The likely ecological impacts are loss of biodiversity, changes in vegetation and land use and altered ecosystem functions. The future of transhumance depends on how government and local people respond to the current trends (states) of the transhumance systems. If the government promotes livelihood options other than transhumance and discourages transhumance, it will accelerate the declining trend. If government chooses to wait and see, the transhumance system is likely decline in current pace. If government creates competitive market for transhumance products and introduces policies to encourage herders, it is likely that some form of transhumance will continue in future.

17.6 Conclusions and Policy Implications

Using DPSIR framework, this chapter analysed the current states, drivers of change and likely socio-ecological impacts from the current and emerging trends of transhumance systems in Nepal. The drivers of changes to the transhumance systems come from different spatial scales (global, national and local) mainly resulting shortage of labour and reduced flexibility. The review and analysis showed that the transhumance system in Nepal is in declining trend with less numbers of people involved in the system and with smaller herd size. The declining trend/status of transhumance systems might have adverse impacts on the livelihood of local communities and the health of associated ecosystems. The complementary relationships between crop and livestock production in transhumance suggest that the loss or decline of transhumance can reduce livestock as well as crop production that can adversely affect livelihoods, food security and the overall wellbeing of mountain communities. The grazing abandonment from the loss of

transhumance systems or changed grazing patterns from the decline in transhumance systems can alter vegetation composition, land use and ecosystem services in the rangelands.

These results have several policy implications including contributions towards achieving various sustainable development goals (SDGs). First, the chapter provides a comprehensive knowledge for policymakers to make important policy decisions including whether to encourage or discourage transhumance systems. The findings are relevant to the entire Himalayan region and other parts of the world where historically practiced transhumance systems are facing unprecedented changes due to globalisation (labour migration and tourism) and other socio-economic and environmental changes. The status of the transhumance systems in combination with the opportunities and threats from the recent global social and environmental changes provide insight for policymakers to make such policy decisions. Second, the socio-ecological impacts from the decline or loss of transhumance system have been highlighted. The adverse impacts on livelihood and food security of mountain communities and ecosystem services from the mountain landscape due to decline or loss of transhumance systems provide another important policy insights for policymakers. These findings indicate how the sustainability of long-standing transhumance systems contributes to achieve SDGs including no poverty (SDG 1), zero hunger (SDG 2) and life on land (SDG 15). Third, the findings of this chapter highlight an important issue to be considered in revising conservation policies in higher Himalayas as there are indications of changing grazing regimes from overgrazing to grazing abandonment in the context of declining trends of transhumance systems. The adverse ecological impacts from the grazing abandonment in the Himalayan rangelands should be acknowledged in future conservation policies. Finally, this chapter provides an important methodological insight in the study of social-ecological systems experiencing multiple change stressors around the world as this chapter used a DPSIR framework in the study of transhumance systems.

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Sustainable Fisheries and Aquaculture for Food and Nutrition Security in Nepal

18

Madhav K. Shrestha, Narayan P. Pandit, and Ram C. Bhujel

Abstract

Potential of aquaculture and fisheries sector was not realized in Nepal despite its recent expansion. A review of literature related to the sector was carried out to assess the present status, trend and future scope, and also to make policy recommendations on fisheries management and aquaculture development. Our study showed that an estimated 91,832 mt of fish was produced in 2020, which is the third most important animal protein source after buffalo and poultry. Fish contributes nearly 20% of the total animal protein intake in Nepal. However, annual per capita fish consumption is only 3.5 kg which is six times lower than that of global average (20.5 kg). About 23% of the total fish is caught from the wild by mainly ethnic communities for their

families. The remaining comes from aquaculture which grew at 15% annually during the last decade. As wild catch is declining due to illegal fishing practices and river water diversion, aquaculture is the only way to meet increasing demand for fish. About 0.6 million people are engaged in aquaculture and fishery sector and it contributes about 4.25% of the agricultural GDP and 1.33% of the national GDP in 2019/2000. Aquaculture is considered mainly as small-scale, livelihood-based enterprise. Traditional polyculture of carps in ponds accounts for almost 90% of the aquaculture production in Nepal. Commercial culture of rainbow trout, tilapia, pangasius and other catfishes are spreading rapidly due to their high productivity. However, shortages of seed and quality feeds are the major constraints. If the government gives high priority and develops favorable policies and practical action plans, it would take off soon. Therefore, it has great potential to help solve many problems associated with the sustainable development goals (SDGs) of the UN such as poverty, hunger, health and wellbeing, gender equality, employment, and life below water.

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Keywords

Aquaculture and livelihoods • Commercial aquaculture • Household nutrition security • National food security • Small-scale fisheries

18.1 Background and Introduction

Globally, food habit of the people is shifting from red meat to white meat then to aquatic food. Fish along with aquatic animals ranks number one among the animal protein sources consumed and traded across the borders annually in terms of volume (FAO 2020a). In Nepal, however, the daily average animal protein consumption is only about 20%, which is considerably lower than the minimum level (33%) recommended for good health (AIT 1994). Among the animal protein sources, fish with the production of 91,832 mt/year ranks third after buffalo meat and poultry (meat and eggs) (Fig. 18.1, MoALD 2020), indicating that it can play a prominent role in food and nutrition security of the Nepalese people. When it comes to priority for the government planning, human resource development, and budget allocation, it remains near the bottom of the list. When income of the people increases, they consume more protein-rich foods of animal origin. However, animal proteins are scarce and expensive, and most people can't afford on a regular basis, as a result they rely on carbohydrate-based diet. Therefore, there is a need to re-consider and recognize the fisheries and aquaculture which could play greater roles if they receive adequate attention. This also suggests that Nepal needs effective multi-faceted solutions to address the problems associated with food and nutrition security.

This chapter is based on the literature review—both published and unpublished or grey literature and authors' long and extensive experience of working in Nepal (Bhujel et al. 2008, 2014). In addition, information obtained from interactions or discussions with key informants and experts in government organizations (GOs) and non-government organization (NGOs) during national workshops and conferences were used in the preparation of this chapter.

18.2 Why Fish?

Fish and other aquatic animals are highly delicious and nutritious foods (Reames 2012) that provide high quality protein and depending on the species, varying levels of essential polyunsaturated fatty acids (PUFAs) and highly bio-available essential nutrients such as minerals and vitamins (Castine et al. 2017; HLPE 2014). They are considered as the best sources of protein as they contain all the essential amino acids, omega-3, Vitamin A and D, and many important minerals (Table 18.1). They can be easily farmed and are often available free in the natural water bodies such as rivers, rice fields, lakes and swamps. Fish is considered healthy white meat. For those who purchase food from the market, fish is perhaps 3–4 times cheaper than mutton in Nepal. But due to traditions and customs, people prefer goat meat the most. From nutritional point

Fig. 18.1 Sources of animal protein by volume in Nepal (Chicken includes eggs as well). Data sourced from Poudel et al. (2020), MoALD (2020)

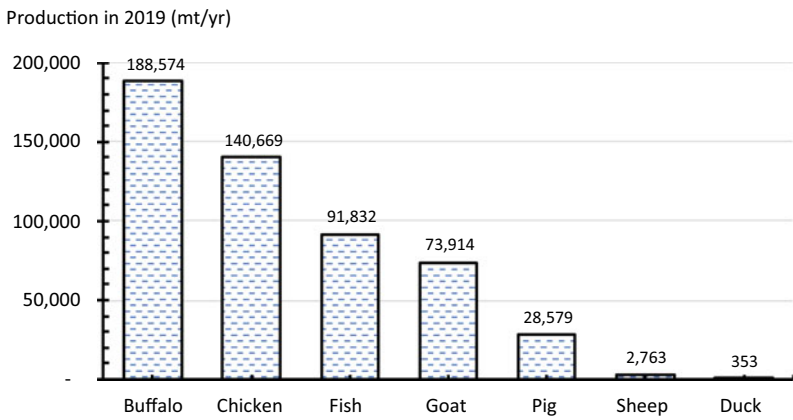


Table 18.1 Nutritive value of different fish species

Nutrients per 100 g	Tilapia ^a	Rainbow trout ^a	Atlantic Salmon ^a	Rohu ^b	Pangasius ^b
Energy, kcal	96	148	208	97	161
Protein, g	20.1	20.8	20.4	17	14
Total amino acids	19.9	20.0	19.6	–	–
<i>Lipids</i>					
Total fat, g	1.7	6.6	13.4	1	11
EPA, mg	5	202	862	–	–
DHA, mg	86	528	1,104	–	–
<i>Minerals</i>					
Calcium, mg	10	43	9	650	180
Iron, mg	0.56	1.5	0.34	1	–
Magnesium, mg	27	22	27	–	–
Phosphorous, mg	170	245	240	175	130
Potassium, mg	302	361	363	–	–
Sodium Selenium, µg	52	52	59		
<i>Vitamins</i>					
Vitamin A, IU	–	57	50		
Vitamin B12, µg	1.6	7.8	3.2		
Vitamin E, mg	0.4	0.2	3.6		
Vitamin D, IU	124	155	–		
Vitamin K, µg	1.4	0.1	0.5		

Sources ^a USDA/ARS (2011); ^b Gopalan et al. (2004)

of view, it would be far better if a person buys 4 kg of fish to feed the family at least 4–5 times a week instead of buying 1 kg of goat meat to offer once in a week at the same price. Fish is valuable food in the diet for the people of all ages, and should be encouraged to consume regularly, especially to include in women's diet during the pregnancy for the physical and mental health of infants (Longley et al. 2014).

18.3 Fish Consumption

Unavailability of fish in most of the hilly and mountainous regions of Nepal is the main problem caused by limited production and lack of proper processing, packaging and marketing systems. Domestic production is about 91,832 tons of fish which do not fulfill the demand and over 10,000 metric ton of fish is imported annually from India costing about 2 billion rupees (approx. US\$17 million) (DoC 2020; Rijal and Jha 2020; Ranjan 2019). The per capita fish (from catch, culture and imported) consumption is approximately 3.5 kg/year (DoC

2020; Rijal and Jha 2020;), which is about six times lower than the global average of 20.5 kg (FAO 2020b). While most of the other Asian countries, especially from east and southeast Asia consume more than 30 kg/year. Import of value-added products is occurring from Asia (China, Japan, Korea, Malaysia, and Vietnam) and Europe (Norway, Holland, France, Germany, Italy, and Spain) (UN Comtrade 2020). Traditionally, fish and other aquatic products have been contributing to food and nutrition security in Nepal, providing nutritious and delicious supplements to the diversified and nutritious diets. The fisheries and aquaculture contribute approximately 20% of the total animal protein (Fig. 18.1).

Fish is mainly derived from two sources: aquaculture and capture fishery. Catch from the wild source is declining due to overfishing, destructive fishing practices, damming the rivers and other forms of habitat destruction. Therefore, aquaculture has been emerged as an important sector of Nepalese agriculture and is one of the fastest growing agricultural subsectors. However, Nepalese aquaculture is lagging far behind and

the volume of fish produced is too low compared to the production in other Asian countries, nevertheless, the progress achieved during 2010–2019 is highly encouraging (FAO 2021). The annual combined growth rate of capture fisheries and aquaculture is about 13% in the last decade, which is the highest among the SAARC nations (CFPCC 2019). Capture fisheries supplies about less than one-third of the total fish but is rather declining. Therefore, when considered separately aquaculture is growing at faster rate, i.e. 15% and is the only way to compensate the catch decline and fulfill the increasing demand. The demand for fish is growing and will continue to grow due to increase in population and awareness about the health benefits of fish and aquatic foods. Therefore, mass-scale commercial farming is needed to make the fish available to all throughout the year. Less productive low land rice fields, rivers, lakes and reservoirs, and swamps needed to be utilized developing immediate and long-term strategic plans listing it on high priority in government policy and plans. At the same time, possibility of establishing processing plants, storage and efficient transportation should be explored so that people in the areas where fish are not produced can also access fishery products at reasonable prices.

18.4 Governance, Priorities and UN's SDGs

Nepal's Agricultural Development Strategy (2015–2035) and, Food and Nutrition Security Plan of Action, prioritize the efforts to increase access to and availability of nutrient-rich foods. Aquaculture sector has been recognized, to some extent, as a potential sector in contributing to policies, goals, and the priorities of the Government of Nepal (GoN) to address hunger, malnutrition, and poverty as well as the UN's sustainable development goals (SDGs), especially related to #1 (poverty), #2 (hunger), #3 (health and wellbeing), #5 (gender equality), #8 (employment), and #14 (life below water). Realizing the potential contribution of aquaculture to poverty alleviation, and food and

nutritional security in Nepal, this sector is gradually receiving increasing attention from the local, provincial, and federal governments (Gurung et al. 2021). Some new attempts have been made from the Government of Nepal, e.g. including rainbow trout as one of the priority products under one village one product (OVOP) scheme. Government of Nepal has initiated commodity-based commercialization plans under the Prime Minister's Agriculture Modernization Project (PM-AMP) creating Pocket areas, Blocks, Zones and Super zones depending upon the resources and future scope for various commercial products including aquaculture commodity (PM-AMP 2021). However, there are shortages of human resources, appropriate technologies, practical and specific plans and favorable policies for the implementation of such programs at all levels of the government. Local level government should be provided with clear plans including required human resource and inputs.

18.5 Fisheries

18.5.1 Water Resources

Rivers, lakes, reservoirs, swamps/wetlands, and floodplain and canal connected irrigated paddy fields are the major water bodies with a total area of 821,259 ha including the recent pond area (Rijal and Jha 2020) where fish are available or can be/are farmed. Low land irrigated paddy fields cover 48.5% followed by rivers representing 48.1% of the total water area. Ponds account for about 1.6% based on the recent data i.e. 12,759 ha (Rijal and Jha 2020). Lakes and reservoirs cover 0.8% and open waters cover approximately 5.6% of the total area of Nepal. There are more than 6,000 rivers covering 25,000 km in total length. Lakes are scattered throughout Nepal, with about 5,000 ha of water surface area. Much studied tectonic lakes of Pokhara valley—Phewa (523 ha), Begnas (328 ha) and Rupa (135 ha) have well established cage aquaculture and capture fisheries. About 200 Jalaris (i.e. fishermen) who used to

depend on fishing roaming around for fishing were supported to culture fish in cages and settle down forming their own communities (Nepal et al. 2011). More than 24 indigenous fishes have been reported from the lakes in Pokhara valley (Husen et al. 2021).

Nepal has several reservoirs constructed for hydropower and irrigation purposes. Their total water surface area is approximately 1,500 ha. The first commissioned man-made reservoir for hydropower was Indra-Sarovar at Kulekhani which has a fishery station and many fish cages. The fishing communities displaced by reservoir were provided with cages as compensation. Nepal plans to have many reservoirs for hydropower which envisage to cover about 153,200 ha, i.e. 100 times more area than at present. Thus, it will offer a great scope for expansion of cage culture. Wetlands, swamps, and paddy fields are scattered throughout the country, which are mostly connected to rivers from where fish enter during monsoon, could also be used for aquaculture.

18.5.2 Capture Fisheries

Rivers, lakes, reservoirs, wetlands/floodplains, and irrigated paddy fields are the major habitats of wild fish. Finfish is the main group of aquatic animals harvested from these water bodies. They provide shelters for more than 236 indigenous fish species of Nepal (Shrestha 2017). Karnali river basin alone provides the habitat for 196 fish species (Wagle et al. 2020), and upper and lower stretches of Karnali river alone produce about 375 mt of fish/year (Neiland et al. 2020). Capture fisheries contribute about 0.4% of the total GDP engaging nearly half a million people; part- or whole-time basis, for their livelihoods; majority are women. The estimated total fish catch is 21,000 mt/year (Rijal and Jha 2020). The contribution of rivers, lakes, reservoirs, marginal swamps and paddy fields are 7110, 1000, 525, 5200 and 7165 mt respectively. Despite having a huge area, irrigated paddy fields, contribute only one-third of the total catch though it might be underestimated. Accurate data collection is almost impossible because there are no recording

systems of fish catch from the rice fields and natural water bodies.

It has been recognized that open waters are overfished and capture fisheries has declined, but the magnitude of the problem has been grossly underestimated. Overfishing especially using destructive practices such as poisoning, dynamiting, and electric shocking are considered the causes of fisheries depletion. In addition, the anthropogenic activities causing habitat destruction such as river water diversion for hydropower, irrigation, sand and gravel mining in rivers, sedimentation and eutrophication, hazardous pesticide uses and pollution, and climate change play substantial roles on fish depletion (Gurung 2012).

Besides finfish, over 45 species of mollusks (gastropods and bivalves), and crustaceans (freshwater prawns and crabs) are found in the freshwater habitats of Terai region (Brandis and Sharma 2005; Nesemann and Sharma 2003; Wagle et al. 2021). A report showed there are about 25 species of gastropods and 20 species of bivalves. Out of these reported 45 mollusks at least 25 species are consumed (Subba and Ghosh 2000; Subba 2012). Although, data are not available, ethnic communities of Terai harvest considerable quantities of edible mollusks each year which play an important role in food and nutrition security of some minority ethnic groups. About 25–30% of the total population of the Terai communities are involved in harvesting and consumption of mollusks (Subba 2012). They are cheap non-conventional sources of good quality protein for a large population, especially ethnic poor.

Importance of mollusks for nutrition and food security of local communities of the Terai region can be accounted with its consumption of average 42.6 kg/household/year (Wagle et al. 2021). Mollusks are nutritionally rich and gastropod muscle contains 16.2% crude protein (CP) and low in fat (1.0%), while that of bivalves contain 11.0% CP and 0.6% fat on fresh weight basis. They are also rich in calcium and iron contents (Wagle et al. 2021) (Table 18.2). Mollusks are not considered as common foods and not commercially cultured yet and usually harvested from the

Table 18.2 Nutritional quality (fresh weight basis) of commonly consumed mollusks (Wagle et al. 2021)

Nutrients	Flesh/muscle	
	Gastropod	Bivalve
Moisture, %	74.7	72.4
Dry matter, %	25.3	27.6
Crude Protein, %	16.2	11.0
Crude fat, %	1.0	0.6
Crude Fibre, %	0.3	0.4
Total ash, %	7.6	7.2
Iron (mg/100 g)	98.7	92.6
Calcium (mg/100 g)	174.2	204.2

wild. However, harvest data of those mollusks along with indigenous freshwater prawns and crabs are not available, though their role in food security and nutrition has been remarkable to the community that consume these aquatic products. More research is needed to collect information on their species, their nutritional compositions, their breeding and feeding habits so that they could be promoted for commercial culture as in other countries. It would be helpful in diversifying the aquaculture to achieve better food and nutrition security and create opportunities for income and employment to the people.

Wild edible aquatic plants also have noteworthy roles and contributions in Nepalese diets and food security since time immemorial. These aquatic plants (e.g. Water chestnut, Makhana, Lotus, Water mimosa, Water spinach or Morning glory, Watercress etc.) serve as wild food to community and play significant role in socio-economy and culture. Although, there are no data on quantity of edible aquatic plant harvested, they have significant contributions to food and nutrition security of local communities and households. Thus, more studies on shellfish yield, population dynamics, and contribution to the food and nutrition is required.

18.5.3 Fishing Communities and Methods

Fisheries sector provides, either directly or indirectly, a great employment opportunity for many

people in Nepal. There are many traditionally involved tribal and ethnic communities (Tharu, Majhi, Danuwar, Kumal, Kewat, Musahar, Bote, etc.) in fishing activities since ancient time (Gurung 2014). These communities live in the vicinity of water resources depending on such resources for their livelihoods from generation to generation. There are about half a million people engaged in capture fisheries, among them about 60% are female (Rijal and Jha 2020). Females in capture fisheries assist in preparing and caring of fishing gears, repairing nets and other equipment. More importantly, mostly women sell fisheries products in the markets and participate in financial activities. All those fishers operate by one or two members of the family and are categorized as small-scale fisheries. Fishing is done traditionally using cast nets, gill nets, lift nets, seine nets, hooks and lines, light and spears/knives, traps, and small fishing gears. More recently, illegal methods such as poisoning, dynamiting, and electric shock are also used. Some of them are very destructive and are banned. However, monitoring and control has not been easy. Most of the fishing communities catch fish for their families while others sell to get some cash. Caught fish are mostly consumed or sold fresh. Surplus fish may be dried or smoked to keep for longer period or sold to the market, but it is very limited. Although the quantity of fish production is normally low from natural waters often ignored by researchers and extensionists. Aquatic environments are engaging women of various communities in rural and isolated areas and

offering self-employment, nutrient rich food, and social harmony. Therefore, research and development of fisheries sector should be one of the priority areas of federal, provincial, and local governments.

18.6 Aquaculture

Aquaculture, broadly defined as farming of aquatic animals and plants, has been considered the most efficient and environment-friendly food production system. Fish normally can convert feed (i.e. FCR) almost three times more efficiently than the pig and two times less than chicken (GAA 2018). It requires 100 times less land and 10 times less water use than pig (Armstrong 2017; Clark and Tilman 2017). It also has three times less carbon footprint than lamb (EWG 2011). Many scholars recommend fish to grow and put back on the menu to feed the ever-increasing population (Béné et al. 2015). Aquaculture practices in Nepal include pond culture, raceway culture, cage culture, integrated farming with rice/vegetables and animals, and swamp culture (Table 18.3). The culture systems can be categorized into small-scale livelihood-based aquaculture, semi commercial-scale, and commercial-scale aquaculture. Annual farmed fish production in Nepal is more than three times higher (70,832 mt, Table 18.3) than the wild catch which is estimated at 21,000 mt (Rijal and Jha 2020). Average annual growth trend of aquaculture for last decade (2010–2019) was impressive double-digit growth, i.e. about 15% (Fig. 18.2).

In Nepal, planned aquaculture development was initiated in 1980. However, lack of appropriate policies and strategic plans for human resource and technological development or adoption, it grew slowly until 2010. Nevertheless, during that three-decade research, training, and outreach programs serve as bases and it is taking off since 2010. If the current trend continues, by 2030 production shall increase by two folds from the current production level (2019) and four folds in two decades from the level of 2010. It would make the country self-reliant for fish (Fig. 18.2). But more efforts are needed to address the shortages of good quality seeds caused by low survival (Jha et al. 2015). Farmers have to depend on import of seeds (e.g. tilapia and catfish/pangasius), and issues such as shortages of quality feed and access to improved technologies and other inputs need to be addressed. Aquaculture species of Nepal are: common carp (*Cyprinus carpio*), silver carp (*Hypophthalmichthys molitrix*), bighead carp (*Aristichthys nobilis*), grass carp (*Ctenopharyngodon idella*), rohu (*Labeo rohita*), mrigal/naini (*Cirrhinus mrigala*), catla/bhakur (*Catla catla*), Nile tilapia (*Oreochromis niloticus*), pangasius (*Pangasianodon hypophthalmus*), catfish/magur (*Clarias*), rainbow trout (*Oncorhynchus mykiss*), sahar/mahseer (*Tor putitora*) and few others. However, farming of other aquatic animals, especially crustaceans (freshwater prawns, crabs, etc.), mollusks (mussels, snails, etc.) and plants (morning glory, watercress, etc.) has not been started yet. They could play important roles in food and nutrition security as in many other countries.

Table 18.3 Status of aquaculture production in 2018/2019. Adapted from Rijal and Jha (2020)

Particulars	Total area	Fish production (mt)	Productivity
Pond culture (ha)	12,749	62,725	4.92 mt/ha
Swamp culture (ha)	3816	7289	1.91 mt/ha
Cage culture (m ³)	72,500	305	4.21 kg/m ³
Raceways rainbow trout culture (ha)	3.20	420	130 mt/ha
Paddy fish culture and enclosure (ha)	98.8	93	0.94 mt/ha
Total aquaculture production		70,832	

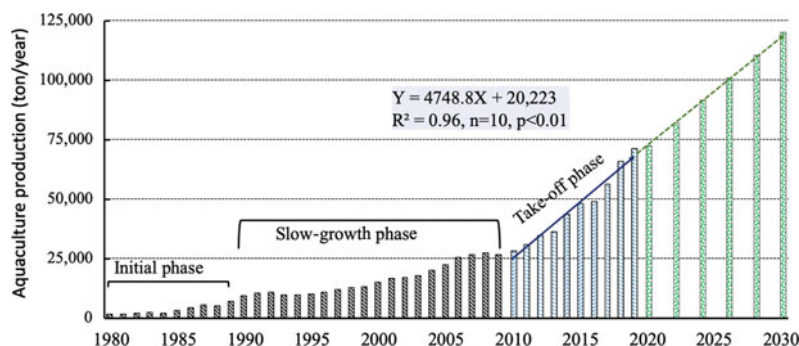


Fig. 18.2 Aquaculture development phases in Nepal since 1980. Production figures for 2020–2030 were estimated using simple linear regression model based on

the data during the take-off phase i.e. 2010–2019. Data sourced from FAO (2021)

18.6.1 Culture Systems

18.6.1.1 Ponds

Pond culture is a major fish production system in Nepal. Almost 90% aquaculture production in Nepal comes from earthen ponds which have reached nearly 45,000 spreading in about 55 districts with the total area of 12,759 ha (Rijal and Jha 2020). Pond aquaculture is mostly in rural areas representing small-scale subsistence in nature and mainly livelihood based. The remaining are operated as commercial purpose, almost all production is for selling in markets. Almost all the pond farms are managed as semi-intensive polyculture of carps, or monoculture of catfish, pangasius, and tilapia with an average productivity of 4.91 mt/ha (Rijal and Jha 2020).

Presently, semi-intensive carp polyculture has been widely disseminated in the southern plain and mid-hills of the country and as it has become the viable and common aquaculture activity along with mono species commercial culture and generates 67.5% (70,832 mt) of the total finfish production (Rijal and Jha 2020) (Table 18.3). Recently, some farmers have started to intensify using aerators and floating or sinking pellet feeds. A unique example is an intensive culture of mrigal under single stocking but multiple harvesting to produce smaller size of juvenile fish of the size ranging from 30 to 100 g, popularly known as *Chhadi*. Farmers in Central Terai harvest 12–15 mt/ha/year (Kunwar and Adhikari 2017). They are popular because they look like from the natural

water bodies as they are small and slender. This has been very successful in Nepal because it takes shorter period to produce, can be dried or smoked easily, and has high demand in the major cities especially in Kathmandu valley and other markets located alongside the highways adjacent to the rivers, e.g. Malekhu, Mugling and other towns (Kunwar and Adhikari 2017).

18.6.1.2 Raceways

Raceway is a system of fish culture in running water. Rainbow trout is one of the best known, a high-value fish species suitable for raceway system in cold waters. With a view to utilizing vast cold-water resource, brown trout, rainbow trout, and other trout species were introduced to Nepal since the late 1960s and early 1970s from UK and India. These were reared in Godawari and Trishuli fish farms. Later on, rainbow trout (*Oncorhynchus mykiss*) was reintroduced from Japan in 1988 (Nepal et al. 2002). At present, rainbow trout farming has demonstrated as one of the successful enterprises in most of the mid- and high hills of Nepal (Rai et al. 2005; Gurung et al. 2017). With the technological innovation of commercial rainbow trout aquaculture, it has spread to over 34 hilly and mountainous districts of Nepal with the prospect of expanding in more areas. By the end of fiscal year 2018/2019, rainbow trout production in Nepal has reached to 420 mt (Rijal and Jha 2020).

The rainbow trout has been a unique and one of the most expensive food commodities in

Nepalese market because of its taste and high nutritional value. Farming integrated with a resort and/or restaurant has been one of the most common and successful businesses in Nepal. As Nepal, has perennial glacial fed rivers and streams with clear water, there is an opportunity for more rainbow trout farms to be established. Some of the farms have been smart to utilize natural flow of streams for growing rainbow trout without the need of constructing heavy concrete tanks. This model could be promoted to expand trout farming as it could save cost incurred for concrete tanks. The rainbow trout production is less than 500 mt/year which is not enough for restaurants to offer as daily item in menu. Production in each farm is just enough to feed the domestic tourists who visit their farms. Large volume of trout needs to be produced expanding more raceways as well as installing cages in lakes and reservoirs (Nepal et al. 2021) to bring the price down so that it can be consumed by common people.

18.6.1.3 Cages

Cage fish culture in lakes and reservoirs is the main source of livelihood for a number of ethnic communities; namely, Jalaris (Pode, Majhi, etc.) and other ethnic communities living around major lakes of Pokhara valley and Kulekhani Reservoir. The estimated area of lakes and reservoirs of Nepal is about 5,000 and 1,500 ha respectively, which occupy 0.6 and 0.2% of the total water surface area of the country (Rijal and Jha 2020). Phewa, Begnas, and Rupa lakes of Pokhara valley had fish cages since 1972. About 200 families were involved in cage culture in Pokhara valley (Nepal et al. 2011). Similarly, cage fish culture has been practiced in Kulekhani and Kaligandaki reservoir, where more than 300 families are involved (Gurung et al. 2009). Cage culture contributed about 305 mt fish in 2018/2019. An estimate shows that cage volume has reached nearly 72,500 m³ with an average fish productivity of 4.2 kg/m³ (Rijal and Jha 2020). The environment-friendly, subsistence-type and small-scale cage culture is practiced in Nepal without feeding, entirely depending on plankton feeder fish, such as bighead carp and silver carp.

Fish cages are cheaply made using bamboo frames. Fish are grown with naturally available phytoplanktons, zooplanktons, detritus and some aquatic vegetations. Cage fish farming of grass carp in monoculture feeding with aquatic macrophytes was found to be far more productive (8.4 kg/m³ vs 1.3–5.5 kg/m³) in comparison to planktivorous fish species (Gurung et al. 2005; Prasad et al. 2012; Husen et al. 2018). As feeding is not allowed due to the fear of pollution in the lake, only planktons available naturally in the lake water are not adequate to support good growth of other species. If farmers want to grow other species than grass carp, feeding would be necessary. Such subsistence cage culture was beneficial for some supplemental income for the landless fisher communities who were displaced or affected by inundation of water while storing large volumes as a reservoir for power generation (Gurung et al. 2009). However, cage culture is confined to only few lakes of Pokhara valley, and Kulekhani and Kaligandaki reservoirs. The productivity of cages without feeding and stocking at 10–12 fingerlings/m³ is considerably low which ranges from 1.3 to 5.5 kg/m³ (Husen et al. 2018). Allowing farmers to stock at higher densities and feeding the fish could enhance productivity by at least four folds which is becoming popular in SE Asia. Intensive feedlot cage culture, especially that of tilapia with productivity of 20 kg/m³, is expanding in many countries (Bhujel 2014, 2019; Bhujel and Suharman 2021). There is a possibility to increase the productivity by adopting it in Nepal. Cage culture with pellet feed could also be done as a way to increase productivity (Fig. 18.3; Shrestha 2002; Mandal et al. 2014). This technology could also suit for deeper and larger ponds in addition to lakes and reservoirs (Fig. 18.3, Nepal et al. 2021).

18.6.2 Small-Scale Integrated Aquaculture

Majority of farmers in Nepal are small-scale where farming is characterized by integration of crops with livestock and/or fish (Shrestha et al. 2012, 2015) (Fig. 18.4). The role of integrated



Fig. 18.3 Left: Cages in a pond initiated in Jhapa by a participant of the tilapia training organized at CAARP (photo by Nandan Thapa). Right: Cages in Indrasarovar, Kulekhani (photo by Ram Bhujel)

farming on the household food and nutrition security and income generation has been increasingly appreciated in recent years. The concept of having a small-household pond is to improve the nutrition of rural poor families. Small ponds usually smaller than 500 m² each is commonly constructed using family-owned land-based utilizing limited resources. Several species of fish are raised in polyculture system (Shrestha and Bhujel 1999; Farquhar et al. 2019). About 50–80% of the fish produced are consumed by the households and the remaining are sold for supplemental income (Bhujel et al. 2014; Farquhar et al. 2019; Pandit et al. 2020; Shrestha et al. 2012) (Table 18.4).

Polyculture of small indigenous fish species (SIS) such as mola/mara (*Amblypharyngodon mola*) mixed with carps has potential to improve nutritional status of poor families through regular harvesting and consumption of SIS is required (Gupta 2011; Rai et al. 2012, 2014). The SIS, which are usually eaten whole including organs, heads and bones, contain large amounts of minerals such as calcium, phosphorus, iron, iodine, zinc, etc., and vitamins A and D (Table 18.5). The bones of SIS are very rich in calcium, eyes, heads and other organs are rich in vitamin A, iron and zinc (Roos et al. 2003). SIS reproduce many times within a year; therefore, they can be harvested many times increasing the frequency of fish consumption which is important for

maintaining good health. Rural households could benefit a lot from carp-SIS polyculture (Rai et al. 2012, 2014).

18.6.3 Commercial Aquaculture

Majority of aquaculture in Nepal is operated as semi-commercial scale. Pond size may range from 2000 to 6000 m², mostly operated by a family member. Carps and tilapia are the major species produced in this system. Productions are for household consumption (20–25%) and rest are for local markets providing food and nutrition security for family households and for local communities. Full-fledged commercial aquaculture are registered fish farms either by individual entrepreneurs or by groups on leased or own land. Farm sizes vary from few hectares (2–4 ha) to several hectares (15–20 ha). Fish are fed with commercial pellet feeds. Most common commercial aquaculture systems are carp polyculture, or catfish culture, pangasius culture, trout culture, or tilapia culture. Annual productivity of carp ranges from 4–9 mt/ha, whereas it can be considerably enhanced (range 21–45 mt/ha) if catfish, pangasius or tilapia are stocked instead (Table 18.6, Khanal et al. 2020). Furthermore, over 100 mt/ha can be produced from trout in raceways but it requires clean and cold water, and high investment for concrete structures (Rijal



Fig. 18.4 Small-scale integrated rice/vegetable-fish, buffalo/pig-fish (Photos courtesy of Madhav Shrestha and Ram Bhujel)

Table 18.4 Pond size, production, consumption, and income of small-scale aquaculture

Particulars	Characteristics (<i>n</i> = 159)
Pond size (m ²)	30–700
Mean fish productivity (mt/ha)	3.03
Production range (kg/pond)	12–340
Consumption range (kg/household)	3–135
Sales range (kg/household)	4–205
Supplemental income range (NRs./household)	480–24,600 (approx. US\$4–210)

Source Shrestha et al. (2012)

and Jha 2020). Expansion of intensive and highly productive commercial aquaculture, especially tilapia and pangasius, is the key to increase production which could help achieve national and household level food and nutrition security. Aquaculture development and expansion is occurring mostly in expense of some rice fields because rice farming requires a lot of labor and may not be profitable if a farmer calculates all the costs involved. Therefore, aquaculture has been considered as an alternative option.

Average rice productivity in Nepal is about 3.2 mt/ha (Tripathi et al. 2019) whereas average fish productivity of traditional carps can be more than two folds, i.e. 6.9 mt/ha (Table 18.6; Pandit et al. 2018; Khanal et al. 2020). Fish production can be doubled if intensive culture of catfish, pangasius, and tilapia are done in the same area of pond (Jha et al. 2020; Khanal et al. 2020). However, mass seed production of the species and good quality feeds are lacking which are very much needed for commercial aquaculture.

Table 18.5 Nutrient contents (on dry matter basis) of small indigenous fish species

SIS	Protein (%)	Lipid (%)	Vit. A (^a RAE per 100 g raw cleaned parts)	Fe (mg per 100 g raw cleaned parts)	Zn (mg per 100 g raw cleaned parts)	Ca (%)	P (%)
1. Dedhuwa (<i>Esomus danricus</i>)	57.5	10.6	107.5	6.2	4.5	1.46	1.02
2. Mara (<i>Amblypharyngodon mola</i>)	63.0	22.0	685.5	2.4	4.3	1.17	1.87
3. Pothi (<i>Puntius sophore</i>)	55.5	26.8	56.0	3.1	4.2	2.34	2.17
4. Faketa (<i>Barilius</i> sp.)	65.7	22.6	84.5	1.0	3.6	NA	NA

Source Hossain et al. (1999), Rai et al. (2014), Hossain et al. (2015)

^aRetinol Activity Equivalents

Table 18.6 Commercial aquaculture and fish productivity in Nepal

Culture system	Productivity mt/ha/year	References
Carps (mean and range)	6.9 (4–9)	Pandit et al. (2018), Khanal et al. (2020)
Pangasius (mean and range)	33.4 (21–45)	Khanal et al. (2020)
Nile tilapia (range)	14.4–50.8	Jha et al. (2020), Mandal et al. (2020)
Rainbow trout (mean)	130	Rijal and Jha (2020)

Although, there are 14 government stations and 83 private hatcheries in the country (Rijal and Jha 2020), none of them are producing the seeds of catfish, pangasius, and tilapia. Government policy should be favorable toward developing specific technical skills, establishing hatcheries, marketing and seed supply systems. Similarly, fish feed production is very limited and often farmers must depend on import. Therefore, seed and feed production need to be supported by the government especially with the involvement of private sector. More importantly, price of fish is 8–10 times higher than that of rice. These are the reasons why farmers choose aquaculture. An estimation showed that if 1.6% rice field is converted to aquaculture ponds, fish production could be doubled that would be adequate to replace fish imports and double the present per capita fish consumption of Nepalese people. However, strategies should be to utilize less fertile rice fields or swamps and fallow lands.

18.6.4 Advanced Aquaculture

Recently, advanced intensive commercial aquaculture systems; namely, Aquaponics, Biofloc technology (BFT), and Recirculating Aquaculture System (RAS) have been initiated in the country. Several youths have started with limited knowledge and resources as these can be set up in small backyard gardens. These are high tech systems with high production capacity per unit area with minimum water exchange and less land area required. In these systems, water is used efficiently, and wastes are recycled. Aquaponic is a system wherein fish and vegetables are grown together recycling the water. Nitrogenous wastes in the water from fish tanks go to vegetable growing beds and serve as sources of nutrients (Somerville et al. 2014). In Biofloc, nitrogenous wastes are converted into bacterial flocs by adding carbon source (e.g. rice or molasses) which can be source of food for fish (Avnimelech

et al. 2014). More recently, a new system called “in-pond raceway system (IPRS)” has been designed constructing long raceway tanks within the same pond to create water flow-through system by using strong pump (Aranna et al. 2018). The production capacity, profitability and applicability of those systems need to be tested and verified partnering with private sector before promoting them for expansion in the country (Bhujel and Woollard 2011). Few Aquaponic farms have been started in Kathmandu valley and several youths have started fish farming using Biofloc system and also RAS in Chitwan, and other parts of eastern and mid-Terai districts.

18.6.5 Aquaculture and Employment

Aquaculture employs many people along the various stages of value chain. Both men and women of different ages are involved. There are about 150,000 people directly engaged in aquaculture, among them males represent 68%, while females only 32% (Rijal and Jha 2020). Fish farming and pond management is easier than many agricultural activities and livestock farming. Most women who stay at home prefer it; therefore, continue once they start (Bhujel et al. 2008; Farquhar et al. 2019; Shrestha et al. 2012). If small-scale aquaculture involving women, popularly known as Women in Aquaculture (WiA), could be expanded throughout the country as campaign, many women could benefit, and it could help achieve food and nutrition security goal more easily (Bhujel et al. 2014).

18.7 Education and Human Resources

Various government reports show that about 0.6 million people are involved in overall fisheries and aquaculture sector which contributes about 4.25% of the agricultural GDP and 1.33% of the national GDP (in 2019/2000) (Rijal and Jha 2020); however, there might be many more unaccounted for who catch fish occasionally. Only 150,000 are engaged in farming, i.e. three

times less than in fishing, but they produce three times more. The aquaculture sector was led by few experts educated or trained from foreign countries including from Asia, Europe, and North America. However, most of the extension services related to aquaculture development was done by professionals whose major academic degrees were zoology, general agriculture, livestock husbandry or veterinary science. The aquaculture sector was constrained heavily due to limited human resource to provide support for its rapid expansion. Realizing the need of formal degrees, Bachelors, Masters and doctoral programs have been started. Every year there are about 15–20 graduates and about 10–15 post-graduates entering the sector. Occasional vocational training programs and community development projects have been designed and implemented by public as well as private sector; however, more is needed.

18.8 Fish Consumption

Fish was not a part of regular diet of majority Nepalese people in the past. Only few ethnic minority groups living nearby natural water bodies used to consume somewhat more frequently. Most communities catch fish from the rivers especially during winter or during summer when fish migrate upstream for breeding, and juvenile fish are found even in rice field and small streams. Unlike pork or chicken, fish is widely accepted by all the communities in Nepal. More recently, due to awareness about health benefits, more people are consuming fish more frequently which has raised the demand. Chinese and Indian Major Carps are the main species which are farmed. Presence of intra-muscular bones in carps is the main reason that many people avoid eating fish as regular diet. Alternative fish species like tilapia, pangasius, and trout are getting popular to those who are afraid of fish bones. Nutritional value and the taste of fish depend on how fresh they are and how they are prepared and cooked. Cooking methods are mostly boiling with water or making curry adding several spices, e.g. turmeric, ginger, etc.

which are rich in nutrients and immuno-stimulants. Recently grilling and deep frying in oil are becoming popular but steaming, one of the best methods, is not practiced yet. Consumption of value-added fish products are still not so common in Nepal except some locally smoked fishes or dry products found in the cities imported either from India or other countries, and their imports are increasing. However, the smoked and sun-dried fish found in open markets contain excessive molds and micro-organisms (Pradhan et al. 2017, 2020). Proper processing and packaging methods need to be followed to avoid or minimize them. Regular monitoring and quality control by the concerned agency is needed.

18.9 Fish Markets and Import–Export

Fish is one of the highly and globally traded food items. More than 35% of the global production is traded across the countries (FAO 2020a, b). Production takes place mostly in developing countries while the high value markets are in developed countries, e.g. Australia, Japan and many other countries in Europe and North America. China earns about US\$20 billion from fish/year, and India, Vietnam and Thailand earn US\$6–8 billion/year (FAO 2019). Fish are mostly consumed fresh and sold at the farm or nearby local markets. Many live fish selling vendors started during the last decade in most of the districts where fish are produced. Live fish vendors were initiated to provide fresh fish to the communities and replace almost spoilt fish coming from Andhra Pradesh of India. But Rohu and pangasius are still entering to Nepal to meet the demand in the cities.

Since 2012, about 10,000 mt of fish is imported annually which is costing about NRs. 2 billion (approx. US\$17 million) annually (DoC 2020; Kunwar and Adhikari 2017; Ranjan 2019). More than 50% of the total import is Rohu from India followed by pangasius. Fresh pangasius is mainly from India and frozen from Vietnam (UN Comtrade 2020). Frozen fillets, steak or whole Salmon are also imported from Norway and it is

increasing. Similarly, canned tuna, mackerel, and anchovies imported from Thailand and other countries are available in the supermarkets like Bhat Bhateni, and many other grocery stores in major towns. There are plenty of processed fish items found in other countries which could also be produced in Nepal e.g. fish powders, pickles, pastes, cakes, and so on but mostly imported. Few local items are starting to appear. They are important in terms of food and nutrition security because they have long shelf life and easy to transport (Pradhan et al. 2017). During COVID-19, most people purchased these processed items in large volumes to keep longer period at home to ensure their families could still enjoy nutritious food. Some fresh fishes from Nepal are also sold across the border to India as Bihar and Uttar Pradesh do not have good aquaculture base. If Nepal could produce more fish, a huge market exists nearby as these two states of India have over 300 million people.

18.10 Policy Recommendations

18.10.1 Education, Research and Development

As a new and emerging sector, there are plenty of rooms for education, research and development; therefore, aquaculture and fisheries sector should be managed well. The followings are the recommendations:

- The sector should be governed by an authoritative entity such as “Faculty or College of Aquaculture and Fisheries” in universities, and “Department of Aquaculture and Fisheries (DAF)” under the Ministry of Agriculture and Livestock Development (MoALD) at the federal, provincial, provincial and municipal/village levels.
- Improvement of curricula and development of effective training programs for unemployed youths or adults in fisheries education, research, extension activities.
- Attracting more entrepreneurs and financial institutions to invest more for the development

of this sector to create more employment, produce more fish for food security, and substitute fish import.

- More research needed to improve the existing carp productivity and hatcheries to increase survival of hatchlings, fry and fingerlings and enhance the seed quality.
- Conducting adaptive research on commercial farming of catfish, tilapia, pangasius and giant freshwater prawn.
- Adoption of latest and advanced aquaculture technologies to carry out research, verification trials and technology transfer to private sector; namely, aquaponics, biofloc, in-pond recirculatory system (IPRS), and RAS (recirculatory aquaculture system in tanks) to enhance productivity.
- Intensifying the existing cage culture method in lakes and reservoirs by adding more fish and feed as in other countries. Cage culture could also be tested in large and deeper ponds to enhance the productivity.
- More cage culture of carps and rainbow trout should be in existing reservoirs and also new ones to be constructed as a part of hydro power generation.
- Continuing some efforts of producing seed and grow-out of Sahar (Jha et al. 2017; Pandit et al. 2018), Giant freshwater prawn (Bhujel et al. 2008), Asala (Shrestha et al. 2014), and Magur and Singhi (Yadav and Bart 2003) to refine and verify their technologies.

18.10.2 Fisheries Management Policy

- Governance related to fisheries resources conservation and sustainable utilization should be clearly defined and well-structured at all the newly formed government system at all levels, i.e. federal, provincial, district and local governments, and also in the research and academic institutions.
- High priority should be given to the sector recognizing it as an important source of animal protein and means of solving the problems of food and nutrition security.

- Emphasis should be given to aquatic biodiversity conservation and sustainable harvest of the fisheries resources developing appropriate policies and guidelines for any infrastructure development programs, e.g. road, hydro-electricity dams.
- Include fish ladder, fish passage or fish hatchery for indigenous species as a part of hydro-electric power generation projects.
- Breed indigenous species to promote enhanced fisheries by restocking of hatchery produced fingerlings in lakes and reservoirs.
- Protect small-scale fishers dependent on fisheries resources for their livelihoods and their food and nutrition security.
- Monitor strictly and control destructive fishing practices such as poisoning, electro-fishing and dynamiting.
- Create awareness among the public against the use of antibiotics, pesticides and other chemicals in the farms especially close to the natural water bodies.

18.10.3 Aquaculture Development Policy

- Organizational structures, policies, plans and activities related to aquaculture should be developed well and incorporated in the newly formed government systems at all levels, i.e. federal, provincial and local, and also in the research and academic institutions.
- Recognizing the roles of and plan for the development of three levels of pond aquaculture, i.e. small-scale and integrated farming or semi-commercial aquaculture for the family nutrition with surplus for local communities, and commercial aquaculture for national food security.
- Intensifying existing pond culture systems encouraging feeding and higher density with aeration to increase productivity.
- Expanding feed-based commercial cage-culture selecting the appropriate sites or locations and species such as pangasius, tilapia and trout in addition to carps.

- Due to high profitability and ease of doing it, aquaculture is expanding using some rice fields. Therefore, developing guidelines and making strategy to utilize less productive or fallow land for aquaculture is important.
 - Developing appropriate models of rice/vegetable-fish farming specific to Terai and mid hills.
 - Exploring new areas for expansion such as swamps and low land areas where most of the crops cannot be grown due to water logging problems.
 - Utilization of existing reservoirs and new ones to be created for hydro power.
 - Establishment of on-farm feed plants and commercial feed manufacturing plants through public–private partnership.
 - Establishment of specialized hatcheries, nurseries, and seed supply systems for pangasius, tilapia, giant freshwater prawn and others.
 - Promoting carp polyculture with tilapia and pangasius with fattening finishing stage with feeding and aeration.
 - Conducting adaptive research for Aquaponics, Biofloc, IPRS and RAS for technology verification.
 - Exploring more indigenous species including crustaceans, bivalves, mollusks and aquatic plants for their farming and biodiversity conservation.
 - Proper processing, value addition, storage, packaging, and marketing of aquatic products through public–private partnership.
 - Monitoring quality of aquatic food items sold in the markets to ensure food safety.
 - Developing quality of aquaculture/fisheries education, training, and community development projects.
2. Wild fish stock needs sustainable harvest and conservation plans as fish catch has declined due to over-fishing using destructive practices, pollution, dam construction, and other human activities.
 3. Increased demand for fish has showed tremendous scope for improvement of fisheries sector through research and development but more people should be involved in commercial aquaculture to utilize abundant water resources.
 4. Rainbow trout has been a good choice for hilly regions, and traditional carp culture in Terai plains where aquaculture is moving toward high density intensive culture of catfish, pangasius, and tilapia.
 5. Production of good quality fish seeds and feeds, and appropriate technologies and human resource development in fisheries are the needs of the country.
 6. If present growth continues, production shall be double by 2030 to make the country self-reliant on fish. The sector has a great potential to help solve the country's problems such as poverty, malnutrition, unemployment, gender inequality, etc. and contribute to SDGs of the UN.
 7. Appropriate fisheries and aquaculture policies and strategies focusing on institutional strengthening and result based actions to achieving the targets of national food and nutrition security are needed to develop and manage the sector.

18.11 Conclusions

1. Fish is a good alternative source of protein with rich profile of all essential amino acids, omega-3 and 6 fatty acids, and all macro and micronutrients.

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Part III

Forestry, Community Forestry, and Agroforestry

Ecosystems Services from Community Forestry: Prospects and Challenges for Improving Local Livelihoods in Nepal

19

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Abstract

Nepal's community forestry is touted as a development success, especially in relation to how local community groups can be empowered by the state to conserve and manage communal forest areas for local livelihoods improvements. However, this success is limited in relation to the production and supply of conventional forest products or a narrow range of ecosystem services (ES). The concept of ES has recently

landed in Nepal's policy domain and an evolving body of research has also highlighted the potential of applying ES in community forestry for augmenting livelihoods improvements, climate change adaptation and mitigation, and biodiversity conservation. Yet, there is still a lack of evidence on the degree to which community forest user groups are expanding their forest management practices by including additional range of ES. Drawing on 14 case studies of community forests from across the country, as well as a recent review of literature and analysis of secondary data, this chapter assesses the potential of an ecosystem centred approach to community forest management for local community livelihoods in Nepal. We identify a variety of emerging initiatives towards ES-based management of community forests, demonstrating the need for a strategic shift away from the narrowly focused, subsistence-oriented forest management to a more holistic management of forest ES. We also identify priority challenges that need to be tackled in facilitating this shift to achieve the sustainable production of ES for livelihoods improvements and its contribution towards climate change mitigation and sustainable development goals.

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Keywords

Community forestry · Ecosystem services ·
Marketing of forest products · Forest and
poverty

19.1 Introduction

It is now well accepted both in theory and practice that community conserved- and managed forest has the potential to contribute to livelihoods improvements and environmental sustainability (Gilmour 2016; Lund et al. 2018; Ojha et al. 2009; Thwaites et al. 2017). Nepal's community forestry (CF) is one of such successes globally. However, its success is demonstrated mostly in the context of subsistence livelihoods, with a focus on a narrow set of ecosystem products such as timber, fuelwood, and fodder (Paudel and Ojha 2013; van Oort et al. 2015). The policy and practice of CF has been slow to embrace the agenda of ecosystem services (ES), which is claimed to have the potential to serve both livelihoods and environmental conservation (Chaudhary and McGregor 2018).

More recently, the potential of ES has been acknowledged, with an emerging tendency to promote ES beyond subsistence levels, towards contributing to social justice by reducing poverty. Despite this acknowledgement, evidence related to whether and how community management can benefit from the emerging markets for diverse forest ES is still limited (Bhatta et al. 2014; Lamsal et al. 2018; van oort et al. 2015). Moreover, there is also a lack of clarity on policy directions as to how increasing market values of ES can be mobilized for enhancing livelihoods of the poorer section of the society. The prospect for improved local livelihoods is particularly important in countries like Nepal where forest ES are traditionally used for subsistence livelihoods (Rana et al. 2017). However, increased market values are not automatically translated into livelihoods, as policies and institutions need to provide necessary support and enabling environment. In Nepal, effective and meaningful policy to promote ES is slow to emerge, amidst the general tendency of slow policy responses, even when there is increasing body of evidence supporting the positive roles ES play in social and economic development (Acharya et al. 2020a; Paudyal et al. 2017). Amidst this

situation, the question of whether ES approach is going to help the poor is particularly intriguing. The question of who benefits from the marketing of ES is particularly crucial in view of the findings of some studies which report that the access of the poor to natural resources is more secure in the subsistence-based resource management systems than when ES are promoted to the market (Paudel 2016).

Against this backdrop, this chapter aims to bring new evidence from community forestry to demonstrate how a variety of new ES management practices are being promoted in Nepal, mostly initiated at the community level, under the policy environment lacking clear direction or regulatory framework to support ES centred CF practices. Drawing on 14 case studies, complemented by a review of literature and analysis of secondary data, we also identify diverse management strategies adopted by community forests user groups (CFUGs) to recognize, develop, and promote non-traditional (those beyond timber and fuelwood) ES, such as ecotourism, drinking water supply, and watershed conservation. Based on our initial research, we explore the potential of market-oriented and ES centric community forestry, in a way that generates multiple benefits to the community, including the poorest and socially marginalized. We further explore policy directions for upscaling ES-based innovations in view of the potentials and challenges identified.

19.2 The National Context: Ecosystem Services and Community Forestry

Since the Millennium Ecosystem Assessment (2005), the ES agenda has gained global recognition. The concept has its origin in western environmental management contexts where attempts have been made to value the intangible services including the aesthetic and spiritual services of ecosystems in monetary and marketing. Over the past two decades, the concept has also been promoted to the developing world and the most recent work of Intergovernmental

Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has further reinforced the relevance of ES approach by highlighting nature's contributions to people to ensure sustainability of ecosystems.

In the last three decades or so, the policy emphasis on natural resources management has shifted from the state centric system to community-oriented approach. Initially such a shift was primarily about managing the subsistence-oriented livelihoods of local communities whilst creating additional incentives to create sustainable management practices and institutions. More recently, the community-based natural resources management systems have also been recognized for their potential to manage wider range of ES, not just at the subsistence level but also the commercial and market-oriented management.

Nepal's CF has emerged as a proven local institution to conserve forests and manage those ES such as timber and fuelwood which are essential part of the rural livelihoods systems. The CFUG institution has proved to be resilient and has filled the strong gap that was created by the nationalization of forests in 1957, which dismantled many local institutions and alienated local communities from their land and resource base. The introduction of CF in the 80s brought a new era in forest governance, empowering communities in the management and use of accessible forest areas. This led to significant positive impacts on forest conservation and the fulfillment of forest products needs of local communities. Community forestry in Nepal has brought about ecological, economic, and socio-political benefits to the local communities (Acharya et al. 2020a; Birch et al. 2014). Not limited to the rural landscape, the benefits that the CF render, for instance, climate regulation and carbon sequestration are realized at regional and global scales (Lamsal et al. 2018; Paudyal et al. 2015).

However, this did not bring much shift in the practices of forestry considering the changing scenarios at the global and local scales. The traditional and narrowly conceived forestry practices have continued in the community-based

regime too, and this sits oddly with the emerging contemporary research which shows that community forestry areas have high potential for ES (Paudyal et al. 2017). Evidence from Nepal and elsewhere however indicates that CF also supports multiple ES such as carbon sequestration (Lamsal et al. 2018), water regulation and purification (Lamsal et al. 2018; Paudyal et al. 2017), biodiversity (Dorji et al. 2019; Sears et al. 2018), timber (Van oort et al. 2015; Adhikari et al. 2018; Wangchuk et al. 2021), spiritual and religious values, research and education (Chaudhary et al. 2017; Lamsal et al. 2018), and erosion/landslides control (Acharya et al. 2020a; Lamsal et al. 2018).

The range of ES which CFUGs conserve, manage, and mobilize are closely linked with the diversity of small forests and livelihood patterns of local inhabitants, especially in the mountains of the country. Potential ES typically provided by community forests of Nepal are presented in Table 19.1, using Millennium Ecosystem Assessment (MEA) category and their indicators. The actual type and quantum of ES generated by a CFUG depends on the location of CF, species composition of the forest, and management regimes within which CFUGs are operating (Lamsal et al. 2018; Paudyal et al. 2017).

In the field of community forestry research globally, the ES concept gained prominence since 2009, when Payments for Ecosystems Services (PES) began to be instituted to encourage for biodiversity conservation in community managed forests areas (Wunder and Wertz-Kanounnikoff 2009). This was followed by many ES research initiatives which focused on different ecological, social, and political aspects of ES in community-based forest management, such as forest ES focusing on regulating services (Lamsal et al. 2018), environmental justice and ES in community forests (Chaudhary et al. 2017), and relations between forest carbon and species richness.

Following the global trend and national research initiatives, Nepal's forest sector policies also began to recognize the larger spectrum of ES. The ES concept was mentioned in REDD+ Social and Environmental Standards 2013, which

Table 19.1 Typical list of ecosystem services from community forests in the study region, with description and potential indicators relevant to the study area and measurement units. ES based on MEA ES. 2019 Adapted from Paudyal et al (2015), Paudyal et al (2017), Dorji et al. (2019), Adhikari et al (2018)

Ecosystem service category	Type of ES	Description of ES	Indicator of ES	Measurement units
Provisioning services	Freshwater	Water available for drinking, irrigation, and hydropower	Number of springs, ponds and streams; volume of water; hydroelectric infrastructure capacity	No. site ⁻¹ ; volume of water flow (m ³); hydroelectric generator capacity (kWh)
	Timber production	Timber stock at harvestable age in the forests	Number of large and mature trees per ha of dense forest	No. of commercial trees household ⁻¹ (HH ⁻¹)
	Firewood production	Presence and abundance of preferred firewood species	Number of fuel wood species, volume of fuel wood	Head Loads (HL) HH ⁻¹
	Food production	Provision of food from forests: berries, wild fruits, mushrooms, wild vegetables	Amount of food materials	kg HH ⁻¹
	Leaf litter	Leaf litter collected for cattle bedding	Amount of leaf litter collected	HL HH ⁻¹
	Grazing land	Area available in the forests for grazing	Number of grazing animals in the forest	No. HH ⁻¹
	Forage production	Forage production potentiality from forests and grasslands for local livestock	Number of fodder producing areas	HL HH ⁻¹
	Local medicines	Variety of tree, shrub, and herb species with biomedical value	No. of species of medical value and harvestable amount	kg HH ⁻¹
	High-value NWFP	Non-timber forest products with bioprospecting or high commercial value	No. of species and production potential	No. HH ⁻¹ or kg HH ⁻¹

(continued)

Table 19.1 (continued)

Ecosystem service category	Type of ES	Description of ES	Indicator of ES	Measurement units
Regulating services	Fresh air regulation	Trees provide fresh oxygen and absorb dust particles/toxins from atmosphere	Total leaf area; amount of pollutant in air	Air quality (ppm of key pollutants)
	Carbon sequestration	Atmospheric carbon capture by trees, shrubs, and herbs	Increasing forest cover and increase in biomass	ha ⁻¹ year ⁻¹
	Groundwater recharge	Vital role of vegetative forest cover in regulating flow and retention of water	Ground water recharge rate (net amount of water availability throughout the year downstream)	Volume of water
	Natural hazard regulation	Forests act as a natural buffer, helping to protect from strong winds, landslides, and other disasters	No. of landslides and other natural hazard cases per year	No. year ⁻¹
	Water purification	Pure water running in streams	Quality of purified water	Macroinvertebrates
	Disease reduction	Reduced diseases by regulating fresh air and water purification	Number of people affected by water and air borne diseases	No. of incidents year ⁻¹
	Crop pollination	Increased production of crops from larger population of bees and other insects that help pollinate forests and agricultural crops	Number of pollinators	No. of species observed
	Soil protection	Does forest help in soil protection and conservation? Landslide prone areas covered by vegetation	Incidences of landslides, soil erosion, or degradation	No. year ⁻¹
	Biodiversity/habitat	Provides refuge to many plants and wild animals	Observed/reported recurrence of wild animal and plant species in the forests	Diversity ha ⁻¹
	Maintenance of genetic diversity	Invasiveness/alien/native species	Appearance of new plants and animals	No. ha ⁻¹
Cultural services	Spiritual and religious values	Presence of temples and religious sites	Locations of temples and spiritual sites; no. of people visiting these locations	No. of visitors year ⁻¹
	Aesthetic values	Enjoyment of a landscape's scenic beauty	No. of visitors appreciating the visual quality of the landscape	No. year ⁻¹
	Recreation and ecotourism	Opportunity for recreation and ecotourism	No. of recreation sites; no. of visitors	No. of visitors year ⁻¹

aims to promote improved community forest management to increase carbon, biodiversity, and social wellbeing. Similarly, Forest Policy 2015 (amendment) and Guidelines for Community Forestry Development both encourage the valuation of ES and adopt PES mechanisms to promote sustainable management of forest ecosystems. Formulation of a draft policy on PES in 2016 envisages long-term vision to sustain ES across scales, especially at local community (Chaudhary and McGregor 2018). Similarly, the Forestry Sector Strategy (2016) promotes PES to enable community groups to benefit from their investments in sustainable management and use of ES, such as biodiversity conservation and carbon sequestration. The Forest Act (2019) also provides legal basis for PES to support forest ES, whilst the National Climate Change Policy (2019) encourages natural resources management groups to integrate climate resilience in ES promotion through PES. ES have also been accommodated in Nepal Biodiversity Strategy and Action Plan (NBSAP) (2014–2020)—a principal instrument for ecosystem management and biodiversity conservation in Nepal. The Government of Nepal explicitly mentions PES in its Forest Investment Program and encourages to develop and promote appropriate institutional arrangements for Forest ES certification and PES.

Clearly, all forest and related policies have supported the promotion and sustainable use of ES from community forestry and other systems of resources management. ES specific

arrangements are yet to be formalized in regulatory provisions, planning processes, training curricula, and institutional practices of government agencies. An analysis of the forest policy discourse and the government decisions made in the last 10 years (since 2009) clearly shows an exclusive focus on timber, a few non-timber forest products (NTFPs), or mining (Table 19.2), and recently additional ES. Almost all major policy decisions are solely focused on conservation and management of the forest biomass and there is little reference of the diverse components of forest ecosystems (Bastola et al. 2020). Still, policy decisions tend to emphasize protection of trees, over ground vegetation, and other biomass (Shrestha et al. 2010). Policy concerns are clearly on trees, conventional forest products, or sustainability in a narrow sense.

Despite some research on ES and their recognition in forest management, the forest sustainability agenda continues to remain narrowly conceived as related to maintaining the forest stock, crown cover, biomass, or invoke conservation of biodiversity as a global good in a wide sense (Lamsal et al. 2018; Luintel et al. 2018). The narrow conceptualization and sole focus on tangible forest products has also been reflected in the government's institutional framework in forest sector. The forest sector is included in the jurisdiction of the two departments: Department of Forest and Soil Conservation (DoFSC) and Department of National Park and Wildlife Conservation. However, when we see forest from wider ES view, we see several

Table 19.2 Major policy decisions on community forestry management in recent years in Nepal

Dates	Key decisions that have direct implications to community forestry
December 2009	Declaration of three new protected areas through the meeting of the Council of Ministers held at Everest base camp
July 2010	Implemented President Chure Conservation Programme that restricted annual tree harvesting
July 2010	Forest Act (1993) amendment proposal
July 2010	Ban on tree felling in two consecutive years: 2010 (to curb illegal logging) and 2011 (International Year of the Forests).
June 2011	New pricing system for timber
July 2011	Declaration of half a dozen of protected forests
2014	Scientific management of forests guidelines

other agencies involved in various ES. There are over half a dozen of ministries and departments to manage the ecosystem in any watershed/landscape; for example, several federal ministries handling agriculture, forest and environment, water resources, and land reform. Added to this list are newly created provincial ministries and their directorates covering these sectors. These ministries and departments have their own narrowly conceived mandates and authorities, conventionally framed around resource sectors rather than ecosystems and services. Both training and working institutions are highly compartmentalized and departmentalized that often undermine the holistic notion of nature and ecosystems, that underpins sustainable ES promotion.

There is a lack of coherent and comprehensive ES-focused policy and guidelines that can guide CF practices to augment ES (Acharya et al. 2020b). The current policy guidance at best is related to 'economic valuation', without offering any further guidance in designing and implementing ES initiatives at community scales. In this early stage of ES policy development, Nepal's CF is seeing a range of local level ES management practices across the country. An assessment of such emerging initiatives can offer deeper insights into the functioning of ES management and how policy can enable and reinforce them (Bastola et al. 2020). This forms the rationale of this paper.

Amidst such localizing trend of ES concept in Nepal, at least four questions have become crucial. First, to what extent the CFUGs are internalizing the idea of ES and then expanding the practices of forest management to include wide range of ES? Second, what challenges the CFUGs are facing as they try to respond to new opportunities for the development of new ES or for more active and market-oriented management of existing / traditional ES? Third, what opportunities exist for catalyzing the shift towards CF systems and practices that put ES at the centre of forest management? Finally, what policy directions need to be in place to achieve ES-optimized

CF in Nepal? This chapter attempts to generate some answers to these questions, and hence offer some strategic insights into the sustainable and equitable promotion of ES in Nepal's context.

19.3 Data Sources and Methods

This paper is based on 14 cases of CFUGs selected purposively from across the country, considering the diversity of ES management practices, diversity in ecological regions, and potential of CF in addressing poverty. Cases from the Mountains, Hills, and Terai and from both outside and inside the protected areas were represented (see Fig. 19.1). An overview of case studies is presented in Table 19.3. The information was collected during 2014–2015 using content analysis of CFUGs forest management operational plans, interview with officials of the concerned CFUGs, review of previous studies and secondary information available from the Department of Forests and Soil Conservation (then Department of Forests). To complement the case studies, we also reviewed the recent literature on CF and ES focusing on Nepal.

19.4 Findings

19.4.1 Community-Level Ecosystem Services Management Practices

Our analysis of the 14 cases reveals that CFUGs have initiated several activities to manage new types of ES, leading a wide range of benefits to community members. Ecosystem services provided by community forests in the studied cases are summarized in Table 19.4. We categorize these services into two groups: traditional forest products and services with an age-old practice of management and use for subsistence purposes; and newly added ES for market-oriented management.

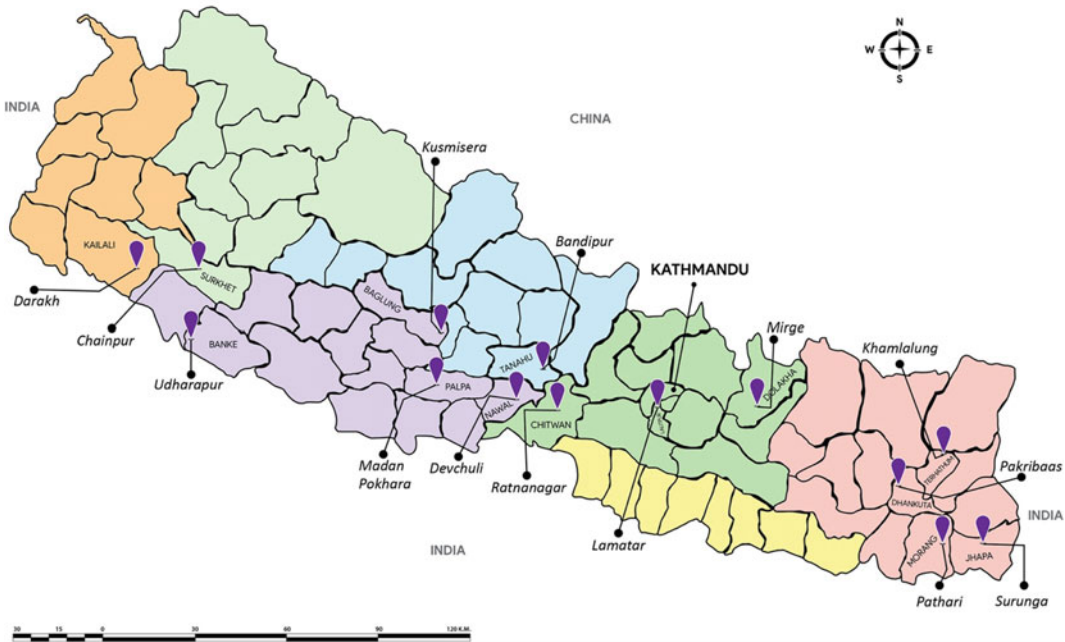


Fig. 19.1 Locations of case studies selected from across Nepal

19.4.1.1 Traditional Forest Products and Services

Grass, fodder, leaf litter, and fuelwood are the widely available and frequently used forest products in all the case studies. These products form essential components of Nepal's predominant agrarian economy where livestock, agriculture, and forest management are intricately linked. Small farmers and peasants with small piece of land practice subsistence farming and rely heavily on forests for grass and fodder to feed their livestock. They collect leaf litter to use in their farm and fuelwood as the main source of energy for cooking and heating (Maren et al. 2013). Both rich and poor and all caste/ethnic groups of the local CFUGs, primarily the women, collect these products, though their availability varies with the ecological zones and forest types.

The CFUGs adopt modest management interventions in conserving and harvesting these products. The most common intervention is banning or limiting grazing. This is accompanied by limiting the volume of collection and seasonal restriction, which applies particularly to

fuelwood and leaf litter. Timber is an important product available in all 14 cases, with varied quality across the ecological zones. Whilst in the hills, it is softwood of diverse variety, in the Terai, it is usually the strong hardwood of Sal (*Shorea robusta*) or Sissoo (*Dalbergia sisoo*), both being the choice for construction and furniture. The CFUGs carry out thinning, pruning, singling, weeding, leaf litter collection, and fire line construction as management tools for promoting timber.

The timber is either used internally by the CFUGs and/or sold in the market. Currently, timber is the largest source of income for all groups. The recent economic survey showed that the community forests produce 10.2 million cubic feet of timber, generating Nepalese Rupees (NRs) 279.9 million in revenue (MoF 2020). Likewise, NTFPs take a significant share of household income in Nepal (Shrestha et al. 2020). CFUGs manage a variety of NTFPs including medicinal herbs, essential oil, and grass, amongst others, in promotion of small-scale enterprises in Nepal (Kunwar et al. 2013). Diverse types of herbs, medicinal plants, wild

Table 19.3 Overview of selected case studies, locations, and ecosystem characteristics in Nepal

Name of CFUG	Location (local government, district)	No of households	Main caste and ethnic groups	CF area (ha)	Ecosystem characteristics	Year CFUG established (AD)
Kankali	Chainpur, Birendranagar, Surkhet	1905	Brahmin/Chhetri	760.73	Tropical sal forest, stream, ponds	1996
Baghmara	Ratnanagar, Chitwan	780	B/C, Tharu	215	Dense forest, grasslands, wetlands	1995
Sundari	Devchuli, Nawalparasi East	1553	B/C, Dalits	384.75	Tropical sal forest, stream, NTFPs	1996
Adheri Khola	Madan Pokhara, Palpa	184	B/C, Dalits	18.20	Forest, grass, NTFP	1996
Chautari	Pathari, Morang	580	B/C Dalits	128.75	Tropical sal forest, stream, NTFPs	2000
Jamunbari	Shurunga, Jhapa	563	Rai, B/C	401.75	Forest, wetlands	1995
Jautar	Pakribaas, Dhankuta	66	B/C,	28.95	Forest, grass, NTFPs	1993
Baisakheshowari	Mirge, Dolakha	155	Tamang, Sherpa	103.85	NTFPs, grass, fuelwood	1997
Ahhaldada	Bandipur, Tanahu	193	B/C, Janajati, Dalit	154.64	Mixed hill forest, fodder,	1993
Pallopakho	Kusmisera, Baglung	94	B/C, Dalit	10.75	Mixed hill forest, fodder,	1995
Goldanda	Lamatar, Lalitpur	104	Tamang, Dalit	119	Mixed hill forest, fodder, NTFP, scenic beauty	1996
Gijara	Udharapur, Banke	270	Tharu	119.94	NTFP, scenic beauty	1995
Kattike	Khamlalong, Terhathum	31	B/C	40.80	Mixed hill forest, bamboo, NTFPs, fodder	1995
Tenguwa	Darakh, Kailali	78	B/C, Tharu	41.75	Tropical forest, wetlands,	2003
Bhedichowk	Mai Pokhari, Ilam	157	B/C, Rai, Limbu, Sunuwar, Sherpa, Gurung, Tamang and Magar	200	Cloud forest (east-Himalayan oak-laurel forest)	2001

food, fibres, and other NTFPs are available in the forests. The availability and diversity of these products however varies depending on altitude, climatic zone, and topography. Many groups are

managing bamboo and broom grass, nurseries, plantation, protection, sustainable harvesting, and small-scale enterprises. Several herbs form the essential elements of local health care system,

Table 19.4 An overview of ecosystem services development activities by CFUGs in the studied cases in Nepal

Name of CFUG	Key ecosystem services development activities
Kankali	Forest management (cleaning, singling, thinning, pruning, fire line construction, tree plantation, bamboo and broom grass plantation in erosion prone area), irrigation channel and tube-well construction, allocating forest area for grass, bamboo, and broom grass farming as well as stream for fishery, tourism interventions (swimming pool, minizoo, picnic spot, safari)
Baghmara	Forest and grassland management (weeding, cleaning, controlled fire, grassland improvement and extension), nursery establishment and plantation, fireline improvement, waterholes construction, tourism interventions (elephant riding, jingle safari, picnic spot, bird watching, view tower, boating), fishery
Sundari	Forest management and protection (cleaning, singling, thinning, pruning, fire line construction, removal of dead, dying, diseased, and deformed trees), allocating forest area to group of households for grass and Asparagus farming, leaf plate production, and <i>Triphala</i> (a traditional medicine prepared from the fruits of three wild plants) production enterprises
Adheri Khola	Forest management (cleaning, singling, thinning, pruning, bamboo and rattan plantation), grass production plot management
Chautari	Forest management (cleaning, singling, thinning, pruning, bamboo and rattan plantation), construction of irrigation channel, allocation of forest area for grass production
Jamunbari	Habitat management in 6 blocks (cleaning, singling, thinning, pruning, plantation, spurs construction), wetland management, tourism interventions
Jautar	Forest management (cleaning, singling, thinning, pruning, plantation)
Baisakheshowari	Forest management (cleaning, singling, thinning, pruning), water management (renovation of irrigation channel), Argeli (<i>Edgeworthia</i> spp) plantation in CF by poor households
Ahhaldada	Forest management (cleaning, singling, thinning, pruning)
Pallopakho	Water resource protection, irrigation channel and public ponds construction
Goldanda	Forest management (cleaning, singling, thinning, pruning, plantation), lapsi (<i>Choerospondias axillaris</i>) collection and processing enterprise
Gijara	Forest management (cleaning, singling, thinning, pruning), allocated 2 ha of forest land for group of 15 households for asparagus (<i>Asparagus</i> sp) farming, tourism interventions (picnic spot, community park)
Kattike	Forest management (cleaning, singling, thinning, pruning, plantation, fire line construction), allocated 7.5 ha of forest land for group of 13 households for Lokta (<i>Daphne</i> species) and Argeli (<i>Edgeworthia</i> spp) farming, tourism interventions, handmade paper production enterprise, tourism interventions (picnic spot, community pond)
Tenguwa	Forest management (cleaning, singling, thinning, pruning), tourism interventions (picnic spots, parking facility, entrance fee), fish farming
Bhedichowk	Forest management (cleaning, singling, thinning, pruning, plantation, nursery development, ecotourism (picnic spots, hiking), religious tourism, Homestay

and, in some cases, the groups have started to manage, harvest, and sell these products commercially in the market.

Wetlands of diverse types including streams, lakes, swampy lands, small ponds, and water springs are important forms of ES available in the studied cases. These water bodies are managed for different purposes—fishery, irrigation,

drinking and swimming pool, and spirituality. For example, the Kankali CFUG in Chitwan has constructed a fishpond and has leased out it to the identified poor group of Musahar for fishery. These are indigenous fishing community, who are increasingly experiencing threats to their livelihoods due to decreasing availability and access to nearby rivers. They have also

constructed a swimming pool for visitors which secure a regular income for them. Swampy lands provide several unique types of aquatic plants, wild vegetables, fishes, and other edible items usually collected by the indigenous people in the area.

19.4.1.2 Newly Added Ecosystem Services in Community Level Forest Management

The 14 cases also show a good presence of new sets of ES being developed and managed by CFUGs in Nepal (see Table 19.5). These include water, ecotourism including through wildlife, education, and NTFPs and enterprises. Ecotourism is primarily about attracting visitors. Baghmara case in Chitwan, for instance, is an iconic case in Nepal, which has been portrayed as a model benefitting through ecotourism. Since the early 1990s, Baghmara CF began to manage wildlife habitat by improving grassland, controlling fire, constructing water holes, establishing wildlife rescue centre and wildlife observatory tower. The forest provides habitat to a wide range of wildlife including rhinos, tigers, and deer that attract a huge number of tourists annually. It earned almost nine million rupees (USD120,000) in 2011.

In almost every case, we observed initiatives in generating income and employment for the poor through tourism and other forest-based enterprises. The Baghmara CFUG (Case 1) is the best-case scenario highlighted in a plethora of studies. Increasingly there are more cases that demonstrate employment opportunities through tourism (Cases 1, 2, and 6). Community-based tourism is different from ordinary one since major part of benefit from it is retained in the community. The poor people are employed as guide, elephant *Mahutes* (one who controls and takes care of the elephants), tourism operation, and development of related infrastructure. Women-led homestay (Case 15) has been able to generate income for the local people and build capacities of the poor and women (ICIMOD 2020).

To a lesser extent, nearby CF has also begun to manage wildlife and has attracted visitors. There is a huge potential of expanding this enterprise to many of the CFs along the protected areas' buffer zones especially in the Terai. With increased ecotourism in CF and its nearby areas, homestays by the local communities have been innovative in generating revenues and experiencing local culture and lifestyle. This has been an incentive for the communities to protect their forests, and hence improve their wellbeing (ICIMOD 2020).

Maximizing collective income and investing in pro-poor activities has been the most adopted strategy by the CFUGs in addressing poverty. They have been earning from sale of forest products, depositing the funds in their bank accounts, developing their own annual plans, and investing the funds in various pro-poor activities, including funding pro-poor enterprises, providing educational support to children from poor families, and providing emergency and accidental support during natural disasters amongst others. For instance, at least 35% of the total income from CF is allocated to the poverty reduction-based programs in Bhedi Chowk CF (Chaudhary et al. 2017). Community infrastructure is another important area where such revenue is being invested. These include construction of local roads, trails, drinking water supply outlets, school buildings, and community halls and health posts. Forest-based revenue has funded these services in areas where the CFUGs have generated good earning.

Creation of jobs within forest-based enterprise is more common in local forest management. Jobs are created in regular forest management, thinning, pruning, fire line construction, timber harvesting and processing, and transportation to depot. This is equally common in other enterprises: traditional medicine making (Triphala, prepared from mixing three wild fruits) (Case 3), leaf plate making (Cases 3 and 6), broom grass cultivation (Cases 4 and 6), and planting medicinal plants (10 cases). Employing poor people in such CFUGs managed collective enterprise is largely an accepted norm. These are also encouraged by the policy (e.g., CF

Table 19.5 Emerging management practices of ecosystem services development by the CFUGs in the studied cases in Nepal

Ecosystem component	No. of cases	Management interventions	Key evidence
Timber	All	Block-based silviculture management; nursery and plantation; fire line improvement; cleaning, thinning, pruning, singling; harvesting of dead, decayed, and drying tree	– Cash earning: (Kankali: Nepalese Rupees (NRs) 5 million; Sundari NRs. 6 million); – Better-off people have used best timber/furniture in their houses; Timber for community buildings—school, Village Development Committee offices, etc.
Fuelwood/fodder	All	Bamboo and broom grass plantation; allocation of land area for grass farming; grassland management (e.g., weeding, cleaning, and controlled fire); fire line construction	Fuelwood collection for cooking and heating, livestock feeding, construction materials, household uses, and cash earning; Pro-poor enterprise development (e.g., making leaf plates from <i>Shorea robusta</i>)
Herbs/medicine	10	Plantation of seedlings of medicinal plants like Asparagus and bamboo	Household use of herbal medicines, cash earning through sale
Water bodies	6	Management of forest area for enhancing water bodies; construction of irrigation channel and tube wells; construction of water holes	Increased supply of water for irrigation and drinking; improved drinking water spots for wild animals
Wildlife	3	Habitat management; construction of water holes; wildlife risk centres; and wildlife observation centres	Revenue generation through tourism (Baghmara NRs 8.78 million; Kankali NRs 1 million), employment to locals
Fishery	3	No such intervention accounted	Livelihood source for some communities like Musahars (totally dependent on fishing for subsistence); source of income for the user groups; source of food
Soil conservation	10	Bamboo and grass plantation on erosion prone areas; spur of about 11,600 cubic meters constructed; ban on harvesting in erosion-prone areas	Reduced erosion
Religious, scenic places	3	No such management intervention recorded	Source of income for the group (visitor fees); employment generation

Guideline 2014, Forest Policy 2019) and are generally supported by the government, the Federation of Community Forest User Group Nepal (FECOFUN), and development agencies.

CFUGs have been active in promoting niche products for supporting livelihoods of the poor and marginalized groups. For instance, local people are supported by CF to initiate/implement

tea farming (Case 15). Similarly, milk is another product of the area and local people are supported for livestock farming and marketing of dairy products. Dairy and milk collection centre and cheese factory have been established in the village for collection and transportation of milk and cheese to city centres and the Kathmandu valley (GoN 2012).

19.4.2 Collective Action and Equitable Access

Analysis of the cases shows that the CFUGs have developed diverse ways to link ecosystem management with poverty reduction outcomes. There are surprisingly interesting innovations in translating the natural capital into physical, financial, and other forms of capital assets, which can be grouped into the following six patterns (Table 19.6).

Collective action in common pool resources alone cannot explicitly support the poor. In many cases the benefit sharing was based on equality—that all the CFUG members invested in forest management equally and received equal benefits from it. However, this practice does not consider the historical differential interactions with nature, differential dependency on the forests, and unequal capacity to realize the benefit from forestry. With this realization, many CFUGs have introduced land allocation to identified poor members of the group (Cases 2, 4, 7, and 15). They have allocated small patches of forestlands to identified poor members and supported them for productive land use within the CFUG regulatory framework. The poor members have cultivated bamboo, broom grass, fodder trees, or even high value cash crops such as cardamom. Similarly, in two cases (1 and 2), the fishponds are given to traditional fishermen who enjoy the benefit from fishery. The government has also experimented this idea through leasehold forestry in which small patches of forest are leased to identified poor (usually 7–11) for a period of 40 years. The group can then grow fodder trees, broom grass, and bamboo or other plants, and benefit from that. (FAO/IFAD 2015).

Whilst the membership to any CFUG is based on residency and all residents are legitimate candidate to it, there are problems in practice. In fact, one of the criticisms of CF is that it has not been adequately inclusive as many households, especially the poor and marginalized sections of the group have been excluded from membership mainly due to high cost. However, due largely to the networking effect through FECOFUN and support from development agencies, many

groups have begun to provide membership to poor free of cost (for example, Cases 1, 2, 3, 5, 6, 8). This has ensured their access to critical forest products to support farming, energy, construction materials, and medicine.

CFUGs in Nepal have an established norm of conducting a well-being ranking through which poor households are identified. The well-being ranking is then linked with CF benefit distribution schemes. One of the important aspects that many CFUGs have now introduced is the differential pricing of timber and other forest products benefitting the poor through which they pay less for the same quality of timber than the standard price set by the group. For example, in Sundari CFUG, the poor get *Shorea robusta* timber @ NRs 225¹/cft whilst the better off members pay NRs. 325/cft. Several groups have set such differential pricing for forest products (Cases 2, 3, and 5). Though initially there was some resistance from within the group to introduce the differential pricing rule, the international and national discourses of equity forced policy documents and CF actors to respect and support equitable arrangements. As a result, such rule was introduced in the CFUG governance system.

Analysis of the cases shows that most of the groups generally created rules that ease access to many basic forest resources—grass, fodder, leaf litter, wild fruits, vegetables, and herbs. Fuelwood collection is generally allowed throughout the year though some restrictions are in place where its availability is scarce. Timber is highly restricted and wildlife hunting is prohibited by the law. As most of the poor rely on the marginal components of forest ecosystem, the current CFUG rules and decisions favour poor people's access to these components. Easy access to these basic forest resources can partly be attributed to locally informed decision by the CFUGs. This would not be possible for government managed forests as collection of any of these items is illegal. The poor and socially marginalized groups have also been allowed to collect wild edibles from community forests for household consumption (Case 15).

¹ USD 1=118 NPR on August 8, 2021.

Table 19.6 Emerging practices in linking ecosystem services to poverty reduction through community forestry in studied cases in Nepal

Ways of linking ES to poverty	Number of cases	Evidence of emerging practices
Generating CFUG revenue and funding to pro-poor activities	All	• Interest free/low interest loan to poor households (1–10 cases) • Scholarship/school support to kids of the poor households (1–10 cases) • Construction of houses to the poor (3,8) • Employing poor in timber/NTFPs enterprises (1,6,8) • Supporting the poor on health service (3,6) • Purchasing enterprise share for the poor households (8) • Low interest rate for business
Land/resource allocation to poor		• Part of the CF land allocated to the identified poor households (3, 6, 8, 15) • Allocation of fishpond to indigenous fishermen (1,2)
Income and job creation through tourism		• Income from picnic spots/swimming pools, zoo (1,2,6,8,14) • Income from visitors (1, 2, 6) • Income from wildlife observation e.g., from view tower, elephant riding, jungle safari (1, 2, 6) • Homestay
Income and job creation through forest-based enterprise	All	• Timber extraction (all) • NTFPs collection/processing/sale (1, 3, 6, 8, 11, 13) • Trifala production /sale (3) • Leaf plate production (3) • Fishery (1) • Rubber collection/processing (6) • Shareholding in forest-based enterprises (2 cases) • Lapsi (<i>C axillaris</i>) collection/processing (all except 2) • Handmade paper (8) • Broom grass (2,6)
Increase access to resources of the poor by providing membership in free of cost	6	• Free/reduced membership fee for poor HHs (1, 2, 3, 5, 6, 8) • Relief to wildlife victims (2) • Distribution of forest products free of cost to disaster victims (4, 8)
Differential pricing system of forest products favouring the poor	9	• Indigenous communities have fishing rights (2) • Reduced price of forest products for the poor (2, 3, 5, 6, 11, 14) • Support to disabled members (1 case) • Free timber/other forest products for certain number of poor households each year (4, 5, 6)
Creating rules for easing access to basic forest products—grass, fodder, fuelwood	All	• Free of cost collection of grass/fodder/leaf litter/dried branches throughout the year (all) • NTFPs collection permitted (1, 7, 9, 11, 12, 13) • Wild edibles for household consumption
Conserve ES that maintains and enhances productivity of land	6	• Management of stream for fishery (2) • Bamboo/broom grass plantation (2) • NTFPs research plots (3, 8, 13) • Nursery establishment and plantation of timber/non-timber forest species (1, 3, 4, 6, 7, 12) • Construction of spurs (2, 5, 6)

The CF Directive (2008 and 2014) pays specific attention to the poor and marginalized groups. Amendments were made to require at least 50% women representation and proportionate representation from the poor and other groups in CFUG's executive committee. Either the chairperson or the secretary of the committee must be a woman. This is reflected in Case 15 where there were at least 50% representations from women, poor, and other marginalized groups in different capacity building trainings. Such trainings and exposures have capacitated the poor to put their voice in meetings and decision-making system (Chaudhary et al. 2017).

The CFUGs are allowed to take forest management decisions on their own; they can set their priorities on forest management, identify the potential opportunity, and respond to both internal needs and external demands (Ojha and Hall 2021). Accordingly, they develop their long term and annual plans and identify key strategies to achieve those plans. These diverse innovations in CF in many CFUGs studied can largely be attributed to the decentralized governance system and the transfer of tenure rights to local autonomous institutions. The emerging market for diverse forest products and ES has also induced many of such innovations. For example, the tourism market in Chitwan has induced tourism-oriented management in Baghmara and Kankali CFs. Similarly, the emerging market of herbal medicine has induced Sundari and few other CFs in investing on NTFP enterprise. Part of the innovations can be attributed to the charismatic leadership, particularly their ability to learn and adopt from their involvement in wider networking. Apart from planned exposure visits and educational tours, the networking has increased leaders' exposure to diverse local initiatives and increased their enthusiasm and confidence (see Banjade 2013 for details of forestry innovations in CF).

19.5 Discussion: Prospects, Challenges, and Policy Implications

The CF case studies complemented by the literature review presented above show the emergence of several initiatives linking ES with poverty reduction and livelihoods improvements. These initiatives involve a range of non-traditional ES and are shaped primarily by emerging markets, regulatory constraints and opportunities, and the leadership and the capability of local institutions. On regulatory front, tenure security, autonomy in management decisions, and access to full benefits appear to play an important role in CFUGs taking ES related initiatives. The support from various external agencies especially during initial phase appears to help a significantly in establishing an enterprising culture amongst the members of the groups, ultimately triggering ES related initiatives.

The incorporation of ES in CF has the potential to bring diverse opportunities for poverty reductions and livelihoods improvements in Nepal. Embracing ES concept in CF management has triggered realization and better understanding of the importance of intangible benefits like carbon, water regulation, air purification, greenery and others, which are not mentioned in traditional CF management plans. Both tangible and intangible benefits associated with CF are, not always, subjected to valuation and acknowledged through payment system. Adopting ES concept in CF management may help better govern ecosystems and promote development, mainly through putting economic values on ES and then informing potential PES mechanisms. The intangible benefits like water regulation and purification are now gradually integrated in policies and regulations around CF, but effective translation in practice is still a long way to go.

With an increasing trend of valuation of ES including carbon, REDD+, and PES have emerged as an opportunity for sustainable development (Bhatta et al. 2014). With strategic planning, and effective implementation, PES shows opportunity for high financial flows in CF system through marketization of non-traditional services like water preservation, purification, and carbon. The increased finance mobilization which may result through integration of PES mechanisms has the potential to reduce dependencies on international funding for the management of ecosystems. Such financial autonomy at the national level would create an enabling condition to prioritize local and national issues, without having to be driven by donor's strategies and conditions.

Promoting ecosystem services in CF also holds high promise for resilience building against climate change. As approximately 45% of the land of the country is under CF system, there is a tremendous opportunity for CF to contribute to resilience of social and ecological systems, not only through subsistence level management of ES but also through market-based economic incentives to boost practices of sustainable resources management. These prospects are not going to be realized easily, however. The chances of emerging ES development initiatives being upscaled depend on several contextual factors including the following:

- The degree to which diverse policy areas and regulations mainstream and support ES centric CF development.
- The degree to which the forest administration of Nepal, which is historically developed to monitor and administer timber-oriented forestry practices, changes to embrace diverse ES as integral part of forest management.
- Ability of the community groups and their networks to voice their concerns around restrictive regulatory provisions.
- The ways in which ES agenda is contextualized in the policy and practice of CF in Nepal.

Besides, any positive effects of ES development will not automatically be equitable, nor will

it be ecologically sustainable. Social equity effects will be determined through the processes of decision-making by the CFUGs, as well as the policy and regulatory systems within which they operate. Some of the case study CFUGs have adopted pro-poor strategies of ES development, targeting sub-groups or individuals. But some ES will require actions by the whole groups and support of external stakeholders, which means equity effects need to be managed more strategically, beyond just allocating an opportunity to a targeted sub-group of disadvantaged groups.

The role of the government Department of Forest as well as its provincial counterparts is found to be crucial. Despite some inspiring innovations at the grassroots in developing ES, the national forestry regime appears to be lagging in facilitating and supporting such innovations. Almost all forest policies, regulatory instruments, and forestry institutions are not ES friendly in concrete sense; for example, they tend to limit forestlands to forest or trees and do not adequately embrace the evolving notion of ES. The policies and institutions have promoted trees, vegetation, or above ground biomass as their key domain. It appears that local communities have embraced more deeply and more widely than the policy makers.

The sluggish policy response to ES could be due to the old schooling of experts, who prioritize sectoral resources and a narrow range of conventional ES products over ecological functions and complexity of ecosystems. For example, the techno-bureaucratic set up of the Department of Forest has failed to embrace the community led innovations in the forestry sector (Giri and Ojha 2011), despite the fact that some individual foresters were at the forefront of initiating community forestry (Ojha and Hall 2021). The centralized and bureaucratic mindset has framed forest management on 'forest' as timber and other tangible products (Ojha 2006) ignoring the systemic reality of forest as an ecosystem. As a result of these underlying institutional factors, what there is a lack of supportive policy regime in the forestry sector to the adoption of ES innovations in CF. As result of such policy environment, there is a decreasing trend of

interest in CF at local scale (Bhandari 2013; KC et al. 2021), a trend that can reverse local enthusiasm around ES development.

We have identified some positive changes in wider policy environment, with potential encouragement to ES development. However, such changes have been confined to the level of text and have hardly been translated into practice. For example, despite recent forest policy changes to facilitate market-oriented management of ES in forest ecosystem, these are still not adequately reflected in regulatory texts, administrative procedures, and institutional practices (Acharya et al. 2020b). There is also a lack of consensus amongst prominent ES stakeholders on the degree and scope of support that should be provided by the policy to upscale ES management practices in the forest sector (Acharya et al. 2019a, b).

Another key challenge associated with marketing of ES is the likely commodification of ecosystems and its services, which may lead to over-extraction of valued services like water, carbon, or wild animals, and to downplaying services which may be economically less valuable but are socio-ecologically critical. On the societal front too, local political dynamics always tend to drive the marginalization of the poor and disadvantaged social groups, who are already suffering from pre-existing inequities and injustice. If new ES initiatives are not planned and implemented through effective deliberations and participation of all interested or affected, conflicts may escalate, or elite capture in resources may be reinforced, leading to more inequitable outcomes than the pre-ES stage. Preoccupation with economic valuation thinking may overshadow aspirations for livelihoods, wellbeing, and justice which have remained key normative foundations of community forestry development in Nepal.

Within the community, how far local livelihoods interests remain as an incentive to sustainable and active forest ecosystem management is a key to local level initiative. With out-migration for work becoming the key livelihoods strategies in many rural areas of Nepal and with limited economic incentives received by youths from CF, community dependency on forest is

declining in the recent years, thus leading to reduced sense of ownership and overall collective action around forest management. This is an important aspect to be reconsidered in the community forest management system now and adopting ES in CF system may help re-align forest management with changing rural livelihoods strategies (Lamsal et al. 2018; KC et al. 2021). Considering this, a national legal framework that provides detailed guidelines, methods, and strategies for the implementation of ES could reinvigorate community forestry and incentivize stakeholders and right holders to maximize the socio-ecological benefits for poverty reduction, livelihoods, and overall human wellbeing. Enhanced emphasis on ES at CF policy and practice has the potential to contribute climate resilience and various Sustainable Development Goals (SDGs), including Goals 1 (no poverty), 2 (zero hunger), 13 (climate action), and 15 (life on land).

19.6 Conclusions

This paper has assessed the emerging practices of ES integration in Nepal's CF and has explored ways to improve ES-based CF management, based on the analysis of challenges and opportunities identified at the local community as well as policy levels. The ES agenda has landed in Nepal at a time when CF has come a long way since its inception in the early 80s, and when increased community expectations of incomes or livelihoods benefits from it.

Our empirical analysis shows that most of the 14 case studies have clearly sought to promote and develop new ES beyond the traditional products like timber and fuelwood, depending on ecological and economic contexts. In the changing economic and environmental policy contexts, a range of ES originating from CF have increased in values beyond local subsistence use of forest products. This emerging shift to ES approach marks a shift away from the narrowly focused, subsistence-oriented management of forests to more holistic management of forest ES. This has led to increased economic opportunities

around marketing of wider range of ES for the benefit of local communities. This ES shift in forest management has been catalyzed by a wide range of factors including the transfer of tenure rights and autonomous institutional spaces for collective action as guaranteed by the prevailing forest law.

We conclude that increasing market value of ES has the potential to contribute further to poverty reduction if communities are granted secure tenure rights over forests and if there is an enabling environment for networking, innovation, and learning amongst community groups. Although policy and regulatory space remains limited for ES development and promotion, local communities have identified, conserved, and managed diverse ES and derived multiple benefits, considering the changing economic contexts which have opened or expanded markets. We have also discussed how ecosystem specific management interventions have been proved appropriate in sustaining nature, deriving multiple ecosystem benefits, realizing poverty reduction, and improving livelihoods and human wellbeing. The evidence presented here also demonstrates that national forest policy, regulations, and institutions are yet to fully recognize such local level changes, much less create more enabling environment that help flourish such innovations across the CFs in Nepal. We have also identified some gaps between community innovations in valuing the integrity of ecological functions and managing complex ecosystems to ensure sustainability and human wellbeing in its environmental, social, and economic terms.

The findings further suggest that policy actors, forest administrators, and forestry professionals must revisit their conservative stance about the potential of community management and marketing of ES and recognize and encourage the holistic management of forest ecosystem for maintenance of ecological integrity, poverty reduction, and livelihoods improvements. Besides, institutions that were developed during the 80s and early 90s must be transformed to embrace the evolving notion of ES in the changing socio-economic contexts. To embrace

these broader notions of forests, Nepal's forestry institutions must embrace long-term goal of the nation, 'Prosperous Nepal, Happy Nepali', through sustainable ES development in forest ecosystems. Integrating ES into forest policy systems can contribute to climate and various SDGs, including Goals 1 (no poverty), 2 (zero hunger), 13 (climate action), and 15 (life on land).

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An Assessment of Selective Logging Policies and Practices in Nepal

20

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Abstract

The efficient use of forest goods and services is crucial for sustainable forest management (SFM). The selective logging (SL) is one of the dominant forest harvesting practices and contributes nearly 15% of global timber need. However, there are contrasting views and opinions about its environmental and economic impacts. This chapter assesses the policies and practices of SL in Nepal and evaluates its impact on timber production and carbon emissions along the production value chains. The thorough review and analysis of forest policies and practices was performed with special

emphasis on selective logging whereas the environmental, economic, and livelihood impact of SL were analyzed from the primary data collected from the case study site, the Nawalparasi District of Nepal. The results of the study indicate that the policies and practices of SL are basically guided by technical and legal aspects of forest conservation in Nepal and are predominantly limited to subsistence livelihood. Frequent and inconsistent changes to policy, lengthy administrative procedures, and heavy engagement of state forest agencies in forest product harvesting and sales are contributing to sub-optimal production and hindering sustainable forest-based livelihood. However, the higher rate of recovery from harvested trees and minimal carbon emissions in logging processes as commonly found in Nepal may offer lessons even to the highly mechanized and countries of Asia and the Pacific for REDD+ initiatives.

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Keywords

Forest · Nepal · REDD+ · Selective logging · Timber

20.1 Introduction

Principles of sustainable forest management (SFM) emphasize the optimum forest production and sustainable use of forest resources. The wise

and balanced use of multiple forest resources plays a significant role in sustaining the supply of forest-based goods and services (Wijewardana 2007; Milledge 2015) including wood production, carbon sequestration, and biodiversity conservation. However, there are numerous challenges in operationalizing SFM principles, mostly due to the conflicting needs from forest and trade-offs of the society and the environment (Boman and Mattsson 2006; Triviño et al. 2017). To address the challenges in optimum utilization of forest goods and services, scholars often suggest that the adoption of multi-functional perspectives in SFM could meet needs of forest users without forest degradation (Sarre and Sabogal 2013; Schmithüsen 2013). Since one of the key goals of SFM is to promote the long-term productivity of forests without forest degradation (Sands 2013), finding a practice that promotes efficient harvesting of forest goods and services is of utmost concern (International Tropical Timber Organization 2016). Among all forest harvesting practices, selective logging is one of the dominant forest harvesting practices contributing nearly 15% of global timber needs.

A critical assumption in the promotion of selective logging is that by selectively removing only those trees with commercial value, revenue is maximized, while a greater level of other ecosystem services is achieved than would be the case with, for the most extreme example, clear felling (Putz et al. 2008; Sasaki et al. 2016). However, there are increasing concerns that selective logging practices are contributing to forest degradation (Shearman et al. 2012; Pearson et al. 2017). Moreover, natural forests are not being sustainably managed mainly because of ineffective selective logging practices (Ximenes et al. 2008; Zimmerman and Kormos 2012; Putz and Romero 2015), which in turn undermine productivity, profitability and sustainability of the forestry system. Selective logging practices may also affect the carbon sequestration potential of forests as well as harvested wood products (HWP). Since each part of the tree, including dead biomass, stores carbon, it is essential to explore the optimum harvesting age, techniques and use of forest products to make the forest a

better sink of carbon (Maraseni 2007). Poorly managed selective logging can exceed the emissions generated through deforestation (Pearson et al. 2014) and therefore it would be useful to better assess such practices.

Effective management of selective logging practices could address a number of challenges associated with the increasing demand for wood products (d'Annunzio et al. 2015), increasing carbon emissions from forest degradation (Pearson et al. 2014; Köhl et al. 2015), decreasing terrestrial biodiversity (Leadley et al. 2014) and addressing many UN Sustainable Development Goals such as clean water and sanitation (#6), affordable and clean energy (#7), climate action (#13), and life on land (#15). This also increases the availability of non-timber forests products in the forests and thereby improves the livelihood opportunities and food security for forest dependednt communities (Maraseni et al. 2006). Scholars have highlighted an urgent need to assess effectiveness of selective logging practices (Keith et al. 2015) which can visualize both positive and nagative consequences. Therefore, thorough examination of policies and practices on selective logging is the first step to assess and identiy the key factors that are affecting optimization of forest management outcomes.

Since harvesting practices are influenced by the intended end use of products, a number of factors along the value chain of timber production also need to be taken into account to derive economic benefits. Studies that focus on, for example, increasing harvest residues and procedural production losses and factors that affect such processes, be it in the case of developing countries or the ones that are developed (Smith and Applegate 2004; Woldendorp and Keenan 2005; Irland 2011), are rare. This is mainly because of limited available evidence to comprehensively understand the implications of inefficient harvesting practices in the timber production chain.

Forest management practices in Nepal are primarily guided by the National Forest Policy 2019, the Forest Act 2019, and the Forest Regulation 1995. Forest management responsibility varies according to the tenure arrangement under

the legislative provisions of these policy documents. National forests,¹ which are under direct management of the forest department, and community forests, which fall under management of forest user groups, follow two separate forest product harvesting, sales and distribution guidelines in the harvesting of forest products (MFSC 2015a). Despite having such specific guidelines, forest harvesting in Nepal is characterized by low levels of mechanization and limited technical capacity to optimize the benefits (Paudel et al. 2014; Sapkota et al. 2020).

On one hand, Nepal still focuses on removing dead, dying and diseased trees with little attention on forest production and economic benefits. On the other hand, Nepal has been facing the issue of sub-optimal timber production and the country is obliged to import timber and timber products despite having 44.6% of the land being covered by forests. Conservation-focused and subsistence-oriented management of community forests and protection-centred management of government forests are identified as key reasons behind this (Banjade 2012; Paudel et al. 2014). There are indications that supply can be enhanced significantly even in less intensive conservative harvesting practice from the most accessible forests alone (Subedi et al. 2014) which would be enough to subsidize the overall import (Kanel et al. 2012) and enhance income and employment opportunities contributing to better livelihood of forest dependent people. However, little attention has been paid either towards making an assessment of the economic and environmental impacts of selective logging practices in Nepal. Moreover, there is a lack of systemic research that focuses on the impacts of selective logging on production potential and other environmental service provisions such as carbon and biodiversity conservation. In these contexts, this chapter aims to assess the economic and environmental impacts of selective forest harvesting practices in Nepal. The specific objectives are: (1) To review the policies and practices of selective logging in Nepal and assess

these against production and protection objective of sustainable forest management (SFM); and (2) To evaluate the environmental and livelihood impact of selective logging particularly referring to wood production and income generation, biodiversity loss, and forest carbon stocks/emissions.

Two different methodological approaches were used to meet the objectives of this chapter. First, detailed review and through analysis of policies and practices related to forest management with special attention on forest product harvesting was carried out. This review and analysis was complemented with the stakeholders' interview in addressing this objective. Second, the case study approach was used to evaluate the environmental, economic and livelihood impacts of forest harvesting practices with special focus on selective logging. The Nawalparasi district of Lumbini Province in Nepal was selected as the case study site. The book chapter is organized in eight different sections. Following this introduction, the genesis of selective logging, and selective logging policies and practices in Nepal are presented in section two and three respectively. Likewise, section four, five, and six gives detailed overview of method, results, and discussions respectively. The section seven summarizes implications of the study, and the last section highlights conclusions and some policy recommendations.

20.2 Selective Logging and Its Genesis

Selective logging is the process of harvesting selected commercially harvestable trees from the natural forests. Selective cutting of the trees as per the need of people is the longest form of practice in forest utilization. However, the systematic integration of this practice as one of the methods of silvicultural systems was initiated in the eighteenth century during the British and French colonial periods in the forests of Malaysia, India, Burma and the West Africa (Puettmann et al. 2015). By 1970, selective logging was already a part of the forest management systems in most of the countries (Schwab et al.

¹ Natural production forests that are under direct management of the national government.

2001). Now, this practice has been one of the dominant timber harvesting practices from the natural tropical forests worldwide and more than a fifth of 400 million ha of global tropical forests are following selective logging practices (Blaser et al. 2011; Edwards et al. 2014; Martin et al. 2015). Even the recent initiatives of close-to-nature forestry and continuous cover forestry in European countries are influenced by the concept and practice of selective logging. Since, selective logging practices determine the outcome of SFM, it is imperative to discuss effectiveness and efficiency of such practices.

20.3 Forest Management and Harvesting in Nepal

Nepal, a small mountainous developing country with only 14.718 million ha of the total land area, inhabits 5.96 million ha forests (Department of Forest Research and Survey 2016). As one of the successful countries to implement participatory forest management, Nepal has increased its forest coverage in the recent years. But at the same time issues of deforestation and forest degradation are still the key environmental issues mainly in the tropical part of the country (i.e. low land). Increasing pressures from infrastructure development and encroachment, forest fire, conflicting land use policies, ineffective governance, illegal forest product harvesting as well as unsustainable harvesting practices are some of the identified key drivers of deforestation among others (Chaudhary et al. 2016). It is increasingly realized that the forest sector of Nepal has not been able to deliver its optimal economic and livelihood benefits compared to its potentials (Gritten et al. 2015; Paudel et al. 2014; Banjade et al. 2011). This has been witnessed by the increasing gap of demand and supply and the trend of timber imports. The main reasons behind this are conservation focused and subsistence oriented management of community forests and protection centred management of government forests (Paudel et al. 2014). For instance, Nepal's forest has potential of producing at least 1.66 million m³ forest products and creating more than

400,000 full time jobs. However, the production is only around 0.5 million m³ (Subedi et al. 2014). Despite the fact that the upper limit of prescription of annual allowable cut in selective logging system of Nepal is 40% of the growing stock i.e., 178 m³ per ha, the actual prescription was far less than that of the limit. In most of the cases, the actual harvesting was not more than 1–2% of this limit (Baral and Vacik 2018). Few studies have indicated that there is a possibility to revert this trend following the principles of silviculture in forest management (Kanel et al. 2012; Subedi et al. 2014). Realizing the fact, the forest policy 2015 and forest sector strategy (2016–2025) are focused towards harnessing the economic potentials of the forests with the vision of “Forestry for Prosperity” (MFSC 2015a).

Forest Act 1993 and Forest Regulation 1995 were the key policy documents that guided forest management practices in Nepal till 2015 before the promulgation of national forest strategy 2016–2025 and Forest Act 2019 (MoFE 2021). According to these policy documents, the forest management responsibility varies as per the tenure arrangement. National forest under direct management of the department of forest and community forest under the management of forest user groups follow two separate specific forest product harvesting, sales and distribution guidelines (MFSC 2015a, 2016). Logging in national forests is carried out either directly through the local and national timber contractors managed by the division forest office or Nepal Ban Nigam (NBN²) whereas the communities following their community forest operational plans and the directive of the government manages forest harvesting in community forests (Fig. 20.1).

After the establishment of the Department of Forests in 1950s and widespread havoc of “Himalayan Degradation” in 1960s, the government of Nepal kept promoting forest protection rather than forest management, harvesting, and utilization. The Master Plan for the Forestry Sector (MPFS) was the first national policy

²The state owned corporation responsible for timber supply.

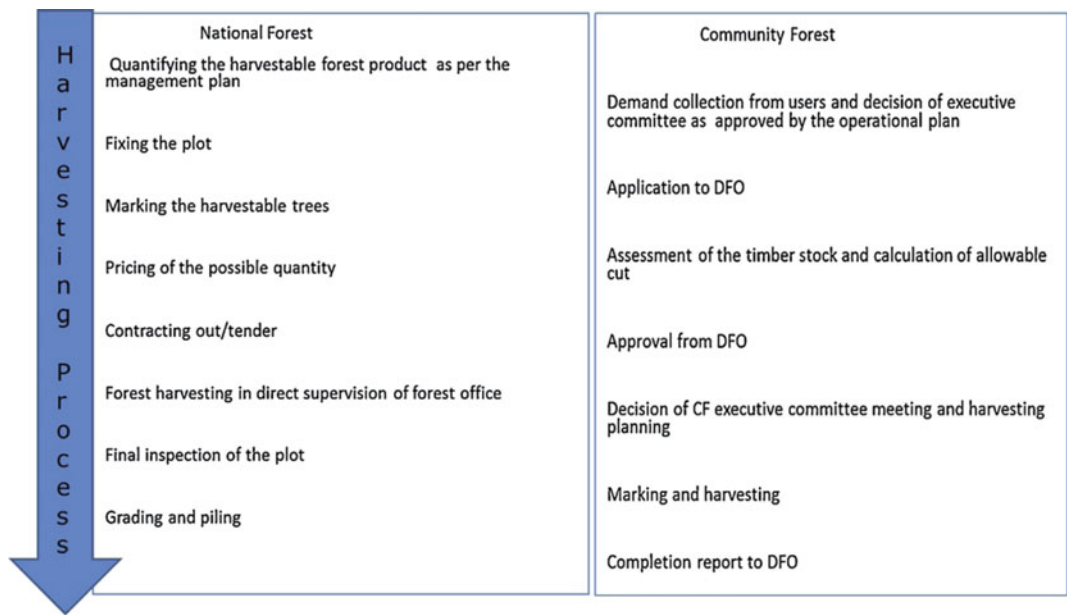


Fig. 20.1 Forest harvesting procedure in national forest and community forest of Nepal (MFSC 2015a, 2016)

document declared in 1988 for 21 years in terms of managing forest resources. On one hand, MPFS had its priority to promote community-based forest management but on the other hand it spelled out on the potential forest production (MPFS 1988). Particularly, community forestry (CF) was promoted extensively after the successful democratic movement in 1990. By May 2020, there are 22,266 community forests user groups (CFUGs) in Nepal managing 2.24 m ha. of forests and are the most dominant institution responsible for forest harvesting in Nepal. Before the rights to harvest forest was given to CFUGs, Timber Corporation of Nepal (TCN) and local as well as national contractors were the sole agents involved in forest harvesting. TCN has now been changed into NBN after 2019 and is still responsible for the supply of forest products.

20.4 Methodology

As briefly indicated above (in introduction section), two broader methodological approaches were used to meet two objectives of this chapter. The first method was the comprehensive review

and analysis of forest policy documents (strategy, act, rules, regulations, and guidelines) of Nepal together with other published literature. The review focused legislative provisions and procedural aspects of forest harvesting practices in Nepal with special attention to selective logging. Secondly, to evaluate environmental and socio-economic impacts of selective logging, both qualitative and quantitative data were collected and analyzed from the selected case study site, the Nawalparasi District of Nepal where selective logging is in practice.

20.4.1 Case Study Area

Selective logging has been practicing in many parts of Nepal. For this chapter, data were taken from the field measurement in Kawasoti, Arunkhola, and Bardaghat areas of the Nawalparasi district of Lumbini Province of Nepal. The district is located 140–250 km South West of Kathmandu, and borders India to the South, with high potential for illegal timber trade. The elevation of the district ranges from 92 to 1936 m above sea level, with high climatic and vegetation diversity.

The study was carried out in the lowland plains, which offer a suitable edaphic and climatic environment for the growth of highly valued commercial timber species. Out of the total forest area of 122,365 ha (55.7% of the total area) of the district, more than 30,000 ha is managed by 208 CFUGs, and nearly 3000 ha is managed by collaborative forest user groups under the CF regime. With less than 2000 ha forest managed under leasehold and religious forest management programmes, the remaining forests of more than 85,000 hectares are under the government-managed systems including protected area.

20.4.2 Data Collection and Analysis

Acknowledging the strength of the integration of qualitative and quantitative research techniques (Table 20.1), this study adopted a mixed research approach. Mixed research method helps not only to answer diverse sets of research questions and triangulation but also overcomes the weaknesses of single method. Qualitative methods included qualitative comparative analysis (QCA), content analysis, key informant interviews (KII), expert consultation and stakeholder workshops, which were used to assess forest harvesting policy, practice, and factors affecting such practices. Likewise, forest inventory, measurement of standing and felled trees, and calculation of the forest product recovery and associated emissions were conducted using quantitative methods.

After review of literatures and a series of discussions with experts, we identified key stakeholders and interviewed them to address first objective (Table 20.2). Based on the position, roles, interests and influences in implementation of forest policies and plans, we categorised those stakeholders as government agencies, private sector (including the group/association of contractors), federation/networks of the forest user groups, under three level i.e., central level, district level, and local/community level. Triple perspective typology (TPT) of stakeholder theory (Steurer 2006) was applied while assessing the evolution of ongoing forest management policies, their adoption, and their

effectiveness, including the relationships between stakeholders.

Qualitative information analysis software NVIVO-version 11 was used to find the pattern of the contents and to group and categorize the information. Likewise, quantitative information gathered from field measurements were analyzed using standard and scientifically established formula and equations. Participant observation was an additional method used to triangulate both the qualitative and quantitative information.

20.5 Results

20.5.1 Policies and Practices of Selective Logging in Nepal

Selective logging practice has been a prominent practice in Nepal since the inception of tree harvesting practice for domestic use as well as for the commercial sale. There are specific forest harvesting policies and rules of forest harvesting in national and community forests in Nepal (as noted in an overview above). A list of policies and guidelines related to selective logging in Nepal is listed in Table 20.3. However, the study found that such provisions, management strategies, and plans are made ineffective by the directives, political decisions, and/or ministerial circulars in line with the changes in political and bureaucratic leadership in forestry institutions. For example, ministerial circular of Ministry of Forest and Soil Conservation (MFSC) on 21 May 2010 declared a plant holiday banning to harvest green trees and another circular from the same institution on 2 Dec 2011 allowed harvesting only the fallen trees within the limit of AAC (Baral and Vacik 2018). More than 90% of the respondents including a high-level forest official from the forest department agreed that such changes have been quite common as a political culture (Poudyal et al. 2020). Even though Nepal has developed national standards of SFM and piloting these standards in some of the community-managed forests, these standards are not being followed while making harvesting

Table 20.1 Overview of the sources and methods of data collection

Research objectives	Data/information required	Sources and methods of data collection
To review the policy and practice of selective logging in Nepal and assess these in terms of SFM	– Forest harvesting provisions on existing forest management frameworks (policies/laws/regulations/manuals/guidelines/long term forest sector plans/ harvesting plans) – Forest harvesting policy direction/governance structure / institutions and compliance of SFM standards – Standards on forest harvesting including the land/block allocation system, trees marking, diameter of trees, methods of felling, machineries to be applied, logging and transportation requirements, and standards set for processing logs into timber/wood products in sawmills/industries – Level of mechanization and recovery of forest products – Royalties and fees in timber harvesting and processing – Forest tenure and ownership – Awareness and skill of harvesting personnel – Compliance with policy /law /rules/ guidelines – Damages to the remaining vegetation to ensure sustainable productivity	– Review and synthesis of official documents and scientific sources/literatures including – Forest acts/policies/regulations – Forest management frameworks – Timber management guidelines – Operational Plans of Community Forest (Nepal) – Policies/Plans relating to operation of sawmills/industries and the plans of industries – Studies/reviewed papers related to forest management, silviculture operations in the respective country and beyond – Field visit (onsite observation) and stakeholder's interview (Forest owners including forest management agencies of the respective government/ Communities/ Private, timbermen, loggers, sawmills) – Cumulative insight from researcher's experience – Stakeholders analysis – Onsite field visit and observation – Review of the relevant scholarly literatures
To evaluate the impact of selective logging on the timber production value chain and forest carbon stocks/emissions	– Standing and felled tree volume (diameter/ height) – Volume and biomass of stump, step, branches and biomass of the foliage – Methods of felling, logging, hauling and transportation – Wood product volume recovery – Sawnwood product recovery – Information related to money flow, materials flow, information /communication flow, and governance or relationship among the value chain actors in wood flow process – Logging damage – Carbon stock in the harvested trees – Emissions from extraction, emissions from infrastructure and emissions in transportation – Net carbon emissions per m³ in wood flow process from forest to the sawmills processing	– Forest inventory/ measurement – Calculation of log and timber volume of the sample block using standard formula as well as application of existing volume table for different species – Measurement of harvested logs and calculation of harvest loss – Measurement of wood and non-wood wastages – Estimation of carbon stock in live tree/stumps/branches/ damaged trees – Value chain analysis in wood flow – Interview with stakeholders in the value chain process (district forest offices, community forest user groups, private owners, contractors and sawmills) – Observation of harvesting operations – Measurement of processed timber and calculation of processing loss – Calculation of emissions in each stage up to the final product for use/export

Table 20.2 Identified key stakeholders, their roles and number of respondents

Stakeholder group (total respondents)	Key stakeholders	Central/district/local	Roles/interests and influence in SFM	Respondents
Government (13)	Ministry of Forest and Environment (MoFE)	Central	Promulgating forest policy and plans, overall coordination and regulation of forest management activities	1
	Department of Forests (DoF)	Central	Coordinating all the district forest offices, implementation of policies, plans and oversight of nationwide forest management activities	4
	District Forest Office (DFO)	District	Implementation of all forest management activities in the district. Balancing protection and production, facilitating user groups, entrepreneurs and the contractors to balance demand and supply	6
	Timber Corporation of Nepal (TCN)	Central	Harvesting, collection and sales of timber and fuelwood	1
	TCN owned Sawmill at Danda, Nawalparasi	District	Processing of logs and production of value added products such as ready to sale poles, frames	1
Federation/networks of forest users (12)	FECOFUN	Central	Ensuring community rights in forest policies, action plans and regulations through active engagement on policy process and advocacy. Facilitating community forest users to utilize their rights and building capacity of users	4
	District/area level FECOFUN	District	Coordination at district level with forest office, management plan implementation	4
	COFSUN Nepal	Central	Building capacity of forest user groups and facilitating policy process	1
	ACOFUN	Central	Advocacy of collaborative forest management collaborative (CFM) user's rights in policies and facilitating implementation of CFM activities	2
	HIMAWANTI Nepal	Central	Women empowerment in forest management, policy advocacy, capacity development of CFUGs	1

(continued)

Table 20.2 (continued)

Stakeholder group (total respondents)	Key stakeholders	Central/district/local	Roles/interests and influence in SFM	Respondents
Private Sector (8)	FENFIT Nepal	Central	Advocacy for enabling environment to the forest products industries, sustainable supply of timber products	3
	Sawmills	Central plus Local	Collection of forest products at local level and sustainable supply of local furniture and wood products	3 (1 + 2)
	Local timber contractors	Local	Collection of forest products and supply in other places	2
Forest user groups (7)	Community forestry user groups	Community	Conservation and management of forest area handed over to them	5
	Collaborative forest management committee/users	Community	Interested in sustainable supply of the forest products for their subsistence need Influence on local forest management decisions / regulations through their network	2
Total				40

Table 20.3 List of the policies and guidelines related to selective logging in Nepal

• Forestry Sector Strategy 2016–2025
• National Forest Policy 2019 (2075)
• Forest Act 2019 (2076)
• National Environment Policy 2019 (2076)
• Environment Protection Act 2019 (2076)
• National Parks and Wildlife Conservation Act 1973
• Nepal CITES Act, 2017
• NEPAL BAN NIGAM LIMITED NIYAMAWALI, 2076
• Collaborative Forest Management Guidelines, 2011
• Forest Product Collection, Sale and Distribution Directives, 2000
• Scientific Forest Management Guidelines, 2015

decisions and practicing them. Although government respondents have claimed that the objectives of SFM are duly considered, other stakeholders request for specific national forest management and harvesting standards. No specific blocks or zones in Nepal are defined as

the forest production area except for the national classification of protected areas for specific biodiversity management and the national forest area that is literally understood as the production area. Moreover, forest policies and plans in Nepal, even the recently promulgated forest

policy of 2019, are silent concerning the health and safety of forest harvesting (MoFE 2019). There are no specific standards, codes of practice or procedures developed in relation to these aspects.

The overall procedure of forest harvesting approval in Nepal is complex and time-consuming. There is no provision for long-term harvesting permits and the contractors are selected each year for the specified harvesting block. Contractors selected for one block need to follow the whole process again if they are interested in harvesting another block. More than that, there is no provision for selling standing trees. Hence, separate tenders and contracts are called for tree harvesting and sales. In the case of national forests, the harvesting proposal of the division forest office needs to go through a number of bureaucratic layers (i.e., Division Forest Officer (DFO)-Regional Director-Director General of the Forest Department, and in some cases up to the Secretary and Minister level). Following the lengthy process of monitoring and subsequent presentation and discussion at departmental level, the department either forwards the proposal to the ministry or approves the proposal itself based on the amount and value of the total resources to be harvested. Then, the DFO commences a tender process to carry out harvesting following the financial guidelines and the standard norms/rates of the district. Generally, the approval process takes up to two or even four months even if the process went smoothly. In the case of community forests, user groups must wait for even longer to pass their proposal even if it is within the authority of the DFO. Respondents including government officials agreed that the process of harvesting approval needs to be simplified. Similarly, representatives of the timber trader's association claimed that harvesters generally neglect the efficient harvesting options in logging operations, as they are not sure who wins the sales contract.

Harvesting of the forest products in Nepal is suffering from low level of mechanization and limited technical capacity to optimize the benefits. Nepal is still using conventional harvesting tools such as axe, sickle, and handsaw in forest

harvesting operations. A small number of the harvesting contractors have started using power chain saws to fell the trees and small tractors for hauling and transporting logs. However, they have to depend largely on manual hauling not only in the slopes but also in the plains. Moreover, natural forest harvesting system is still considered as a collection of fallen trees or cuttings of low-quality trees scattered in a larger area. Our findings suggest that compliance with rules and regulations concerning technical considerations in Nepal is at a satisfactory level. However, harvesting damage to both the regenerations and the harvested tree itself is quite high (Poudyal et al. 2019a). Likewise, we found relatively higher loss in sectioning of the tree into logs, but the process of yarding and haulage was satisfactory as these activities were done manually with care. Although, these manual processes have enhanced employment and livelihood opportunities of local people, attention towards increased risks of health hazards is negligible due to lack of occupational health and safety standards for forest workers as stated above.

In Nepal, key habitat trees (dead, dying, and diseased with hollow) are removed during selective harvesting. This indicates lack of technical considerations on faunal and floral diversity in natural production forests. Concerning the floral diversity, Forest Act has provisioned the special protection for some tree species and banned for harvesting and use (MFSC 2015b, 2016). Likewise, CFUGs have also considered the maintenance of floral diversity in their forests due to the diverse needs of communities including fuelwood, fodder and NTFPs. These policies and practices have supported protection of endangered floral species thereby contributing to species richness and composition (Poudyal et al. 2019b).

The policies and practices in forest management are guided primarily from conservation orientation. Policy makers who worked in such environment might not feel easy in changing their orientation on technical management of forests despite the number of changes in policies and guidelines. Moreover, leadership of the forestry institutions and their perspectives on

technical versus conventional forest management has influenced the forest management guidelines, leading to a number of circulars and notices. Overall, Nepal's forest administration considered forest management as a measure of environmental conservation rather than a means of production to address the need of local people and a source of income and employment.

20.5.2 Selective Logging Practices and Its Impacts on Timber Production and Recovery in Nepal

Detailed measurement and product flow analysis of 72 commercially harvested trees from tree felling to the exit gate of sawmills and interaction with sawmill owners and forest managers in Nepal reveal that: (1) Nepal's logging practice has 94.5% of volume recovery leaving significant utilizable volume in the forest, (2) Stump volume represents 5.5% of total timber volume with an average stump height of 43.3 cm, (3) Average sawn timber output from the harvested logs is 61%, (4) In terms of carbon recovery, existing selective logging leaves $0.186 \text{ Mg C m}^{-3}$ on the forest floor while extracting one cubic metre of log volume, (5) Each harvested tree damages an average of five plant species predominantly the seedlings, and (6) Overall logging related total emissions is $0.488 \text{ Mg C m}^{-3}$ of log volume.

Measurements of every part of the tree after felling and calculation of the volume indicated that the stump volume represented 5.5% (0.13 m^3 per tree) and the log volume was 80.2% of total actual volume. Out of the total volume of felled trees (176.9 m^3), 94.5% was recovered, leaving only 5.5% tree woody volume as forest residues. The result showed that, an average of 0.13 m^3 woody volume was left on the forest floor from every tree harvested (Fig. 20.2). The median length of the logs extracted was only 1.85 m. These tree logs taken to the sawmills are recovering an average of 61% of the total log volume as sawn wood volume. Remaining 39.1% is produced as odd-sized products and sawdust residue.

Likewise, a total 364 plants at different stages of growth were damaged during harvesting of 72 mature trees where the dominant species was Sal (*Shorea robusta*). Results revealed that seedlings were the most damaged category followed by saplings, poles, and trees. On average, felling a mature tree damaged 3 to 4 seedlings and one sapling. Likewise, the damage harvest ratio for poles is 1 in 3 harvested whereas for trees it is 1 in 5 harvested. Finally, we estimated total harvest related emissions taking three factors into account: log extraction, logging damage, and logging infrastructure. The total emissions factor of the sampled trees was $0.488 \text{ Mg C m}^{-3}$.

20.6 Discussions

Findings of this research suggest that effective and efficient forest harvesting practices that optimize both production and protection outcome are rare in Nepal. This has limited the generation and utilization of potential forest-based benefits such as in enhancing income, employment, and livelihood from this sector. Selective logging (SL) has been considered for improving SFM outcomes globally (Applegate et al. 2004). Researchers have highlighted that the improved harvesting practices such as reduced impact logging (RIL) in SL outweighs benefits of conventional practices. It has been revealed that RIL provides better outcomes in environmental services, mainly carbon storage (Medjibe et al. 2011; Sasaki et al. 2012) and biodiversity (Medjibe et al. 2011), while providing an opportunity to maintain consistent wood production if cutting cycles are maintained (Sasaki et al. 2012). Conventional techniques may provide higher timber production for a short time, but they have longer-term negative impacts on carbon and regeneration of plant species (Sasaki et al. 2012). However, Martin et al. (2015) have questioned the contribution of RIL to benefit tree species richness, demanding evidence-based research.

With the special focus on assessment of damage caused by selective logging, Picard et al. (2012) compared logging damage rates between

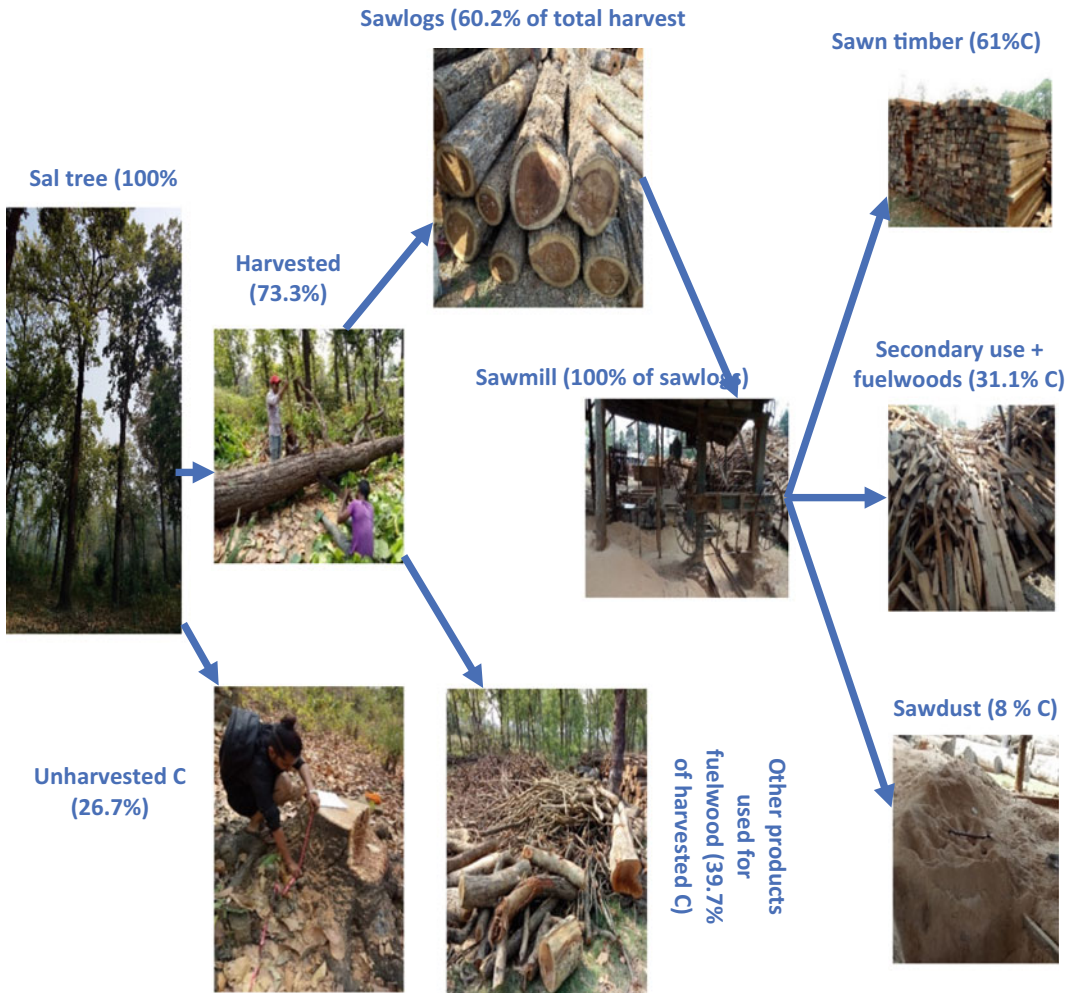


Fig. 20.2 Pictorial flow of carbon in tree harvesting and processing in Nepal

South America, Africa, and Southeast Asia with their findings showing minimal damage in South American countries because of higher sizes and classes of trees in the forests. Putz et al. (2012) reviewed the long-term impacts of selectively logged areas on sustaining timber production, conserving species, and carbon stocks, and concluded that reduction in collateral damage and the application of active silvicultural treatments increased the long-term forest yield. Likewise, researchers have studied various aspect of selective logging impacts including long-term forest growth and recovery (Barreto et al. 1998; Osazuwa-Peters et al. 2015; Roopsind et al.

2017), amount of deadwood stocks (Carlson et al. 2017), and tree regeneration dynamics (de Carvalho et al. 2017). Lasco et al. (2006) attempted to deal with the implications of selective logging on forest carbon stocks in the tropical forests of the Philippines and found that selective logging reduced the overall carbon stocks of forests due to lower timber recovery (only about 40%) and increased emissions from forest fires or decay. A study highlighted that the current practices of selective logging in Queensland, Australia have not been able to recover more than 53% of the forest product volume despite higher levels of mechanization

compared to Nepal, where the recovery rate of the harvested products is more than 90% (Poudyal et al., 2019a, b). In addition, overall logging-related emissions in Queensland are more than double than those of Nepal. The main reasons behind as highlighted by that study are the difference in the level of dependency on forest resources, overall harvesting and processing costs, and the market driven standards.

The central element of SFM is the wise use of forest resources (MacDicken et al. 2015; Mill-edge 2015) where the essence of better forest harvesting practices comes into play (Sasaki et al. 2016). However, implementation of SFM has remained a challenge (Sarre and Sabogal 2013). Negligible adoption of improved harvesting technologies and limited consideration of changing socio-economic and climatic contexts make SFM an ongoing challenge (Putz et al. 2008; Putz and Romero 2012; Sasaki et al. 2012; Wiersum et al. 2013; Härtl et al. 2015; Ruslandi et al. 2017). Furthermore, poor understanding of the capacity of forest resources to offer multiple but heterogenous services, and of the trade-offs among them (Gamfeldt et al. 2013; Rana et al. 2016; Triviño et al. 2017), is also an issue constraining SFM outcomes. Our results suggests that improved understanding on the trade-offs and synergy among those services is crucial to assess the effectiveness of existing practices. For this to happen, it is essential to critically analyze existing practices and explore ways to minimize losses and maximize gains relating to trade-offs for better SFM outcomes.

Practices of forest harvesting differ as a result of socio-economic conditions, geographical location and political context of the country. Such diversity can be compared on the basis of harvesting methods (Mousavi 2009; Enache et al. 2016), harvesting tools and equipment (Norizah et al. 2012; Enache et al. 2016), productivity and cost of technologies (Berg et al. 2012; Ghaf-fariyan et al. 2017), and other factors, including codes of practice, geography, and technological access and capacity (Cristan et al. 2016; Enache et al. 2016). Researchers have claimed that developing countries have less access to

technology and equipment compared to developed countries, making them relatively less efficient in forest harvesting (Mills Busa 2013) and weaker in delivering forest management outcomes (MacDicken et al. 2015). However, as noted above, our study shows otherwise; Nepal is better in timber recovery and carbon emissions outcomes. This is mainly because of the wise use of all types of forests products in Nepal (timber, bark, twigs, foliage etc.). Moreover, in Nepal, logs upto 10 cm diameter are easily processed in all sawmills whereas in developed country (such as Australia), logs less than 20 cm diameter are discarded (Maraseni et al. 2007).

Timber stock and recovery quantity however depend on the intensity of tree removal, which affects the growth of remaining trees in the harvesting sites (Roopsind et al. 2017). Scholars have argued that trade-offs among harvested timber and carbon storage can be optimized if sustainable harvesting intensity and cutting rotations are maintained (Levers et al. 2014; Roopsind et al. 2017). A number of studies present evidence regarding the rationale for improved forest harvesting techniques to accelerate overall biomass and timber stock recovery (Medjibe et al. 2011; Putz et al. 2012; West et al. 2014; Vidal et al. 2016). Our study agrees with these findings. Beyond these aspects, our findings suggest that socio-political factors, economics, and governance of forest management are equally important.

20.7 Implication of the Study

This study identified the factors affecting sub-optimal forest production outcomes and offered information to make natural forest land economically competitive among other forms of land use. Furthermore, the study provided empirical evidence as to whether existing forest harvesting system/s need modification to serve the multi-functional objectives of the forests to respond to global challenges such as climate change. In terms of policy and actions, the study has suggested improvements/revisions of timber

harvesting guidelines that minimize wastage and produce more logs, with positive impacts along the timber production chains and increased carbon storage. This will help to sustain the wood-based industries with additional positive impacts on industry profits, carbon benefits, state revenues, and employment and livelihood improvement of local communities.

This research has a linkage with IPCC fifth assessment report (Smith et al. 2014) which clearly suggests sustainable timber production, reduction of logging waste, efficient use of wood products, and minimizing damage to remaining trees are the strategies for carbon stock enhancement through forest management (Smith et al. 2014). However, there are limited discussions on the factors affecting such aspects and the ways to achieve those strategies at local levels. Therefore, the assessment of on-ground forest harvesting practices is important.

Similarly, the research has implications for the implementation and operation of REDD + in many developing countries in Asia-Pacific region, specifically in Nepal. It has highlighted the relevance and role of production and utilization of harvested wood products (HWPs) in global climate change mitigation. Despite the fact that improved forest governance in key forest management modalities, i.e., community forestry, collaborative forestry and national forests, are equally important to enhance REDD+ outcomes in Nepal (Poudyal et al. 2013, 2020), this study offers evidence on why active forest management and harvesting are critical in optimizing natural forest production including carbon benefits.

Furthermore, this will support active forest management activities, including the adoption of regular silvicultural practices. Overall, the study has several policy implications for sustainable forest management and forest-based emission reductions in Nepal, with broader impacts on global targets set under UNFCCC, and to some Sustainable Development Goals (SDGs) such as clean water and sanitation (#6), affordable and clean energy (#7), climate action (#13), and life on land (#15).

20.8 Conclusions and Recommendations

Our findings suggest that: (1) Nepal's current forest harvesting policies and practices have paid limited attention to the implications of lower timber recovery on the overall wood production value chain and the associated carbon emissions; and (2) there is strong belief among forest administrators and policy makers that a protection-centred approach is the best way to conserve biodiversity. This has resulted in passive silvicultural practices with the fear of negative implications on carbon emissions and an increased focus on protection-oriented forest management. Forest harvesting practices resulting from this dominant perception has undermined the potential of forests in generating incomes and enhancing livelihood of local communities. Our study suggested that focus should be on designing forest harvesting protocols for broader forest management framework, while at the same time ensuring multi-functional outcomes from sustainable forest management efforts.

Based on the above finding, we recommend that revision/improvement of natural forest harvesting guidelines should be the first important step in improving forest product recovery and to minimize harvesting damage to the forest undergrowth. This will minimize forest harvesting wastages and increase forest product supply. More quantity of forest products/logs will have positive impacts along the forest production and utilization chain and at the same time support the enhancement of carbon storage. An increase in production can help sustaining the wood-based industries, by increasing industrial profits, government revenue, and income and employment opportunities to local communities. The results may contribute to positive outcomes under forest-based emissions reduction schemes, i.e., REDD + in Nepal.

Based on this study, following strategic actions are suggested to improve natural forest harvesting policies and guidelines in Nepal. First, action needs to be taken to reduce the

bureaucratic burden. Nepal is placing more emphasis on bureaucratic/administrative procedures in forest harvesting and management with negative or less positive implications for forest production outcomes. Minimum involvement of the state forest agency in day-to-day harvesting activities (except supervision and compliance monitoring) will ease forest harvesting operations; and provision of single long-term periodic permits will reduce transaction costs compared to the current multi-stage tender process in Nepal's forest harvesting system. Second, policy action is needed to harmonize log measurement. A poor link between grading, commerciality, and marketability creates inefficiency in the market. Since existing rules/practices of log measurement, log grading and log sectioning in Nepal are not responding to market needs, in terms of size and utilization potential (primarily of the construction timbers), urgent policy action is suggested.

Third, Nepal lacks a detailed occupational health and safety codes of conduct. Integration of health and safety codes of conduct and their compliance might help to promote sustainable use and management of natural forests. Therefore, occupational health and safety codes of conduct and a detailed forest harvesting code of practice, specifying technical requirements and compliance mechanisms in natural forests, are urgently needed for Nepal. Fourth, capacity building should be an important policy priority. Our study has reiterated the fact that policies and practices of forest harvesting need to emphasize capacity development of forest management stakeholders, primarily forest harvesters, as an essential component of the forest production chain. Nepal needs to focus on the development of silviculture-based forest management skills of forest managers and users to operationalize forest management practices effectively and efficiently. Moreover, better compliance with forest management plans and capacity development of community forest users in forest management operations need to be a strategic policy priority to achieve production and protection outcomes from natural forests.

Finally, in the context of Nepal's active participation in forest-based climate change efforts and contribution to the conservation of global terrestrial biodiversity, timely harvesting of mature trees and minimal damage to neighbouring plants need to be the priority in policies and action plans. Such actions will help to stock more carbon in harvested forest products as well as in the forest biomass.

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Assessing the Potential of Agroforestry in Nepal: Socio-economic and Environmental Perspectives

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Abstract

Raising trees in and around farmlands with field crops (agroforestry) is an age-old farming practice in Nepal. However, modern agriculture has overshadowed tree-based farming as it emphasized high-yielding crop varieties to increase profit and farm productivity. Moreover, the importance of institutional setup and policy framework supporting its promotion has also been ignored in Nepal. As a result, we have witnessed environmental problems such as land degradation, water quality deterioration, and biodiversity loss, leading to food insecurity in some cases. In recent years, when the climate change issue

surfaced, the importance of integrating trees with crops has received new impetus, with numerous examples of agroforestry systems improving farmers' livelihoods and food security and contributing to degraded land restoration and biodiversity conservation. This development is positively contributing to several UN sustainable development goals (SDGs) such as eliminating poverty (#1), clean water and sanitation (#6), climate action (#13), and life on land (#15). Agroforestry systems with integrated land use hold the potential of becoming a more sustainable alternative to crop-focused farming in Nepal. There are, however, constraints to it, such as small landholding, lack of an institutional setup, lack of access to credit facility, lack of market infrastructures, and in some situations, farmers' indifference towards environmental benefits. Some agroforestry practices are less labour intensive, which is an opportunity in the present socio-economic context of Nepal, where farmers are forced to leave their farmlands fallow due to labour scarcity resulting from youths out-migrating for jobs. More research is needed to explore the full potential of such promising systems with integrated land use in Nepal.

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21.1 Introduction

The coinage of the term ‘Agroforestry’ dates to the 1970s. Even though the term is relatively new to science, the practice of raising trees on farms with field crops is not new at all; rather it is an age-long form of agriculture that farmers had practised long before sedentary agriculture came into practice. There is evidence of home garden, a form of agroforestry, to have evolved during the Mesolithic period (Kumar and Sikka 2014). Shifting cultivation is another form of agroforestry, which also evolved before the advent of sedentary agriculture some 10,000–15,000 years ago. Though primitive in nature, it is still practised in various parts of the globe including South American and African countries (Spencer 1996). Also known as ‘slash and burn’, ‘swidden agriculture’, and ‘*Jhum*’, shifting cultivation is still the dominant form of farming system in Southeast Asia and Northeast India (Li et al. 2014; Behera et al. 2016). Nair (1993) documented eighteen different agroforestry practices under the three broad categories of agroforestry systems, which are in practice globally (Table 21.1).

Ironically, the farming system in the modern era has shifted towards high-yielding monoculture to meet the growing food demand following the world population explosion after 1950. This shift in farming system sidelined agroforestry (Nair 2007). The world population was 6.9 billion in 2010, which is more than double from 2.5 billion in 1950. During the same period, agricultural (grain) production increased fourfold from 600 million tonnes in 1950 to 2400 million tonnes in 2010 (Gupta 2019). Such a dramatic gain in grain production resulting from the development and adoption of improved agricultural technologies and high-yielding varieties contributed to reducing global food insecurity in the long run (Shiferaw et al. 2013; Stabile et al. 2020). The questions have emerged as to whether these gains are sustainable or the agricultural technologies that have been developed are friendly to land, water, forests, and the overall environment, which provide ecological foundations for agriculture.

Evidence suggests that these technologies have adversely impacted the land and water resources (Rokonuzzaman 2016; Rani et al. 2018; Warren-Thomas et al. 2015). As a result, the present generations of agricultural stakeholders are facing dual challenges: on the one hand, they need to increase productivity to meet the growing needs of food, but on the other hand, they need to maintain the quality of land and water resources and conserve biodiversity for future generations. The dual challenges posed by the input-intensive monocultural production system (IMPS) have led to recognition and appreciation of the values of the age-old practice of combining trees with field crops (Andres et al. 2016; Santosh et al. 2019). Several studies confirm that the tree-crop combination has the potential of offering a range of goods and services to society whilst contributing to halting land degradation and water quality deterioration, as well as mitigating climate change and enhancing biodiversity conservation (Nair 2007; Santosh et al. 2019), thereby positively contributing to many of the UN Sustainable Development Goals (SDGs).

In Nepal, farmers have been raising trees around their homesteads since time immemorial, primarily to meet the household’s needs such as fuelwood and fodder. This practice is known as homestead agroforestry (Fig. 21.1), which requires no separate land and uses the land that would otherwise remain unutilized such as, marginal lands and open spaces around the dwellings (Dhakal et al. 2015). The other form of agroforestry that is getting momentum gradually in Nepal is product-specific agroforestry, which is more commercial (Dhakal 2013). It includes fodder-based, timber-based, coffee/tea-based, home garden (horticulture-based), fishery-based (aqua-silviculture), non-timber forest product (NTFP)-based, and cardamom-based agroforestry (Dhakal et al. 2015; FRTC 2019; Joshi and Joshi 2016) (Fig. 21.1). Whilst homestead agroforestry is a more common occurrence in Nepal, product-specific agroforestry is more localized and has limited geographic coverage (Joshi and Joshi 2016; Sharma et al. 2016a). Shifting cultivation is still practised in the mid-

Table 21.1 Types of agroforestry (AF) practices from around the world (Nair 1993)

S. No.	Major systems	Sub-categories	Brief description
1	Agri-silvicultural system (crops—including shrub/vine/tree crops—and trees)	Improved fallow	Woody species planted and left to grow during the 'fallow phase'
		Taungya	Combined stand of woody and agricultural species during initial stages of establishment of plantations
		Alley cropping	Woody species in hedges; agricultural species in alleys in between hedges; micro-zonal or strip arrangement
		Multilayer tree gardens	Multispecies, multilayer dense plant associations with no organized planting arrangements
		Multipurpose trees on crop lands	Trees scattered haphazardly or according to some systematic patterns on bunds, terraces, or plot/field boundaries
		Plantation crop combinations	(i) Integrated multistorey (mixed, dense) mixtures of plantation crops (ii) Mixtures of plantation crops in alternate or other regular arrangement (iii) Shade trees for plantation crops; shade trees scattered (iv) Intercropping with agricultural crops
		Home gardens	Intimate, multistorey combination of various trees and crops around homesteads
		Trees in soil conservation and reclamation	Trees on bunds, terraces, raisers, etc. with or without grass strips; trees for soil reclamation
		Shelterbelts and windbreaks, live hedges	Trees around farmland/plots
2	Silvopastoral systems (trees + pasture and/or animals)	Fuelwood production	Interplanting firewood species on or around agricultural lands
		Trees on rangeland or pastures	Trees scattered irregularly or arranged according to some systematic pattern
		Protein banks	Production of protein-rich tree fodder on farm/rangelands for cut-and-carry fodder production
3	Agrosilvopastoral systems (trees + crops + pasture/animals)	Plantation crops with pastures and animals	Example: cattle under coconuts in south-east Asia and the south Pacific
		Home gardens involving animals	Intimate, multistorey combination of various trees and crops, and animals, around homesteads
		Multipurpose woody hedgerows	Woody hedges for browse, mulch, green manure, soil conservation, etc
		Apiculture with trees	Trees for honey production
		Aqua-forestry	Trees lining fishponds, tree leaves being used as 'forage' for fish
		Multipurpose woodlots	For various purposes (wood, fodder, soil protection, soil reclamation, etc.)



Fig. 21.1 Dominant forms of agroforestry in Nepal. **a** Cardamom-based AF in the eastern mid-hills (Ilam district). **b** Coffee-based AF in the central mid-hills-Kavre district (Source: <http://www.coffeenepal.org.np>). **c** Fodder (*Leucaena leucocephala*)-based AF in western mid-hills (Tanahun district). **d** Horticulture (mango + pineapple)-based AF in eastern terai (Morang district). **e** Homestead

AF (farm boundary-above and marginal land-below) in western terai (Dang district). **f** Fishery-based AF (Aqua-silviculture) in central terai (Dhanusha district). **g** Timber/poles (*Eucalyptus camaldulensis*)-based AF in central terai (Dhanusha district). **h** Homestead AF (marginal lands) in western mid-hills (Salyan district)

hills of Nepal, though it is declining (Amatya et al. 2018). Nepal has also gone through and witnessed land and water degradation following the introduction of IMPS which demands more farm inputs such as fertilizers, pesticides, fuels, and machinery (Raut et al. 2010; Govaerts et al. 2009; Maraseni et al. 2007, 2010). All these inputs, directly and indirectly, accelerate carbon emissions as their production, packaging, storage, and transportation requires a huge amount of energy. To address the IMPS-induced degradation issue in Nepal, a tree-based farming system could be a viable solution.

In this chapter, we examine the potential contribution of agroforestry to the household economy and poverty reduction in the changing socio-economic context of Nepal. The paper also highlights the non-market benefits that this practice can provide to society. Further, we analyse both constraints to and opportunities for agroforestry promotion in Nepal.

21.2 Agroforestry as a Source of Household Economy

A rate of return on investment, by and large, governs the adoption of technology by farmers (Greiner and Gregg 2011). Farmers will only invest in a new land-use practice when the expected gains from the new practice are higher than other potential land-use practices. It is a general tendency that farmers choose modern crop varieties because they are high-yielding and are ready to harvest in a shorter time than traditional crops (Ficiciyan et al. 2018). In agroforestry, however, the shortest harvest cycle (e.g., *Morus alba* and *Flemingia congesta*) is at least one and a half years. The types of tree species and the objectives of raising trees determine the harvest cycle. The longer harvest cycle than that of cereal crops has been one of the bottlenecks to agroforestry adoption by farmers in Nepal (Dhakal and Rai 2020).

Nevertheless, depending on the type of agroforestry, it has the potential of diversifying farm products, increasing total farm productivity, generating employment, and contributing to

many SDGs such as eliminating poverty (#1), clean water and sanitation (#6), climate action (#13), and life on land (#15) in Nepal. Amongst many products that agroforestry can provide, coffee is one of them, the cultivation of which has emerged as important cash earning farm enterprise in Nepal. Studies suggest income from coffee is more profitable than other cash crops and cereal crops (Sharma et al. 2016a). The 2016–2017 production data show that a total of 2626 ha of arable land was under coffee cultivation, producing 466 tonnes of green beans worth USD 416,204 based on the farm gate price (Tuladhar and Khanal 2018). Studies conducted in Parbat and Lalitpur districts showed that coffee shared 16% and 25% of the total household income respectively in those districts (Sharma et al. 2016a; Karki et al. 2018). Based on NPV, B/C ratio, profitability index, and return-to-labour analyses, other studies confirmed that the coffee-based agroforestry practice is a financially attractive enterprise in Nepal (Acharya and Dhakal, 2014; Pandit et al. 2015; Sharma et al. 2016a) (Table 21.2).

In the case of fodder-based agroforestry, studies confirmed that such a system can generate more income than conventional farming. Neupane and Thapa (2001) revealed the farm production to have increased by 90% and 72% in rainfed (Bari) land and irrigated (Khet) land respectively, compared to conventional agriculture. Pandit et al. (2014) also witnessed from the mid-hills of Nepal that the introduction of fodder trees increased the livestock products—milk and meat.

Cedamon et al. (2019) reported the increase in household income from livestock keeping, ranging from USD 170 to USD 340, indicating an improvement in food security in the project area. Further, a study from Dhading District revealed an increase in fodder trees on diversified farmlands with an increase in farm income, and greatly saved women's time for fuelwood and fodder collection (Regmi 2003). Cedamon et al. (2019) in their study from Kavre and Lamjung confirmed that the food security index (FSI) of the project farmers improved by two- to three-fold due to timber (*Alnus nepalensis*)-based

Table 21.2 Financial suitability and profitability of dominant agroforestry practices in Nepal

S. No.	Land use types	Contribution to HH economy (%)	Return		Financial performance				Location	Sources
			Profit (USD ha ⁻¹)	Income (USD hh ⁻¹)	NPV	B/C ratio	R-to-L	PI		
1	Coffee-based AF	5–25	373.30–1515.60	892.30	589.9	1.5–3.8	3.82	1.23–1.47	Mid-hills Districts of Nepal (<i>Parbat, Kavre Palpa, Gulmi, Syangja, Lalitpur, and Arghakhanchi</i>)	Bhattarai et al. (2020), Sharma (2016), Sharma et al. (2016a), Pandit (2008), Acharya and Dhakal (2014), Karki et al. (2018), Pandit et al. (2015), Tuladhar and Khanal (2018)
	Agriculture		373.30	754.7	350.9		3.67			
2	Cardamom-based AF	45	2176.4–3578.1	1771.0–1970.4		1.5–13.2			Mid-hills districts of Nepal (<i>Kavre, Gorkha, Lamjung, Bhojpur, and Dhading</i>) and <i>Rasuwa</i>	Pandit et al. (2018), Sharma et al. (2007), Kalauni and Joshi (2019), Kafle and Pokharel (2017), Khanal et al. (2019), Neupane and Thapa (2002), Gilmour et al. (2014)
	Horticulture-based AF		2051.8			2.3				
	Fodder-based AF		1433.6			2.5				
	Leasehold AF	42		259.0						
	Ginger-based agriculture		1272.0			1.3				
	Chilli-based agriculture		1359.0			1.4				
	NTFP-based AF	18		314.0						
	Rainfed agriculture		728.9	899		1.8–1.9				

Note AF: Agroforestry; HH: Household; B/C: Benefit/Cost; R-to-L: Return to Labour; PI: Profitability Index
 USD 1 = NPR 116.24 (13 March 2021)

agroforestry. Using models, Rana et al. (2018) identified *A. nepalensis* as most suitable for agroforestry system in Central Nepal in moist northwest-facing slope whereas *A. nitida* as most suitable for systems in western Nepal. Dhakal (2013) suggested that timber (*Eucalyptus camaldulensis*)-based agroforestry could be a viable alternative to existing cereal-based agriculture in Terai; yet the upfront cost, a long wait until the harvest, and the need for more land have become major constraints to the adoption of this practice in Terai. Dhakal and Rai (2020) revealed the practice was favourable to large-scale farmers only since they can take the risk of the initial production loss resulting from land sparing between timber tree species and field crops. The smallholder farmers are risk-averse and therefore are not able to afford the initial loss. However, the scope of timber-based agroforestry in Nepal has widened in recent years. Nepal rural areas have witnessed the lack of labour force because of the increasing trend of male youths out-migrating for jobs, and agriculture is becoming increasingly feminized (Cedamon et al. 2017). In the context of labour scarcity being the major driver of land under-utilization and land abandonment, establishing timber-based agroforestry could be a potential solution for Nepal (Dahal et al. 2020).

Cardamom-based agroforestry is financially more attractive than other product-specific agroforestry practices (Sharma et al. 2007). Cardamom has been a sustainable source of household income for many smallholders of eastern mid-hills of Nepal, providing livelihood support to 21,960 households (Shrestha et al. 2018). About 45% of the total household income that a farmer can generate from cardamom-based agroforestry signifies how important the practice is for the rural household economy (Kalauni and Joshi 2019). The practice is considered a highly profitable farm enterprise as the benefit–cost ratio of this practice (13.2) was 7 times more than that of rainfed agriculture (1.9) (Sharma et al. 2007) (Table 21.2).

Pandit et al. (2018) conducted action research on agroforestry in two mid-hills districts of Nepal—Kavrepalanchok and Lamjung. Five different

product-specific farming systems, cardamom-based, fodder-based, banana-based, chilli-based, and ginger-based were promoted in the project sites. Based on the baseline and end-line data, the study revealed that the farm income in three years had increased by 11% whilst the off-farm income decreased by 9%. Cardamom-based agroforestry was found to be the most profitable (USD 2176.4 ha⁻¹ year⁻¹), followed by horticulture (banana)-based agroforestry (USD 2051.8 ha⁻¹ year⁻¹) compared to ginger- and chilli-based farming systems (Table 21.2). The percentage of food sufficient households increased by 17% and the percentage of households below the poverty line dropped by 14% after the project. Gilmour et al. (2014) reported that the household income of agroforestry farmers in Rasuwa district to have increased by 17% after the adoption of NTFP-based agroforestry. A study by Joshi (2015), based on the perception of respondents, revealed that most interviewed farmers were aware of the economic and environmental benefits of tree-based farming; they agreed with the statement that agroforestry enhances soil fertility, restores biodiversity, and avoids the risk of complete crop failure. In contrast, Neupane et al. (2002) revealed that farmers had a misconception that integrating trees with agricultural crops impacts the main crops and reduces yields, which is a barrier to agroforestry adoption.

Some studies have explored the contribution of forest-based agroforestry in reducing poverty. It is the Leasehold Forestry Program (LFP) of Nepal that initiated the forest-based agroforestry to serve the dual purposes of restoring the degraded forest and improving the livelihoods of poor households (Joshi 2015). The leasehold forest user group (LFUG) only promotes the types of agroforestry such as fodder-based, horticulture-based, and NTFP (broom grass)-based that improve the condition of forests. Kafle and Pokharel (2017) reported an annual household income of USD 259 from leasehold agroforestry in the LFP pilot area. Khanal et al. (2019) revealed that leasehold agroforestry covered 42% of the total household income of LFUGs in the Gorkha district. Ohler (2000)

reported that the annual income of leasehold forest users increased by 25% whilst the non-users witnessed a decline by 4% in their annual earning. Shono et al. (2014) documented the impact of leasehold agroforestry that the proportion of poor households having food sufficiency less than three months in 2006 had decreased from 41 to 19% in 2013. Such a visible improvement in their livelihoods has resulted in multiple co-benefits, for example, decrease in time required for fuelwood/fodder collection, farmers' involvement in income generating activities, literacy class attendance, and capacity building training (Kafle and Pokharel 2017). An increase in fodder production brought multiple benefits to leaseholders. One visible benefit was that it discouraged open grazing and farmers started stall-feeding, which brought other benefits such as reduced pressure on the forest, increased farmyard manure supporting soil fertility maintenance, and increased livestock number contributing to household income (Shono et al. 2014).

21.3 Agroforestry as a Land Restoration Strategy

Agriculture is a prime driver of global land degradation. The increased use of pesticides and chemical fertilizers in modern agriculture aiming at increasing global food production to meet the demand of increasing population has deteriorated soil ecology and soil health. Cultivation on sloping lands in mountainous areas of Nepal has accelerated soil erosion, leading to hazardous downstream effects such as flooding, siltation, and a higher concentration of nitrogen (N), phosphorus (P), and potassium (K) in water bodies causing acidification and eutrophication (Dahal et al. 2007). Intensive use of land resources has discouraged nutrient cycling, enhanced GHG emissions, and declined agricultural land productivity. The need for more food and other household demands has resulted in deforestation and forest degradation calling for implementation of land and forest restoration activities. Based on decades of research,

scientists have concluded that agroforestry is one of the best land restoration strategies (van Noordwijk et al. 2020). A plethora of literature supports the argument that agroforestry provides numerous environmental benefits such as soil erosion control, soil fertility improvement, water quality improvement, biodiversity conservation, provision of ecosystems services, and climate change mitigation by C sequestration (Jose 2009; Nair and Garrity 2012; Sharma et al. 2007; Shin et al. 2020) (Table 21.3). The tree component of agroforestry by adding organic matter (OM), which turns into soil nutrients after decomposition, helps improve soil health and maintain land productivity.

Schwab et al. (2015) found that soil OM, N, and P were higher in mature agroforestry (15-years-old fodder-based) than in conventional agriculture in Nuwakot, a mid-hills District of Nepal. However, Neupane and Thapa (2002) in Dhading District in central mid-hills found no significant differences in the amount of soil OM, pH, N, P, and K between agroforestry and conventional agriculture. The plausible reason for such difference might be that the agroforestry in the latter study was at the early stage of implementation (six years only). Studies indicate that a visible change in these nutrients due to the practice of agroforestry occurs only slowly and can take at least 15 years to detect, depending on the types of tree species and soils (Clark et al. 1998; Schwab et al. 2015). Except for N, Pandey et al. (2019) found the amounts of P and K to be higher in an agroforestry system with neutral pH than in agricultural soil with slightly alkaline pH. Sharma et al. (2007) compared the role of four land-use systems in soil and water conservation and found that the soil loss from cardamom-based agroforestry was significantly lower than the other three land-use systems: forest-based and horticulture-based agroforestry and rainfed agriculture. In terms of water conservation, the water retention capacity of cardamom-based agroforestry was 86 times higher than that of rainfed agriculture.

Agroforestry is not only a farm enterprise but also a forest enterprise in Nepal. There are examples of agroforestry well-adopted by forest

Table 21.3 Land restoration potential of agroforestry in Nepal

Land use types	Soil attributes					Soil and water conservation		Location	Sources
	OM (g kg ⁻¹)	N (g kg ⁻¹)	P (mg kg ⁻¹)	K (kg ha ⁻¹)	pH	Soil loss (kg ha ⁻¹)	Water retention (%)		
Fodder-based AF	18.6–26.4	0.9–1.3	73.8	130.2–152.5	4.83–7.05			Central and eastern mid-hills Districts and Terai (<i>Dang</i>)	Neupane and Thapa (2002); Schwab et al. (2015); Pandey et al. (2019); Sharma et al. (2007); Dahal et al. (2007)
Transition to AF	17.5	1.2	46.1		4.40				
Rainfed agriculture	15.3–24.7	0.7–1.3	48.2	123.4–120.9	4.30–7.53	477–1260	83–90.5		
Grasslands	27.8	1.4		144.4	7.47				
Cardamom-based AF						30–450	86–97.8		
Horticulture-based AF						145	95.2		
Coffee-based AF	34–72				5.4–6.0				
Forests						74	94.4		
Bare land						3460	26		

users in leasehold forests. About 43,993 ha of degraded forest has been reforested with agroforestry (horticulture-based, fodder-/forage-based, and NTFP-based) under the leasehold forestry program (Kafle and Pokharel 2017). These agroforestry practices have remarkably rehabilitated the degraded forests and improved the livelihoods of poor forest users (Appanah 2016). The degraded forests have improved their quality in terms of vegetation coverage and biodiversity. Ohler (2000) reported that vegetation coverage has changed from 32 to 90% due to agroforestry adoption, followed by grazing control in the forest. FAO (2013) mentioned that 57% of the leasehold groups perceived an increase in vegetation and reoccurrence of many birds, reptiles, and mammals in the forest. The ground coverage also changed from 10–20% to 70–80% (SEEPOR 2014). Such changes have reduced the soil and water run-off, contributing to checking soil erosion and OM retention and nutrient recycling.

21.4 Agroforestry as a Climate Change Mitigation and Adaptation Strategy

Agriculture contributes 10–12% of global GHG emissions and 13–18% if indirect sources are included (Maraseni et al. 2018, 2020). In the context of global efforts to mitigate climate change by reducing atmospheric GHG not being so effective, agroforestry has come front due to its unique capability to combine twin objectives of mitigation and adaptation. Recent studies on agroforestry across the globe under diverse ecological conditions emphasized that it has the potential of storing C in above- and below-ground biomass (Dhyani et al. 2016; Feliciano et al. 2018; Kim et al. 2016) and dramatically reduced farm inputs attributed to GHG emissions (Maraseni et al. 2011). However, the sequestration potential largely depends on the types and age of agroforestry, climate, previous land use, type and density of tree species, and tree management. Feliciano et al. (2018) found that the silvopastoral system sequesters more soil carbon,

whilst more above-ground C sequestration occurs in improved fallows. The total C (both biomass and soil) was found greater in agroforestry systems in the tropics than those in other climates. The global estimates for C sequestration rate in agroforestry systems across climates range from 0.29 to 15.2 t ha⁻¹ year⁻¹ (Nair et al. 2010). The sequestration potential—both the biomass carbon and SOC—of various agroforestry practices in Nepal and some other selected countries is presented in Table 21.4.

Deforestation and forest degradation releases about 5–9 GtCO₂e (10–18%) of anthropogenic emissions of GHGs annually (Maraseni et al. 2019). Agroforestry is considered as one of the main options to check deforestation and degradation, thus contributing to the reduction of GHG emissions from the forest. There are two more ways that agroforestry can contribute to the global C emissions reduction efforts. One is through the direct accumulation of atmospheric C in tree biomass—both above- and below-ground—and the other is through the accumulation of OM into the soil as soil organic carbon (SOC) (De Stefano and Jacobson 2018). Therefore, agroforestry can be a better choice for afforestation and reforestation programs to restore forest landscape. There is no trade-off between ‘tree production’ and ‘crop production’ in the agricultural landscape and in fact they produce a win-win solution.

Irrespective of the types, the agroforestry system has the potential to store more SOC than conventional agriculture. Within the variants of cardamom-based agroforestry system, the *Alnus-cardamom* stands showed the highest C stocks followed by forest-cardamom and *Albizia-cardamom* stands (Sharma et al. 2007). Pandit et al. (2013) reported a total of 48.7 tCha⁻¹ in mid-hills fodder-based agroforestry system. Bajracharya et al. (2015) found that leasehold agroforestry system had more SOC than conventional agriculture. In a study from the eastern mid-hills of Nepal, Sharma et al. (2007) reported that the SOC was 3.5 times more in cardamom-based agroforestry than in rainfed agriculture. The capacity of agroforestry to store SOC varies with its types. Magar et al. (2020) studied three

Table 21.4 Carbon sequestration potential of agroforestry in Nepal and some other selected countries

Regions	Land use types	Biomass carbon stock (t ha ⁻¹)	Soil organic carbon (t ha ⁻¹)	Sources
West Africa	Fodder bank AF	0.29		Nair et al. (2009)
Ethiopia	Parkland AF	59.65	51.31	Tsedeke et al. (2021)
Ecuador/Costa Rica	Silvopastoral	41–173		McGroody et al. (2015)
Philippines	Multistory AF	92–174		Labata et al. (2012)
Indonesia/India/Sri Lanka	Home garden	36–145	38.81–60.38	Saha et al. (2009), Subba et al. (2018), Mattson et al. (2013), Roshetko et al. (2002)
Indonesia	Agroforest	287.9		Eutis (2003)
India	Poplar-based AF	97.30		Sarangle et al. (2018)
Nepal				
Central mid-hills	Fodder-based AF	48.7		Pandit et al. (2012), Dahal et al. (2014)
	Coffee-based AF	0.33–0.46		
Central mountain region	Fodder-based AF		24.41	Bhatt (2013)
	Homestead AF		20.89	
	Forests		36.31	
Eastern mid-hills	Cardamom-based AF	15.54–128.3	65.27–121.00	Zomer and Menke (1993), Sharma et al. (2007), Shrestha et al. (2006)
	Rainfed agriculture	9.28	12–38	
Central terai	Agroforest/woodlot		19.55	Magar et al. (2020)
	Home garden		24.94	
	Silvopasture		30.25	

tropical agroforestry systems and found that the silvopastoral system had a higher amount of SOC than the other two, agroforest/woodlot and home garden. More SOC was reported in fodder-based agroforestry than in traditional homestead agroforestry in Rasuwa District in central high hills (Bhatt 2013).

The impact of climate change on agriculture has become obvious in recent years. Climate change is expected to reduce global crop yields (Ray et al. 2019). Like elsewhere, Nepalese farmers have experienced decreased farm production due to extreme weather events (EWEs) such as cold spells, floods, and heat waves (Budhathoki et al. 2020). The impact of EWEs is not confined to crop yields only; its long-term consequences are related to damages to water sources, ecosystems, biodiversity, and human health and wellbeing. In developing countries like

Nepal where farmers are unable to afford advanced technologies to cope with EWEs, there is a need of locally available and affordable adaptation strategies to reduce the economic, social, and ecological risks due to such EWEs. Out of many locally affordable adaptation strategies such as changes in farm management and landscape, seeking off-farm employment, emergency management planning, purchasing crop insurance, and the raising of awareness (Biggs et al. 2013; Adhikari et al. 2018; Budhathoki et al. 2020), the change in agriculture landscape by introducing trees on farm could address the climate risks more holistically. Agroforestry can be an effective coping strategy by providing farmers with timber, fuelwood, fruits, and other AF products to sell in the market when agricultural crops are lost due to floods and drought (Quandt 2020). For many reasons, agroforestry can be a

better land-use option to increase the adaptive capacity of farmers and make them less vulnerable to climate variability and change. First, the deep root system of trees helps go deeper into the soil for water and nutrients which can help agricultural crops during droughts. Second, agroforestry increases soil porosity and soil cover and decreases runoff, which promotes water infiltration and retention in the soil, contributing to water stress reduction during low rainfall seasons (Apuri et al. 2018). Third, tree-based farming systems are more diversified and therefore, less risky than other agricultural land uses because of a variety of products, which reduce the likelihood of complete crop failure (Kebebew and Urgessa 2011). Fourth, trees possess the capacity to adapt to a wide range of ecological conditions as demonstrated by *Eucalyptus* species, *Acacia nilotica*, *Dalbergia sissoo*, and *Terminalia arjuna* in Mwanga District of Tanzania (Charles et al. 2013).

The above studies from Nepal and from other countries signify the importance of agroforestry for global emission reduction efforts and as an adaptation strategy. However, due to lack of data about the total land under agroforestry, it is hard to estimate the actual contribution to climate change mitigation. If the abandoned land, which is now mostly covered with invasive plants (Jaquet et al. 2015), is to be brought under agroforestry, a huge amount of C can be stored both in biomass and soil. Therefore, if properly designed and carefully implemented, an agroforestry system could be more profitable than either tree or crop monoculture-based system. Including C benefits, through REDD+, into an agroforestry system further increases its profitability (Holmes et al. 2017; Sharma et al. 2016b).

agroforestry promotion in Nepal. Most farmers in Nepal are smallholders and therefore are inclined to subsistence farming. One of the fundamental requirements for transition from subsistence to market-oriented livelihood is the availability of enough land so that farmers can take risk of adopting a new farm technology. Dhakal and Rai (2020) concluded from a study in Dhanusha District in Terai that timber-based agroforestry is purely the affair of large-scale farmers who can afford the initial loss in farm production. This conclusion has been supported by many other studies. Neupane et al. (2002), Dhakal et al. (2015), and Cedamon et al. (2018) all reported that the farmland size was the most influential factor for deciding agroforestry adoption in both hills and Terai of Nepal. Similarly, Bhandari et al. (2021) found that middle-class households are more likely to grow more trees on their farmlands than poor households.

Land tenure is not an issue when it comes to agroforestry adoption in Nepal since the practice of renting land for raising crops is insignificant. However, empirical studies carried out elsewhere suggest that land tenure plays a crucial role in farmers' decision about adoption of agroforestry. The probability of adoption increases when farmers have a secured land tenure (Nkomoki et al. 2018; Jha et al. 2021; Lawin and Tamini 2019). In Nepal, there are two types of land tenure in case of agricultural land: private ownership and tenancy (leasehold). However, renting farmland is not a dominant form of land tenure since most landowners prefer to cultivate their farmlands themselves (Dahal et al. 2020). Therefore, there have been no studies carried out so far looking into the effects of land tenure in agroforestry adoption decisions in Nepal.

21.5 Constraints to and Opportunity for Agroforestry Promotion in Nepal

21.5.1 Constraints

21.5.1.1 Land Size

Agroforestry cannot be imagined without land. The land has become a major constraint to

21.5.1.2 Ambiguity in Policy

Agroforestry combines two or more subsectors together: forest, agriculture, and livestock. Until 2019 when there was no separate policy on agroforestry in Nepal, farmers would face difficulties whilst selling tree products in the market. Lack of a clear policy created problems in the transportation of farm-grown trees and non-timber forest products (NTFP) independently

and in the promotion of agroforestry in the country (Maraseni et al. 2008; NAFP 2019). For example, all the tree-based products—either farm-grown or harvested from the forest—would then be treated as forest products and come under the jurisdiction of the Department of Forests. Farmers had to follow the prevailing forestry rules for their product harvest, sale, and distribution, which was cumbersome. There was a series of bureaucratic formalities to follow by farmers from the raising of trees to harvesting and post-harvesting. The rent-seeking government officials would make the bureaucratic formalities further complicated. Unlike tree-based products, there were no such legal formalities for agricultural and livestock products. As a result of such an ambiguous policy in place, agroforestry could not get momentum in the past. Now the Nepal Government has endorsed a new agroforestry policy, but it will take time to realize the policy impacts at farm levels.

21.5.1.3 Lack of Market Infrastructure

Farmers are encouraged to adopt a new farm enterprise when there exists a secured market. A fluctuating market creates doubt in farmers about the sustainability of such an enterprise. For example, cardamom is a high-value agroforestry product, and it constitutes 5% of total exports from Nepal. However, the poor market infrastructure constrains the expansion of such a promising farm enterprise. Acharya et al. (2021) reported that no mechanism is in place for connecting the cardamom producers with the consumers; it is a middleman who establishes a linkage with market centres and makes most of the profit from the trade. Some other market-related constraints include limited access to Indian transport infrastructure and a lack of accredited laboratories and warehouses for storage (Acharya et al. 2021). The ever-fluctuating market price for this agroforestry product is another reason stopping it from expanding further (ICIMOD 2019). The middlemen's dominance also prevails in timber trading. Dhakal (2013) reported that the *Eucalyptus* poles, which farmers produce on their private lands, were traded through the middlemen, who determine

the price on a per-tree basis, not on a volume basis by considering all the seen and unseen costs associated with the timber trade. They also take advantage of the ambiguous policy about the forest products produced on private land whilst determining the farmgate price. Proximity to road heads plays a crucial role in the adoption decision of farmers. A study by Dhakal et al. (2012) found that the households living close to the main highway were more likely to promote horticulture-based agroforestry than those having limited access or no access to the road heads. The NAFP (2019) highlights the lack of a market with attractive prices for agroforestry products as one of the bottlenecks for the expansion of agroforestry in the country.

21.5.1.4 Lack of Institutional Set up for Agroforestry Research and Development

Although agroforestry has been practised since ancient times in Nepal, as of now this practice has not gained proper importance due to dependency on multi-institution and multidisciplinary approaches. There are institutions—both government and non-government—involved in agroforestry research and development. However, the efforts made are scanty and mostly donor driven. The impacts of donor-funded projects are short-lived in many instances. There are examples of farmers discontinuing agroforestry after the project phases out in many African countries (Adesina and Chianu 2002). Nepal's experience is no different. It is not that there were no successful models of agroforestry developed in Nepal. The irony was that the successful models were not replicated or scaled up (NAF 2005). The reason may be the lack of institutional support, arising from the ambiguity amongst the government stakeholders (agriculture, forest, and livestock) about who the responsible body is for the extension and promotion of agroforestry in Nepal. Even though the NAFP-2019 has attempted to avoid ambiguity, the National Forest Policy (NFP)-2018 has created confusion by recognizing agroforestry, private forestry, and family forestry as separate entities.

21.5.1.5 Lack of Awareness/ Knowledge/Skills on Agroforestry Management

Lack of knowledge and skills in farmers about agroforestry management is another hurdle to its expansion and promotion in Nepal. Farmers have a misconception about agroforestry. They believe it reduces farm production because of the shading effect and sharing of nutrients. They are unaware that it increases total farm production with numerous co-benefits, which ultimately enhances the farm yield (Neupane et al. 2002). Many authors confirm that agroforestry adopters had better agroforestry knowledge and skills than non-adopters (Neupane et al. 2002; Dhakal et al. 2012, 2015; Dhakal and Rai 2020). They revealed that the likelihood of agroforestry adoption increased with an increase in the level of agroforestry-related knowledge and skills. Numerous studies are there from other parts of the globe that support the above argument (Adesina and Chianu 2002; Mwase et al. 2015; Oino and Mugure 2013).

21.5.1.6 Lack of Access to Credit Facility

Unlike agriculture and livestock, tree crops were not considered collateral to get loans from the bank, and there was no provision of insurance for the tree crops. As a result, farmers were reluctant to adopt agroforestry. These barriers have been addressed by the agroforestry policy-2019, which clearly states that farmers can get loans with their tree crops as collateral, and there is an insurance guarantee for the tree crops. The impact of the policy, however, is yet to be realized at the implementation level.

21.5.1.7 High Initial Investment and Transaction Costs

Despite the attractive returns from agroforestry systems, smallholders still prefer the crop-based farming in Nepal. The initial cost of some agroforestry models such as timber-based agroforestry is higher and allocating land for such land use involves opportunity costs (Dhakal 2013). Due to this high upfront cost, smallholders are reluctant to

agroforestry adoption (Cockfield 2005). There are other unseen costs involved due to Nepal's complex harvesting and transportation rules for tree products. The rent-seeking government officials take advantage of such complex rules (Acharya et al. 2021). In addition, the involvement of multiple government departments (forests, agriculture, transport, local government, etc.) in the release and transportation of tree products creates more hassles and thus transaction costs increase.

21.6 Opportunities

21.6.1 Land Abandonment

Even though land abandonment is not a recent phenomenon in Nepal, the rate of abandonment has drastically increased in the last ten years due to labour scarcity resulting from male youths out-migrating for jobs (Dahal et al. 2020). MoALD (2019) reported that of 4.1 M ha of arable land, a total of 1.03 M ha has been left uncultivated. The abandoned land has been converted into shrubland, grazing land, and grassland. Most of the uncultivated land is covered with invasive plant species, indicating severe land degradation (Jaquet et al. 2015). Farmers now are searching for options that can rehabilitate the fallow land and are less labour-intensive at the same time. The land once a limiting factor for agroforestry practice is now available in the form of abandoned land, which is an opportunity for agroforestry promotion in the country. Dahal et al. (2020) recommended several suitable agroforestry options such as fodder/timber-based agroforest/woodlot, cardamom-based agroforestry, and NTFP (broom grass)-based agroforestry to revive the abandoned land. Farmers opine that these options are less labour intensive than conventional agriculture.

21.6.2 Scope of Carbon Credits Under the Market-Based and PES Mechanisms

Agroforestry is a globally accepted climate change mitigation and adaptation strategy. The

agroforestry farmers can benefit by selling the carbon stored in trees and soil. The carbon sequestered under this land-use system can be traded in the international markets. Some market-based mechanisms such as Reducing Emissions from Deforestation and Forest Degradation (REDD+) and voluntary C markets have recognized agroforestry as eligible land use for C credits (Holmes et al. 2017; Maraseni and Reardon-Smith 2019; Sharma et al. 2016b). In addition to possibility of international trade of carbon, the Forests Act-2019 of Nepal has provisioned payments for environmental services (PES) from trees in its Article 44. According to the article, the private tree growers are eligible to claim for dividends for environmental services including C sequestration if they complete the prescribed conditions (MoFE 2019). This provision could be a motivating factor for farmers to shift to agroforestry from modern intensive agriculture.

21.6.3 Favourable Policy

Even though there still exists ambiguity in forest policies, the formulation of separate agroforestry policy has created a favourable environment for agroforestry promotion in the country in many ways. The policy has identified agroforestry as a potential land-use system for addressing the abandonment issue in the country (NAFP 2019). The policy is also an attempt to address the policy ambiguity about farm-grown tree products. It has created a favourable environment for farmers who wish to adopt agroforestry by provisioning insurance guarantees for tree crop damage or loss. It has emphasized market infrastructure development and physical infrastructure development for the commercialization of agroforestry. Some other provisions such as tree crops as collateral for bank loans, exemption of interest until the harvesting of the crops and exemption of loan at the time of natural disaster favour the farmers willing to adopt agroforestry.

21.6.4 Agroforestry Under the Community-Based Forest Management (CBFM) Regime

There is growing evidence that in some circumstances, agroforestry is more profitable than forestry and agriculture alone and has the potential for providing several social and environmental benefits to farmers and society (Phimmavong et al. 2019). The forest users can take more benefits from their community forests and leasehold forests by introducing agroforestry. The prevailing forestry rules of Nepal allow forest users to plant perennial tree crops in the forest.

It is estimated that the potential community forest area is 5.5. M ha, out of which only 2.3 M ha of forest have come under the CBFM regime (Pathak et al. 2017). There is ample opportunity of putting different types of agroforestry into practice in these areas. The adoption of agroforestry under the CBFM not only increases the overall forest productivity but also generates employment for forest users.

21.7 Way Forward/Conclusion

Agroforestry has gained worldwide recognition as a sustainable land-use practice, with demonstrated positive impacts at various spatial scales. The reported impacts include—increased farm productivity, increased soil fertility, decreased soil erosion, and enhanced biodiversity at the local scale, decreased downstream impacts (flood control, low concentration of Nitrogen, Phosphorus and Potassium in water bodies) at the regional scale, and increased biomass carbon and soil organic carbon contributing to climate change mitigation at the global scale. These multiple financial and environmental benefits positively contribute to many sustainable development goals. However, it had not received proper attention from the Government in Nepal until the National Agroforestry Policy-2019 was endorsed.

Nepal's policy environment has improved after the endorsement of the National Agroforestry Policy in 2019 and has become more favourable for agroforestry promotion and expansion. The policy has pointed out the way forward for the development and research of such promising land use. However, unfavourable legislation and regulations that contradict the agroforestry policy must be amended. Agroforestry needs to be mainstreamed in all sub-sectors, forests, agriculture, and livestock. A co-ordinated effort is required to motivate forest user groups for agroforestry adoption in community forests and leasehold forests. A robust institutional setup is necessary at all levels—from central to local—that could establish coordination with researchers, farmers, extension workers, and industries in relation to information sharing and technology and knowledge transfer. Since Nepal has diverse climatic situations, soil types, and socio-economic conditions, location-specific and economically viable agroforestry models need to be developed. Agroforestry has the enormous potential for augmenting environmental and ecosystems services. These services should be quantified and monetized so that more farmers are attracted to agroforestry adoption. Farmers' profits could be maximized by selecting and practising appropriate agroforestry models and involving farmers in a simplified (low transaction cost) carbon crediting mechanism such as REDD+. In promoting market-oriented agroforestry practices, attention must be paid to ecological sustainability of the agroforestry systems.

Even though the new agroforestry policy is an encouraging news for farmers, the division of the same land use into three categories as private forest, agroforest, and family forest by the National Forest Policy-2018 has created some confusions amongst farmers. In substance, there is no difference amongst these three as they are all associated with agriculture in one or the other way. Therefore, bringing the other two entities (family forest and private forest) under the agroforestry sub-sector could help avoid further ambiguity. Mapping agricultural lands suitable for growing trees under agroforestry systems

would help to scale agroforestry across the country. Towards this end, Ahamad et al. (2021) modelled and mapped cropland areas suitable for planting trees in agroforestry systems in Nepal for the first time across the country. Their study revealed that 83% of rainfed cropland areas exhibit more than 60% tree suitability, which could be harnessed for scaling of agroforestry practices.

Despite good returns, smallholders are however still resisting improved agroforestry systems given the high upfront and transaction costs, lack of enough land, lack of market infrastructure, and ambiguous policy. Amongst these constraints, land is the prime factor stopping smallholder farmers from adopting agroforestry. Collective farming could be an option to address the land issue and engage them in tree-based farming. Also, the government can facilitate formulating a policy in smallholders' favour to secure use rights to the abandoned farmland. Above all, there is a need for a more comprehensive analysis of the key impediments to promoting agroforestry system considering a wide range of options (social, financial, technical, market) to address these issues.

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Part IV

Cross-Cutting Topics

Achieving Water, Energy, and Food Security in Nepal Through Nexus Approach to Planning and Development

22

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Abstract

Nepal's agriculture sector contributes 29% to national GDP and provides employment to about 60% of the labor force. The agricultural development planning in the country follows the sectoral or silo approach failing to understand and adopt the intricate nexus relationship and linkages among water, energy, and food (W–E–F) production and the protection of environment. This paper identifies problems and causes of low agricultural productivity and demonstrates that abundant water resources are available for irrigation of existing rainfed lands to increase agricultural productivity and meet multi-sectoral energy

requirement of the country. It presents three case studies on the application of the nexus framework to improve W–E–F productivity. The first two pertain to multipurpose development projects under construction phase in Nepal while the third pertains to greenhouse gas emissions reduction through conservation agriculture-based sustainable intensification at field level across the Eastern Indo-Gangetic Plains, including two Terai districts of Nepal. The paper provides a perspective on the importance of W–E–F nexus as an integrated planning framework to address the integral issues and achieve the SDGs by developing countries. It argues that the developing countries whose economies are primarily dependent on the natural resources cannot afford to ignore the W–E–F nexus framework to meet the growing needs of water, energy, and food and the sustainability of the natural resource base for the current and future generations. It further discusses the necessity of the nexus perspective for the sustainable development of Nepal where water resources are central for the generation of energy and development of irrigation infrastructures to increase food production. This enhances a circular relation among the nexus elements in which water becomes the key and central element that drives the circularity of the nexus. This is critically important for Nepal because water is the only abundant resource available that must be utilized effectively integrating the

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development of hydro-energy, irrigation infrastructures, flood control, and human and industrial consumptions.

Keywords

Water–energy–food nexus • Nexus planning framework • Multipurpose development projects • Climate smart technology • TBM technology

these resources by strengthening synergies and reducing trade-offs among these interconnected sectors (Hoff et al. 2011; FAO 2014; Cairns and Krzywoszynska 2016). When it comes to mobilizing global political will—the UN’s post 2015 agenda and the post Rio + 20 process of formulating the Sustainable Development Goals (SDGs)—water, energy, and food securities play a critically important role.

22.1 Introduction

22.1.1 Water–Energy–Food Security: Global Scenario

Due to rapid population and economic growths in combination with accelerated urbanization and changing lifestyles, demand for water, energy, and food is rapidly increasing and the natural resources to support such demands have been continually shrinking (Boas et al. 2016; Benson et al. 2017). Currently, 70% of global water usage is consumed by agriculture and 30% of global energy by food production and supply (Kurian 2017). With the global population projected to reach 9.8 billion by 2050, the global demand for food, energy, and water is projected to increase by 35%, 50%, and 40% respectively by 2030 (Rasul 2016; Pandey and Shrestha 2017) and 75%, 60%, and 20%, by 2050 (Maraseni et al. 2020). At the same time, the global water cycle is changing in response to global warming caused by climate change, though the effects are expected to vary across countries and seasons. The interlinkages between these areas further complicate the matter of addressing the growing demands of water, energy, and food. Long-term, optimal, sustainable allocation and management of these resources requires a more holistic approach that considers all stakeholders and the associated interdependent systems, such as energy costs, water and carbon footprints, and tradeoffs of water allocation between sectors (agriculture, energy, and environment). Recently, W–E–F nexus has emerged as a dominant approach to secure the sustainable supply of

22.1.2 Water–Energy–Food Security: South Asia Scenario

South Asia is the most densely populated region with about one quarter of the global population but only 5% of world’s land resource (Rasul 2016). Given the huge population and relatively high population growth rate, and competing uses of available natural resources, South Asia will face an unprecedented challenge of food, water, and energy securities of much higher magnitude than elsewhere in the world. Consequently, the region may suffer from intra- and inter-country conflicts because of the interconnected trans-boundary river basin systems across countries. This suggests that countries in the region need to adopt the integrated W–E–F nexus approach to development planning that not only ensures the water, energy, and food securities for the people but also protects the larger landscape level ecosystems and maintains the resilience of these resources. Scholars have pointed out that ecosystem functions and services provided by mountains are central to food, water, and energy securities (Molden et al. 2014; Rasul 2016). Rasul (2016) suggested that the Hindu Kush Himalayas provide ecosystem services that are critical for water, energy, and agricultural productivity and sustainability in South Asia. Recent studies of the impacts of climate change on the water resources of Nepal’s river systems (Koshi, Karnali and Budhigandaki) have indicated that monsoon is the main hydrological driver of Nepal’s major river systems as it accounts for over 75% of precipitation and flows (Bharati et al. 2019; Pandey et al. 2020). These studies

have projected stronger monsoons with increased impacts and risks for monsoon-related disasters (landslides and floods) in the future. The findings of these studies will have significant repercussion for water resources, energy and irrigation infrastructure development planning and strategies within and across basins for sustainable utilization of water and land resources. This clearly means that the hydrology of the hills and plains, glacier ecosystem in the mountains, forest and watershed, and water resources in the landscape ecosystem need to be integrated into the W–E–F nexus development planning framework to ensure the sustainability of these resources and the services generated by them. The use of scientific and technological innovations for the optimal management of natural resources to keep them in healthy and resilient states and to increase the efficiency of their uses are the only options available today (Mushtaq et al. 2015). The *modus operandi* of the management of natural resources and their uses and the conceptual framework of resource planning and development strategy naturally requires a drastic change to address the issues of water, energy, and food insecurities in the context of climate change.

The objective of this chapter is to provide a perspective on the understanding and importance of W–E–F nexus as an integrated multi-sectoral development planning framework as against currently adopted sectoral framework to address the issues of food, water, and energy insecurities. Due to abundance of water resources available in the mountains of Nepal, the chapter focuses on Nepal by citing examples of high dam mega hydro-projects¹ for development of irrigation and hydropower infrastructures to increase agricultural productivity through increased irrigated area, increased energy availability for various sectors, and adoption of climate smart agriculture to minimize the negative effects of climate change on W–E–F nexus.

22.2 Understanding Water–Energy–Food Nexus

From a systems perspective, W–E–F components are intimately and inseparably connected with each other. Water is required to grow food crops and produce hydro-energy; energy is required to move water, goods, and services across landscapes; and food is used to produce energy and vice versa. The inseparable intertwined interconnectedness and interactions among these components is known as the W–E–F Nexus (Scott et al. 2015; UN 2015; Albrecht et al. 2018). The fundamental aspect of W–E–F nexus framework is understanding the interdependencies and interactions among the components and how their interactions, in turn, impact food, water, and energy securities. Integrated planning and policy framework thus require an awareness and understanding of how these components intersect and interact, and why a greater coordination among them is necessary to achieve the SDGs in the backdrop of shrinking natural resources and climate change.

Increased availability of water causes the corresponding abundance of hydro-energy and vice versa because energy can extract water from surface and underground sources, move it from one place to another across landscapes, and be used for vast number of operations such as water purification for human consumption, and agriculture related heating and cooling systems, etc. This intricate nexus relationship among these resources did not come to the surface in the development planning framework of most countries in the past. Instead, a sectoral development planning approach has prevailed as a dominant framework. Very recently, the W–E–F nexus evolved to its prominence in policy and development discourses in the light of global environmental problems exacerbated by climate change (Scott et al. 2015; Simpson and Jewitt 2019). The global scarcity of water resource and massive growing demands for energy and food to meet the needs of ever-increasing global population necessitated the evolution of W–E–F nexus framework. As water resources become

¹ We consider any hydro-project that generates 300 or more megawatts of energy a ‘mega’ project.

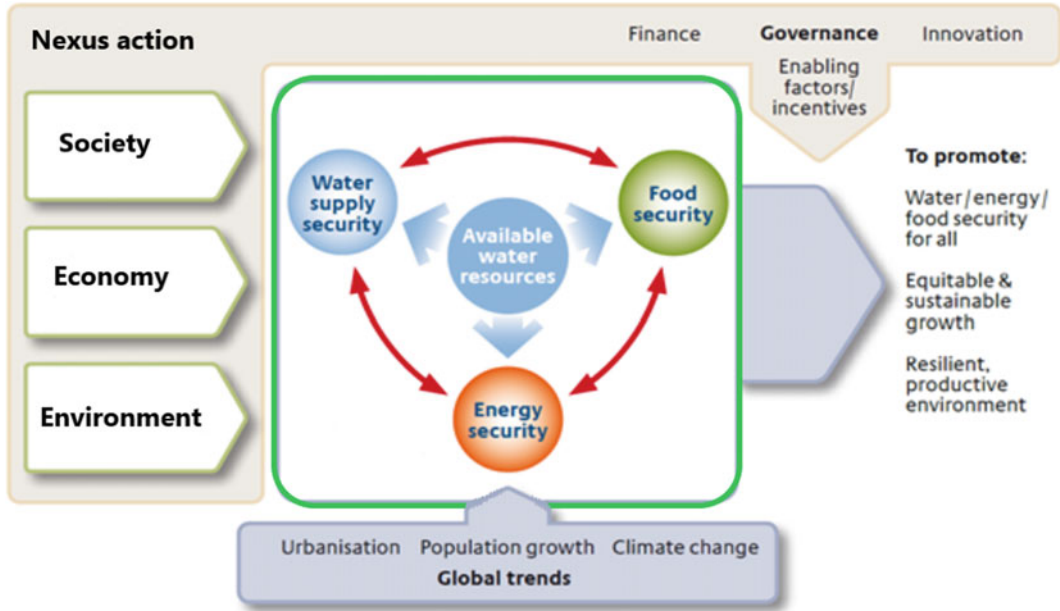


Fig. 22.1 Water–energy–food security nexus (Adapted from Hoff 2011)

scarce, they negatively affect energy and food production and adversely affect most of the SDGs; the decision-makers in all three sectors should focus on water resources management as part of the integrated policy and practices (UN 2015; Salam et al. 2017).

Scholars have pointed out that constant stocks of natural capitals (water, land, biodiversity, forest, etc.) are needed to meet the needs and aspirations of the present generation and to ensure a minimum degree of fairness and equity for future generations (Norton 1991; Daly 1993; Upreti 1994). The key benefits of W–E–F nexus approach can be perceived in terms of maintaining these natural capitals’ productivity, synergy, and the protection of natural ecosystem which is essential to accomplish the SDGs and ensure equity and fairness for future generations. Identifying the interrelationship among these components is of great importance to achieve synergies and avoid potential tensions. Figure 22.1 exhibits the intricate linkages among these critical components requiring an integrated approach to ensure water, energy, and food securities and achieve sustainable development worldwide. One important component that is often ignored in the

discussion of W–E–F nexus is the environment and the ecosystem which play fundamental role in the nexus and therefore should not be left out from the nexus perspective (Molden et al. 2014).

22.3 W–E–F Nexus Framework in the Context of Nepal

In the sectoral development planning in Nepal, water resources are used to generate hydro-energy without considering the development of irrigation infrastructures for food production, water supply for human consumption, and flood control, etc. Nepal government should consider integrating irrigation, drinking water, and flood control infrastructures in the design and construction of high dam reservoir hydro-energy development projects. Development of irrigation infrastructures can irrigate thousands of hectares of agricultural lands with relatively less capital investment, thus substantially increasing the food production in the country. This will greatly motivate the participation of farming community in the watershed and environmental management. With W–E–F nexus framework, it is

possible to design multipurpose development projects integrating hydro-energy and irrigation infrastructures (Devkota et al. 2020). The hydro-energy can be used to move water resources across the landscape for irrigation and human and industrial consumption. Rationale behind such development planning is to harness the synergy created by the integration of W–E–F nexus relation.

Nepal, being a natural resource base economy, needs policy changes that address the complexity of the W–E–F nexus at all levels of their interconnections and interdependencies and the resulting synergy created by their optimal interactions to ensure sustainable food, water, and energy securities for an ever-growing population. While developing high dam reservoirs, hydro-energy must be interlinked with the development of irrigation infrastructures for food production and movement of water across landscape to meet growing demands of drinking water (e.g., recently completed Melamchi drinking water project for the people of Kathmandu) and industries. The W–E–F nexus framework however may face tremendous challenges in the adoption process from the development professionals who are more attuned to the traditional sectoral or silo development planning framework. This is especially true for Nepal where the practice of integrated development planning involving all stakeholders and interconnected sectors is almost non-existent (Aryal et al. 2021; Laudari et al. 2021). This prevailing practice and tradition must change and pave the way to W–E–F nexus framework. For this to happen, coordinated actions among and with the government agencies, non-government organizations and private sectors will be instrumental.

Nepal's major river systems and their tributaries originate in the snow capped mountains of Nepal Himalayas and the Tibet, the autonomous region of China. Though the hydrology of Nepal's river systems is primarily driven by the monsoon, it is equally important to recognize the value of glacier Himalayan ecosystems which will have far-reaching repercussions in the management of the Nepal's river systems (during dry season), watersheds, and vital natural

resources, seriously threatening the sustainability of ecosystem services critical for water, food, and energy securities in the country.

According to MoEWRI (2020), more than 225 billion cubic meters (BCM) of surface water is available every year in Nepal that can be used for the generation of much needed hydro-energy and irrigation infrastructures to increase agriculture productivity. However, due to non-uniform temporal and spatial distribution of the water resources, less than 10% of available water has so far been utilized in the country for irrigating agricultural lands (MoEWRI 2020). Generation of hydro-energy in the river basin and development of irrigation infrastructures to leverage the abundant available water resources provides the foundation for agricultural revolution that not only accomplishes the food self-sufficiency but also provides the basis for achieving economic and social prosperity of the country. Agriculture's contribution to Nepal's gross domestic product (GDP) can be increased significantly making agriculture a game changer in the country's development. To this end, we present below the current state of the art of Nepal's agriculture, development and use of water resources, potential for generating hydro-energy, and increasing agricultural productivity through irrigation infrastructures.

22.4 Current State of Nepal's Agriculture

Nepal's economy largely depends on around 29% of the GDP from agricultural sector, which also employs more than 60% of its population. Nepal used to be an exporter of grains four decades ago but now it has been importing cereal grains and various agricultural produces worth of more than 800 million USD annually from its neighboring countries (Bhattra et al. 2020). The production (yield) data of different agricultural commodities for 2010 and 2017 shows that their annual productivity has increased only little over the years with large gaps between potential and actual production (Table 22.1). The low productivity is due to several factors, the most

Table 22.1 Productivity gaps for selected agricultural commodities

Product	Unit	Potential production (yield)	Production (yield) in 2010	Production (yield) in 2017	Productivity gap
Fish	t/ha/year	10	3.6	4.5	>2.2 times
Timber	M ³ /year	13.4	0.33	—	>40 times
Paddy	t/ha/year	10–12	2.72	3.00	>3.3 times
Vegetables	t/ha/year	17	12.8	14	>1.13 times
Milk	lit/lactation	2000	900	1000	>2 times

Source Adapted and modified from ADS (2014): production data from 2010 reported by ADS (2014) were combined with the production data of 2017

Table 22.2 Irrigated and potentially irrigable land in Nepal

Category	Terai		Hills		Mountains		Total, ha ('000)
	ha ('000)	%	ha ('000)	%	ha ('000)	%	
Cultivated agricultural land	1,594	44.8	1,566	44.0	401	11.3	3,561
Potentially irrigable land	1,480	65.3	627	27.7	159	7	2,265
Present area irrigated							
<i>Surface water</i>	434		170		41		654
<i>Conjunctive use</i>	207		—		—		207
<i>Groundwater</i>	226		8				234
Total	866	79.8	178	16.4	41	3.8	1085
Remaining potentially irrigable land	613	51.4	448	38.5	118	10.1	1180

Source Adapted from DoI (2019), Irrigation Master Plan 2019, Department of Irrigation, Kathmandu

important of which is lack of year-round irrigation. The wide productivity gaps for different commodities however indicate huge potential for improvement.

Nepal's agriculture is predominantly monsoon dependent (approx. 75% of arable land) and the biggest bottleneck for increasing productivity is the lack of irrigation infrastructures, which can only partially irrigate the limited (25%) arable land annually (Table 22.2). Data in Table 22.1 reveal that there is an urgent need to accelerate the production of paddy, milk, fish, and timber with increased inputs and improved management practices. Until Nepal's monsoon dependent agriculture is not transformed into irrigated agriculture with the development of adequate infrastructures, the future of Nepal's agriculture and food security will always remain an enigma. Nepal's overall development depends on the agricultural development due to its multiplier

effects on other sectors including agro-based and cottage industries, tourism, and energy. Hence, the development of infrastructures for year-round irrigation becomes the central axis for the agricultural development in Nepal.

22.5 Potential for Increased Production and Revenue in Nepal

22.5.1 Currently Irrigated and Potentially Irrigable Lands

Table 22.2 depicts the currently irrigated and potentially irrigable lands for agriculture in Nepal. Total cultivated land across the three agro-ecological regions is about 3.56 Mha. The potential arable agriculture land is 2.26 Mha

(IMP 2019), of which only about half (1.08 Mha) has been currently partially irrigated if year-round availability of water for irrigation is considered. Bhattarai et al. (2020) estimated that even if half of the remaining unirrigated land (1.18 Mha) is brought under cultivation, it can provide 6-million jobs and generate revenue of more than one billion US dollar. Terai possesses half of the total cultivated and most of the irrigated (partially) land of the country. Total irrigated land in Terai is 0.87 Mha, of which surface irrigation covers 0.43 Mha and the consumptive use and groundwater cover 0.44 Mha. Likewise, total cultivated land in the hills and mountains is 1.97 Mha, of which only 0.17 Mha is currently partially irrigated as against 0.8 Mha potentially irrigable. If all potentially irrigable land (1.48 Mha in Terai and 0.8 Mha in hills and mountains) can be brought under year-round irrigation and improved production technologies are used, total food production in the country could be increased by 2.5–3 times with increased cropping intensity (CI) of 2.5 (Table 22.3). This will not only meet the food security of Nepal's 29 million people but will also contribute 2–3 billion US dollar to national economy annually. Terai agriculture alone can achieve food security and food self-sufficiency and export the surplus food grains to neighboring countries generating substantial amount of revenue (Table 22.3).

22.5.2 Groundwater Extraction for Irrigation

Table 22.2 depicts that there is more than 0.61 Mha of net irrigable land under rainfed agriculture in Terai alone (IMP 2019). Extraction of groundwater to irrigate this land requires tremendous amount of hydro-energy. Shrestha et al. (2018) reported that only a fraction of available groundwater (i.e., 1.4 billion cubic meter, BCM) is needed to irrigate the summer rice and winter crops and supplement water for the rainfed monsoon rice. This 1.4 BCM constitutes only 20% of total potential rechargeable water. There still exists a tremendous potential for groundwater irrigation of substantial land which receive only some seasonal surface irrigation bringing additional crops to be grown in winter and pre-monsoon summer season. With the provision of year-round irrigation through surface and groundwater (1) agriculture inputs such as chemicals (fertilizers, pesticides, herbicides, etc.), improved varieties, and management practices can be utilized to their full potential; and (2) crop yield and CI can be increased significantly. Likewise, it is feasible to develop irrigation infrastructure to bring 0.56 Mha of currently rainfed land under year-around irrigation in hills and mountains which can increase production by at least two and half times. With

Table 22.3 Potential yield gains in rice and wheat with groundwater irrigation of 0.61 Mha in Terai currently grown as rainfed (revenues are calculated based on the prices of rice and wheat in 2017)

Crop	Rainfed yield (t/ha)	Irrigated yield (t/ha)	Additional yield with irrigation (t/ha)	Additional production with irrigation (1000 MT)	Current revenue (NPR millions)	Revenue with irrigation (NPR millions)	Additional revenue (NPR millions)
Summer Rice	0	3.9		2391	0	112,200	112,200
Monsoon Rice	3.3	3.9	0.6	368	127	150,000	23,000
Winter Wheat	0	2.9		1778	0	85,000	85,000
Total				4537	127	347,200	220,200 2.2 billion USD

If 50% of revenue (2.2 billion USD) is allocated to the production cost, the net benefit = 1.1 billion USD

Source Adapted from Shrestha et al. (2018)

the CI of 2.5, the potential cereal production would be at least doubled amounting to 4.8 million metric tons.

However, the extraction of groundwater requires tremendous amount of energy and reliable access to it. Such energy can potentially come from hydro-energy, which is expected to be about 3000–3500 MW in the next three years (MoEWRI 2020). A rough estimate of 15 MW of energy per day is required to pump 1.4 BCM water to irrigate the potentially irrigable land in the Terai where groundwater is available in plenty at shallow depth (Haavisto et al. 2018; Nepal et al. 2019). Extraction of groundwater by electricity powered tube-wells in the Terai can have significant impact in bringing the arable rainfed land under cultivation of rice and high value crops including vegetables during pre-monsoon summer and wheat during winter. It is reported that there are roughly 120,000 farmer-owned shallow tube wells in the Terai, but they all run on diesel. Given the high cost of diesel, it does not make economic sense for farmers to transplant paddy using diesel pumps (Waterscapes 2021). It is argued that if those 120,000 tube-wells in the Terai were connected to the electricity grid or solar panels and were getting reliable electricity supply for at least six hours a day, farmers would not postpone paddy transplantation owing to the delay in monsoon because electricity is far more affordable than diesel and the cost of keeping land fallow is much higher (Waterscapes 2021). Exactly similar case prevails in the mid hills, where perennial rivers flow at valley bottoms, but water cannot be lifted from the rivers to irrigate fields on hill slopes. Moreover, the carbon footprint (life-cycle emissions) of hydroelectricity and solar power is much lower than that of diesel. Therefore, installation and use of hydro- and solar energy depending upon the terrain conditions to extract and transport water must be considered in the scheme of W–E–F nexus framework.

Shrestha et al. (2018) reported that if only 0.61 Mha of land in the Terai is brought under year-round irrigation with groundwater for the cultivation of summer and monsoon rice and winter wheat, the value of three crops would

generate the revenue of USD 2.2 billion per year (Table 22.3). Even if the production cost is allocated to 50% of estimated revenue, the net benefit would still be USD 1.1 billion (Table 22.3; Shrestha et al. 2018). This will reduce the cereal food grains import from, and will significantly increase the export to, the neighboring countries. With the current state of irrigation and CI of 1.25, the average cereal yield is 3.1 t/ha, but if all irrigable lands (0.61 Mha) in Terai are brought under year-round irrigation, the CI will increase to 2.5 and the average cereal yield will increase to 7.75 t/ha (MoA 2019). Pressurized irrigation system that transports water from low-lying areas to uplands in hills and mountains requires considerable amount of energy that can come from hydropower. In addition to hydro-energy, solar powered irrigation system can be a potential source, especially in the areas where hydroelectricity infrastructures are difficult to build and make them accessible to farmlands. A strategic combination of solar power, groundwater, and surface irrigation systems depending upon the physical ground reality needs to be developed to revolutionize Nepal's agriculture.

Therefore, it is argued here that whenever mega-hydro-projects are designed in the hills and mountains and if terrain conditions and technological challenges can be overcome, provision for the development of irrigation infrastructures must be conceived at the design stage. If development of irrigation infrastructure with the use of modern tunnel technology to convey water from high hills and mountains to mid-hills, valleys, inner Terai and Terai cannot be designed in the high-dam hydro-projects, then a good portion of hydro-energy generated from such mega projects must be allocated for pressurized irrigation to extract underground water in Terai. In such situation, agriculture can become the principal source of national revenue, biggest employer, and exporter of agriculture produces turning the present trade deficit to a net trade surplus. This requires implementation of a well thought out strategic W–E–F nexus planning framework integrating water, energy, and food production and their synergetic interrelationship. We argue

that Nepal cannot achieve “prosperity and happiness” without developing agriculture to its full potential which requires investment in the development of irrigation infrastructures in both hills and Terai.

22.6 W–E–F Nexus and Multipurpose Development Projects

It is to be noted that only about 25% of large hydropower reservoir dams in the world have hydropower generation as the sole objective while the remaining 75% have multipurpose objectives yielding multiple benefits and services (Emmanuel 2017). Tunnel Boring Machine (TBM) technology has made it possible to transport water from the area of abundance to the area of scarcity for irrigation, human consumption, and industrial and municipal uses (Wallis 2020). This is particularly important for Nepal where multipurpose high dam reservoirs projects can be designed and built in the valleys, high hills, and mountains to generate hydro-energy and transport water across hills and mountains and to Terai and inner Terai through TBM technology to boost agriculture productivity. As noted, recently completed Melamchi Drinking Water Project has raised high optimism for the use of this technology in the development of road and irrigation infrastructures, and the transportation of water across the landscapes in the river basins.

The government of Nepal (GoN) recently intensified the much-awaited Kaligandaki Tinau Diversion Multipurpose Project (KTDMP) which will divert 90.6 cubic foot of Kaligandaki water per second from Ramdighat in Syanja district to the Tinau River in Rupandehi district through nine meters wide 30 km long tunnel (MyRepublica 2021a, b). The multipurpose project envisages irrigating 107,000 ha of land in western Terai (54, 000 ha in Kapilvastu and 53,000 ha in Rupandehi) and producing 126 MW electricity. Diversion dam will be constructed at Pipaldanda in Rambha Rural Municipality of Palpa district in western mid-

hills. The estimated cost of project has been reported to be Rs. 138 billion (Gautam 2021). This is certainly an indication that GoN is moving knowingly or unknowingly to the right direction following the W–E–F nexus approach. The GoN has invited foreign investment in the mega hydro-energy projects and government’s investment board has signed large number of hydro-projects with Indian and Chinese companies including Arun-III, Upper and Lower Arun, Budhi Gandaki, Karnali, and Seti, and many others are in the process. However, all these hydro-projects have only one singular objective of generating hydro-energy for the market without considering the development of infrastructures for irrigation and drinking water even in the areas where drinking water sources are shrinking and drying up. Such mistakes should not be repeated in forthcoming mega projects and the government should review the engineering designs of those projects that are in the process of making.

22.7 Case Studies on W–E–F Nexus Approach

Except in one or two isolated cases, water resource development projects in Nepal have never been conceptualized from the perspective of multipurpose uses. Bheri Babai Diversion Multipurpose Project (BBDMP), Sunkoshi Marine Diversion Multipurpose Project (SMDMP), and recently completed Melamchi Drinking Water Project have all raised optimism that water can be transported through TBM technology across landscapes for multiple uses. From the perspective of W–E–F nexus framework, here we present two national/regional level case studies from Nepal followed by one application of the nexus approach for increasing food, water, and energy productivity at field level. These case studies will shed some lights on why W–E–F nexus framework is critically important for Nepal which has massive amount of potentially irrigable lands. We have included two national pride projects (BBDMP and SMDMP), which were originally conceptualized as irrigation projects,

for these studies. Due to the feasibility of generating hydro-energy as a byproduct, now the hydro-energy component has also been integrated into these projects. Both projects have considered construction of irrigation and energy infrastructures to transport water across river basins through TBM technology to irrigate agricultural lands, control floods, and generate hydro-energy. The field-level case study illustrates the research results on conservation agriculture-based sustainable intensification (CASI) in the Eastern Gangetic Plains (EGP) of South Asia that also includes two Terai districts (Dhanusha and Sunsari) in eastern Nepal (Dixon et al. 2020).

22.7.1 Case Study 1: Sunkoshi Marin Diversion Multipurpose Project

The SMDMP is the national pride number one project being developed by the Ministry of Energy, Water Resources and Irrigation of the GoN. SMDMP has been conceptualized as a supporting irrigation project to the larger Bagmati Irrigation Project (BIP) with the aim of diverting part of the water flow from Sunkoshi River into Bagmati River Basin. Being a multipurpose project, SMDMP aims to provide irrigation benefits in addition to hydroelectricity and flood control.

SMDMP is in Sindhuli and Ramechhap districts where water from Sunkoshi River is diverted to the Marin Khola, a tributary of Bagmati River, to augment discharge into Bagmati Irrigation Canal to irrigate agricultural lands in the Terai districts of Rautahat, Dhanusha, Mahottari, Sarlahi, and Bara. SMDMP consists of three sub-components: A dam of 12-m high along the Sunkoshi River, a diversion tunnel of 13.3 km to divert 67 m³/s of water from the Sunkoshi River to the Marin Khola and a hydro-energy powerhouse installation. Upon completion, the project will provide year-round irrigation to 122,000 ha of lands and generate 30 MW of hydro-energy (Wallis 2020). SMDMP shall be the second inter-basin infrastructure project to

make use of TBM technology to transfer water across river basins after the Bheri Babai Diversion Multipurpose Project in Surkhet in far western Inner Terai (Wallis 2020). The total project cost is estimated at USD \$850 million of which the irrigation component constitutes \$314 million, the hydropower component \$390 million and the tunnel excavation component \$134 million. It is expected to be completed in five years (Republica 2021a, b). The year-round irrigation in Terai districts and generation of 30 MW of hydro-energy will significantly contribute to the food and energy securities and the national revenue. Even though the Nepal government conceptualized SMDMP primarily as an irrigation project and hydro-energy seemed to have evolved as a byproduct in the design process, this has potential to be an ideal project to be implemented considering the W–E–F nexus framework.

22.7.2 Case Study 2: Bheri Babai Diversion Multipurpose Project

The BBDMP was conceptualized with the development of river basin diversion multipurpose project for translocating surplus water resource available in one river basin to provide year-round irrigation in another river basin and generate hydro-energy. BBDMP is the first of its kind of inter-basin water transfer project conceptualized to provide year-round irrigation to 51,000 ha of lands in Banke and Bardiya districts and generate 46 MW of hydro-energy (MoEWRI 2020). The project is located at the Bheri Ganga Municipality of Surkhet district and was designed with the aim of discharging water from Bheri River in Surkhet into the Babai River in Bardiya for irrigation and power generation at Chiple of Bheri Ganga Municipality. The project intake site is located at Chiple of Ramghat VDC in Surkhet where 40 m³/s water is diverted through 12.2 km long tunnel across the Siwalik Mountain chain and discharged at Hattikhal powerhouse in Bardiya (MoEWRI 2020). For the first time in Nepal, TBM technology was

successfully used to excavate and efficiently construct tunnels through fragile rocks of Siwaliks. The project promotes the use of this technology in other infrastructure development projects. Thus, the GoN has given high priority to this project and has designated it as one of the national pride projects (TunnelTalk 2019). The following vision statement of the Strategic Plan of BBDMP captures some aspects of W–E–F nexus framework even though this project was not conceptualized from the W–E–F nexus perspective.

Achieve sustainable economic growth of Nepal through enhanced agricultural production and productivity by providing year-round irrigation; and generating reliable electricity with focused development of inter-basin water transfer and multipurpose projects using modern technologies like TBM by the means of effective and efficient public sector.

This is encouraging that even in a small scale, MoEWRI (2020) has initiated these multipurpose projects integrating water for food production through development of irrigation infrastructure and hydro-energy generation. If the W–E–F nexus framework can be extended in the design of multipurpose and mega-hydro-projects considering water, energy, and food, these could bring revolutionary economic transformation of the country through the development of agriculture.

22.7.3 Case Study 3: Comparing Conventional Tillage with Zero Tillage in Rice-Based Cropping Systems in the EGP: A W–E–F Nexus Perspective

The nature of the cropping systems and the production technologies influences the status of the W–E–F nexus. Continuous cultivation leaves soils vulnerable to water and wind erosion, increases runoff, decreases soil water holding capacity and degrades soil fertility, increases energy use and GHG emissions, resulting in loss of productivity, profitability, and sustainability of

cropping systems (Dixon et al. 2020; Magar et al. 2022a, b). To overcome these issues, farmers apply large amounts of chemical fertilizers and pesticides which increase production cost and require huge amount of energy (Timsina et al. 2021, 2022). Zero till (i.e., sowing seeds directly under the mulch layer from the previous crop) or reduced till (i.e., with minimum soil disturbance) is a promising solution, as it can reverse the process by minimizing soil disturbance and provides permanent soil cover (Paudel et al. 2016; Dang et al. 2020; Amgain et al. 2022; Magar et al. 2022a, b). Zero till helps increase crop yields by increasing water-use efficiency (WUE) and reduces soil erosion and CO₂ emissions, and therefore, delivers both adaptation and mitigation benefits. Nepal, being a geographically fragile mountainous country, has additional benefits of practicing zero or reduced tillage as this technology has tremendous soil and carbon conservation benefits (FAO 2014).

To illustrate the application of W–E–F nexus at field level, on-farm trials with different rice-based cropping systems comparing CASI technologies (i.e., zero-tilled direct-seeded or unpuddled transplanted rice; zero-tilled maize, wheat, mung bean, or jute) with conventional tillage (CT) in more than 400 farmers across the EGP showed that, for all cropping systems, food productivity was higher under CASI than with CT, whether measured in total annual food grain or food energy (Table 22.4). Diversifying the rice–wheat (RW) system by incorporating mung bean (rice–wheat–mung bean, RWMb) in sequence increased the annual food rice-equivalent yield by 2.3 t/ha under CT, and by 2.7 t/ha under CASI. Furthermore, the combination of diversifying the RW system by incorporating a jute crop (rice–wheat–jute, RWJ) and converting from CT to CASI boosted annual food productivity from 8.6 t/ha in rice grain equivalent yield (or 304 GJ/ha food energy) to 14.2 t/ha (470 GJ/ha). From the W–E–F perspective, CASI increased rice-equivalent food grain productivity by 3–6% across cropping systems compared with CT. Moreover, in RW and rice–maize (RM) systems, CASI saved more

Table 22.4 CASI contributions to W–E–F nexus by cropping system (Adapted from: Dixon et al. 2020)

System performance indicators	Cropping systems*	CT	CASI	Improvements CASI cf. CT (%)
System grain yield (t/ha/year) and food energy productivity (in parentheses, GJ/ha/year)	RW	8.6 (304)	8.9 (315)	+3.2 (+4)
	RM	11.8 (520)	12.3 (541)	+3.9 (+4)
	RL	12.4 (261)	13.2 (269)	+5.9 (+3)
	RWMb	10.9 (408)	11.6 (408)	+6.2 (0)
	RWJ	13.8 (478)	14.2 (470)	+3.0 (–2)
System energy use (GJ/ha/year) and EUE (in parentheses, MJ/MJ)	RW	30.0 (12)	27.0 (14)	–10.0 (+15)
	RM	35.3 (15)	32.9 (17)	–6.8 (+13)
	RL	20.0 (13)	18.3 (15)	–8.5 (+15)
	RWMb	40.7 (10)	36.4 (11)	–10.6 (+14)
	RWJ	34.7 (14)	32.8 (14)	–5.5 (+4)
System irrigation water use (ha-cm/year) and WUE (in parentheses, kg grain/m ³ water)	RW	20.8 (4.9)	18.2 (6.1)	–12.5 (+24)
	RM	23.1 (8.9)	20.3 (11.1)	–12.1 (+25)
	RL	–(0.50)	–(0.52)	–(+4)
	RWMb	–(0.71)	–(0.75)	–(+6)
	RWJ	–(0.63)	–(0.67)	–(+6)
System CO ₂ equivalent emission (t/ha/year)	RW	1.55	1.36	–12
	RM	1.81	1.65	–9
	RL	1.00	0.90	–10
	RWMb	2.11	1.89	–10
	RWJ	1.71	1.26	–26

than 12% of irrigation water, improving irrigation WUE by 24–25% compared to CT. In other cropping systems, total WUE increased by 4% for rice–lentil (RL) and 6% for RWJ system. Mainly by eliminating tillage and reducing labor and water use, CASI practices saved energy in all cropping systems and increased energy-use efficiency (EUE) by 13–15% for RW, RM, and RL systems. There were also significant reductions of CO₂ equivalent emissions, by 9% for the input intensive RW and 26% for RWJ system. These results demonstrate that smallholder farmers in the EGP can improve the W–E–F nexus by adopting CASI or zero till practices in diversified rice-based cropping systems. However, farmer adoption of these practices in the EGP and particularly in Nepal is lacking mainly due to unavailability of suitable herbicides to control

weeds and machinery and their parts for seeding under no-till conditions. Service provision for machinery supply to private sector and training for farmers and machinery service providers would be necessary for rapid uptake and upscaling of these technologies across the country (Dang et al. 2020; Dixon et al. 2020; Amgain et al. 2022; Magar et al. 2022a).

22.8 W–E–F Nexus and Climate Smart Agriculture

The Hindu-Kush Himalayan (HKH) region, designated as the Third Pole due to its largest permanent snow cover after the north and south poles, houses the origin of 10 river basins including the Ganga, Brahmaputra, and the

Mekong (ICIMOD 2019). Even if the global temperature rise is kept at 1.5 °C, the temperature rise in the HKH region is estimated to be higher at least by 0.3–0.7 °C (ICIMOD 2019; Bhattarai and Karki 2020). The HKH range is the water tower of Asia, providing water, energy, food, and ecosystem services not only to the millions of people in Nepal but close to 2 billion people in the region (ICIMOD 2019; GoN 2020). The impact of climate change on HKH has been reported to be severe; temperature across the mountainous region in HKH has been projected to increase by 1–2 °C or in some places by up to 4–5 °C by 2050 which is far greater than the global average (IPCC 2007; Shrestha et al. 2015; ICIMOD 2019).

Studies have shown that Nepal's agriculture has been negatively impacted by climate change (Panday 2012; Shrestha et al. 2015; Subedi et al. 2019). It is estimated that almost 1.5–2% of Nepal's GDP is lost due to the disasters accelerated by adverse climate change (GoN 2020). The rapid increase of temperature in the high Himalayas and mountains, erratic rainfall patterns, landslides and floods, nutrient and soil loss, prolonged droughts, and increase in the frequency of pests and diseases indicate that the magnitude of the impacts of climate change on Nepal's agriculture is going to be severe (Charmakar 2010; DHM 2015; ICIMOD 2019; Bhattarai and Karki 2020). This underscores the importance of W–E–F Nexus framework to leverage the synergy and efficiency of resource uses and their conservations and protection. For example, declining water availability in an area eventually affects not just the water sector, but all other sectors that depend on water availability. An extended drought often results in crop failures, a drop in the production of hydropower, a reduction in milk and meat production, and a shortage of domestic water supply in downstream areas. From the W–E–F nexus perspective, following two strategies could be considered in national-level planning and implementations considering the climate change issues and impacts.

22.8.1 Promote Climate Smart Agriculture

Climate smart agriculture (CSA) practices are required to mitigate the impacts of or adapt to climate change, minimize the negative effects on W–E–F synergy, and harness maximum benefits from the W–E–F nexus approach (Maraseni et al. 2020). Nepal accounts for 0.03 Gt CO₂e (30 Mt CO₂e in 2008) of greenhouse gas (GHG) emissions, i.e., 0.06% of global emissions (GoN 2020), and 70% of Nepal's emission comes from the agriculture sector. Therefore, increasing crop productivity using less land, water, and energy while reducing carbon footprint and adapting to rapidly changing climate is a major challenge. For this, there is a need to adopt and promote CSA as it increases crop productivity, develops farmers' adaptability to climate change, and reduces emissions associated with agriculture food chain (Maraseni et al. 2020). To accomplish this, we need to: (1) develop policy (similar to Emissions Reduction Funds in Australia; See Maraseni et al. 2009 and Maraseni and Reardon-Smith 2019) so that private sector can be involved in it; (2) identify existing CSA practices and promote them; (3) provide monetary benefits to such farmers; and (4) develop effective communication and extension activities. Subedi et al. (2019) reported that with the adoption of CSA practices in Nepal, a significant improvement in crop yield, reduction in the disease and pest incidence, and improvement in the soil nutrient management could be realized.

22.8.2 Conduct Tradeoff Analysis of Irrigation Systems and Modeling for Profit Maximization

The conversion of less efficient flood irrigation system to more efficient pressurized irrigation system has been heralded as a way of improving WUE but it increases energy consumption and

therefore accelerates GHG emissions (Maraseni et al. 2014). There are different types of pressurized irrigation systems with different levels of water and energy use efficiencies. Therefore, comprehensive research on finding trade-offs of water and energy saving and adopting right irrigation practice in different time and space will be instrumental for the efficient use of these scarce resources. Moreover, to find optimal use of these resources, we need to do modeling for maximizing profits under a series of constraints from on-farm water and energy consumption, crop production, land use, and GHG emissions. Such models can be developed using production function approach or non-linear computational programming using Python-based open-source software (Maraseni et al. 2020).

22.9 W–E–F Nexus and SDGs

The nexus framework holds considerable promise for guiding policy development and governance structure particularly in the context of adverse climate change, degradation of natural capitals, population growth, and inequitable access to resources making it even more imperative to achieve SDGs, and therefore linking of W–E–F nexus assessment with SDGs becomes necessary (FAO 2014; Liu et al. 2018; Rasul et al. 2019; Simpson and Jewitt 2019). The effective use of the W–E–F nexus framework can provide a broad range of goods and environmental services, which in turn can positively contribute to many SDGs such as eliminating poverty (SDG 1), zero hunger (SDG 2), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), sustainable cities and communities (SDG 11), climate action (SDG 13), and life on land (SDG 15) (Weitz et al. 2014; UN 2015; Mohtar 2016).

Malago et al. (2020) developed an analytical framework (Fig. 22.2) based on three important postulates extracted from Liu et al. (2018): (a) *“The nexus is directly or indirectly connected with all SDGs”*; (b) *“Nexus approach promotes the achievement of SDGs since the goals are interconnected”*; (c) *“SDGs are interconnected*

and linked with the pillars of a particular nexus”. This framework illustrates the crucial relationship between W–E–F nexus and the SDGs as three (SDGs #2, #6 and #7) of the seventeen SDGs are directly related to the water, food, and energy sectors (Molden et al. 2014). Nepal government has committed to SDGs and has made appreciable progress toward achieving those goals (GoN 2020). Nevertheless, the government should adopt the holistic and integrated W–E–F nexus planning framework to capitalize on the synergy, resource-use efficiency, and the sustainability of the natural resources.

22.10 Conclusions and Policy Implications

Though Nepal has abundant water resources (richest in water resources in the world after Brazil as portrayed by some), it is an irony that the government’s current agriculture and water resources development policy has failed to conceptualize the possibility of utilizing its valuable water resources holistically by integrating water, energy, and food production from a W–E–F nexus perspective. Government’s policy must leverage the synergy created by the intertwined nexus relationship of these components and their interdependencies. Nepal government’s water resource development policy should incorporate water, energy, and food production in the design of high dam multipurpose hydro-energy development projects so that provision for hydro-energy, irrigation infrastructures for food production, flood control, and drinking water can be integrated and built. Nepal’s biggest bottleneck for increasing agriculture productivity and securing food security is the lack of year-round irrigation infrastructures despite being rich in water resources. This review has shown that there is a huge potential for increasing agriculture productivity through developing irrigation infrastructures and the use of energy inputs. To translate the national slogan *“Prosperous Nepal Happy Nepali”*, Nepal must adopt W–E–F nexus planning framework and conceptualize and design multipurpose development projects

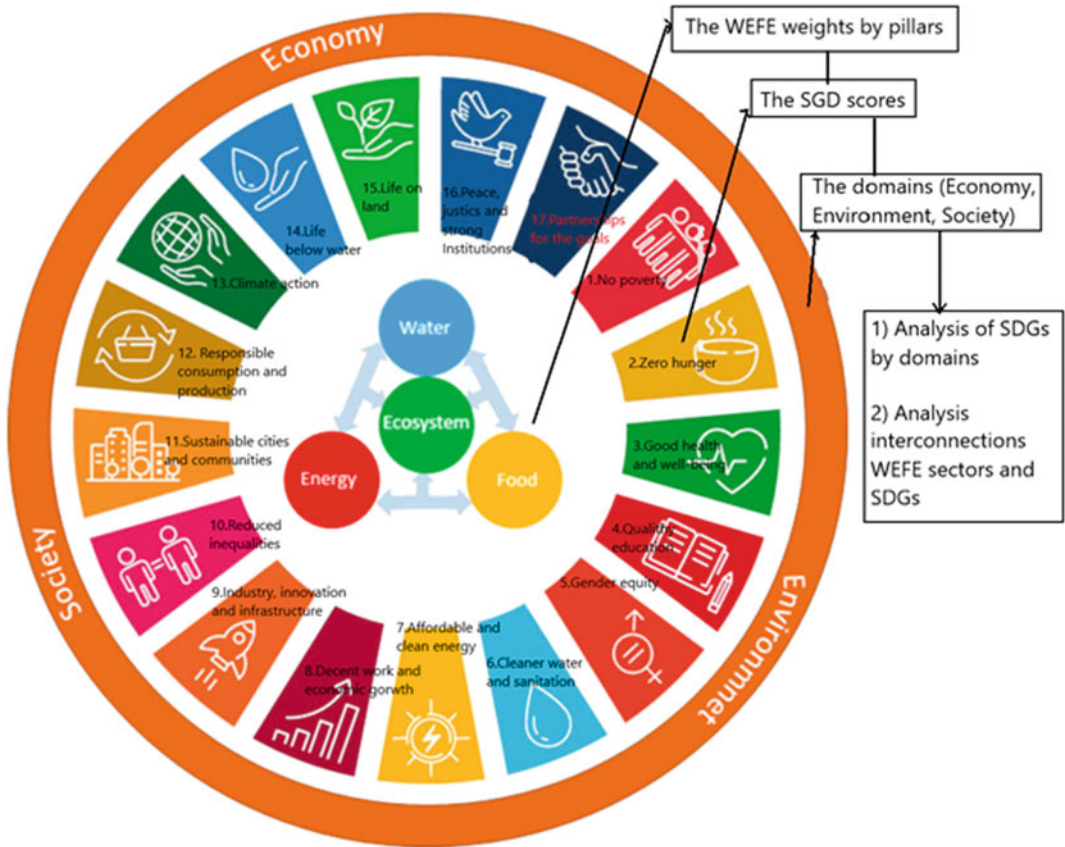


Fig. 22.2 Conceptual framework of W–E–F nexus approach. The sub-figure in the middle represents the W–E–F nexus; the second sub-figure represents all SDGs

numbered from 1 to 17 (anti-clockwise); the external sub-figure shows the three domains that embrace all the SDGs and the W–E–F nexus (Adapted from Malago et al. 2020)

leveraging the synergy generated from their nexus relationship.

It is important to emphasize the fact that water resources development should not be conceived exclusively for hydro-energy without accounting for the possibility of developing irrigation, drinking water, and flood control infrastructures wherever engineering design and the geomorphology of the landscape permits. There is however now some shift in policy from sectoral approach to W–E–F nexus approach. For example, IMP (2019) identified Tamor Morang Diversion Project with tunnel, hydropower station, and storage dam from which about 114,000 ha of lands can be irrigated in the Morang district in eastern Nepal with potential of 732 MW of hydro-energy. The combined benefits of hydro-energy, irrigation, and the drinking

water in Biratnagar metropolitan city and urban areas of Morang district far outweigh the benefits from either hydro-energy or irrigation project alone. This example demonstrates that the Nepal government should pursue its water resource development policy from the W–E–F nexus perspective and should make it a mandatory practice to design and develop future hydro-projects from nexus framework to harness the synergy resulting from the efficiency of resource uses and integration. If possible, all those hydro-projects that are in the design phase should be converted to multipurpose projects with hydro-energy, irrigation infrastructure, and human and industrial consumption needs integrated in the development design. The GoN must pursue a policy of developing multipurpose hydro-energy projects with W–E–F nexus perspective for the

maximum benefits leveraging the efficiency and the cost effectiveness of resource uses. The lack of prudence and the mistakes committed at the design and development phase of Nepal's water resource will have a far-reaching repercussion.

Nepal can immensely benefit from the W–E–F nexus planning framework because of its holistic and more cost-effective approach and its inherent potential to address the challenges of resource scarcity and climate change, maintain sustainable growth, and meet the ever-increasing demand of growing population. One critical aspect of the nexus approach is that it requires collaboration across ministries, different levels of government, engagement and participation of all the stakeholders, and international cooperation wherever applicable. It is expected that Nepal government and its national planning commission recognizes the inherent strength of the W–E–F nexus development framework and embraces it as its development planning paradigm.

In terms of application of W–E–F nexus at the field level, conservation agriculture-based climate smart practices and technologies such as zero or reduced tillage and profitable crop rotations could help increase crop yields, farmer's income, increase water- and energy-use efficiencies, reduce GHG emissions, and help adapt to climate change. Nepal government's policy should seriously consider integrating such technologies in agricultural research and extension. These recommendations in both regional or national hydropower projects and climate smart practices may be applicable and relevant to other countries in the HKH region since they share many similarities with respect to resources and their uses, and topographic and climatic conditions.

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Potential of Crop Simulation Models to Increase Food and Nutrition Security Under a Changing Climate in Nepal

23

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Abstract

With current trends of increasing population, decreasing arable land, and a low yearly increment rate of cereal productivity, Nepal has an annual deficit of >1.3 million tons of edible rice, wheat, and maize. This indicates the urgent need for demand-led agricultural interventions for improving cereals productivity for food security. Crop simulation models and DSS tools have potential to predict potential yields, identify yield gaps, and help make decisions for improved crop, nutrient,

water and pest management. Models can assess the impact of climate change, and help develop adaptation and mitigation measures to lessen the impact of climate change. To date, no review work has been conducted on the potential applications of crop simulation models and their relevance in Nepal. The objective of this chapter is to review and synthesize the relevant studies on the development and application of crop simulation models for major cereal crops: rice, wheat, and maize. We reviewed around 95 published papers and reports from South Asia and Nepal available in Scopus, SpringerLink, and ScienceDirect using the Google search engine. Analysis revealed that yield gaps (potential minus farmers' field yields) of 4.9–9.0, 3.1–6.9, and 4.5–12.5 t ha⁻¹ exist in rice, wheat, and maize crops, respectively. For achieving self-sufficiency in cereal grains, the average national productivity of rice, wheat, and maize needs to be increased to 5.7, 3.9, and 4.9 t ha⁻¹, respectively by 2030. Based on the review, climate change has both positive and negative consequences on cereal production across all agro-ecological zones. Crop simulation models have been applied for enhancing crop productivity and exploring adaptation strategies for climate change resilience. Models can generate various recommendations related to biophysical factors: crop, water, tillage, nutrient, and pest management, crop yield, and weather forecasting. Furthermore,

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models have shown the potential to determine the effects of climate change on crop productivity across a range of environments in Nepal. In conclusion, crop simulation models could be useful decision support tools for policy planning and implementation, increasing efficiency in research, prioritizing research and extension interventions for increasing crop yields, and the way forward to achieve food and nutritional security and some of the Sustainable Development Goals (particularly #1, #2 and #13).

Keywords

Model application • Food security • Climate change • Yield gap • Decision support

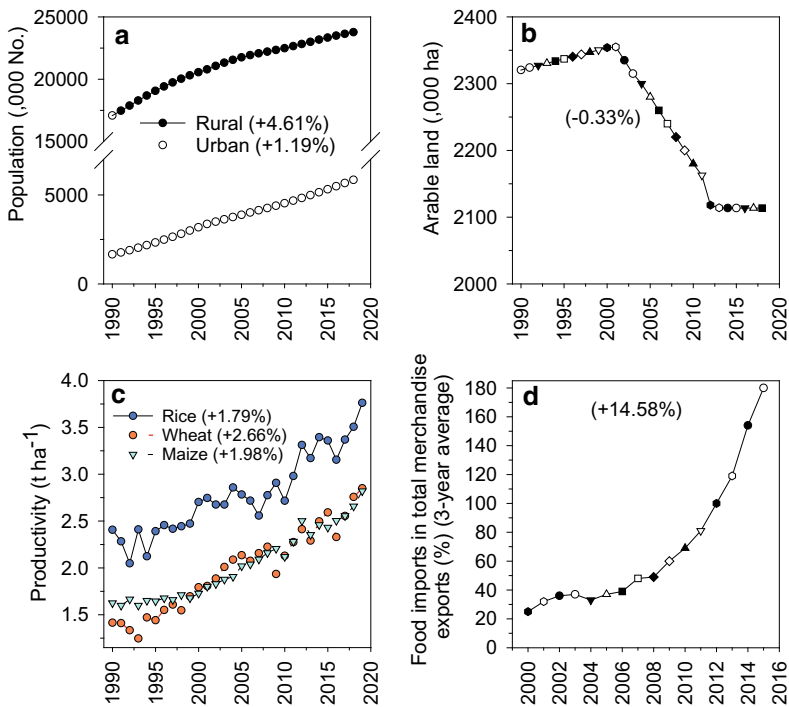
23.1 Introduction

Rice, wheat, and maize are the main staple crops, which contribute more than 72% of the total calorie intake in the Nepalese diet (Kumar et al. 2020). The food security situation in Nepal has

been challenged with the increasing annual population growth rate (+4.61% in urban and +1.19% in rural areas), declining arable land (−0.33%), and low cereal crops productivity growth rate (+1.98%) (Fig. 23.1; FAOSTAT 2021). The analysis of long-term FAOSTAT data compared to the initial (2000–2004) and final 5 years (2011–2016) revealed an increase in reliance of food security on import by almost 3-folds (289%; yearly increment by 14.58%). This trend is likely to increase in the upcoming years unless drastic measures are adopted (Fig. 23.1). Intergovernmental Panel on Climate Change (IPCC) food security projections for Nepal revealed that climate change is already affecting the food security situation and the effect will be much higher in the future, especially in the lower altitude regions. However, the higher altitude regions will see yield increment of the major cereal crops (Mbow et al. 2019).

The prevalence of high variability in soil, climate, and geographic conditions in the country require varying site-specific research recommendations. However, conducting intensive field research for generating site-specific recommendations under

Fig. 23.1 Trends of yearly rural and urban population growth **a**, arable land area **b**, averaged rice, wheat and maize productivity **c**, and value of food imports in total merchandise exports **d**. Data source FAOSTAT (2021). Figures in parenthesis yearly growth rate



diverse growing environments is resource-intensive. Furthermore, field experiments are time-consuming. Therefore, extrapolation of field studies using simulation models over different locations and time could help in scaling-out the recommendations, policy formulation, and adaptation to climate change. Simulation models are knowledge-based decision support systems (DSS) used to translate research results for the extension. Models help answer questions in research, provide pre-season and in-season management decisions in cultural practices, fertilization, irrigation, develop alternative crop management practices, and assist in the formulation of policy strategies and development (Penning de Vries et al. 1989; Boote et al. 1996). Models help improve understanding of the broader perspective of biophysical and socio-economic potential to enhance cereal crops' productivity and profitability to improve food and nutrition security. In this context, the application of crop, cropping or farming systems, and the landscape-scale simulation models are an alternative approach to achieve the intended goal of food and nutritional security with improved resilience to climate change.

Long-term trends (1991–2019) and projections for the next 10 years for cereal yield, population growth, and cereal crops deficits showed that the total deficit of these crops will decrease, with a recent annual deficit of >1.3 million tons (Fig. 23.2). The current trends of yield increments by 73,000 t year⁻¹ in rice, 46,000 t year⁻¹ in wheat, and 49,000 t year⁻¹ in raw maize show that the country still needs to either import a hefty amount of food or needs to launch a rapid productivity enhancement strategy.

This study involves the analysis of around 95 peer-reviewed published papers and reports from South Asia (60) and Nepal (35) available in Scopus, SpringerLink, and ScienceDirect using Google search engine using keywords 'food security, simulation model, climate change, yield gap, model application, agronomic management, and climate change adaptation' in the title, abstract, and entire text of the manuscript. Papers on: the application of simulation models for improving yield, closing yield gaps, and importance of agronomic management practices and crop varieties for improving food and nutritional

security, and climate change impact and adaptation strategies in Nepal and South Asia were reviewed. Also, from the long-term historical data from FAOSTAT, additional productivity requirement for self-sufficiency was projected for the three major cereal crops of Nepal.

23.2 Simulation Model Application Framework

Smallholder farming systems are practiced in diverse biophysical, socio-economic, and policy environments in Nepal and South Asia. It is commonly observed that the biophysical conditions and improved technologies for obtaining desired crop yields do not satisfy sufficient incentives for the adoption of technologies by farmers. Hence, it is important to understand the socio-economic conditions under different scenarios, such as climate change and variability, changes in farmers' management practices ranging from crop to cropping or farming system to landscape level. Simulation modeling is an approach that describes processes of crop growth and development and yield formation as a function of biophysical (weather, soil, water, nutrients, and crop management) and socio-economic conditions using mechanistic and process-based computer models (Jones et al. 2003; Keating et al. 2003; Penning de Vries et al. 1989). Crop simulation models are useful DSS tools as they can generate relevant outputs ranging from crop yield and management recommendations, climate change mitigation and adaptation, ecosystem services, and institutional and policy reform (Fig. 23.3). Such models have the potential to quantify the magnitude of and identify factors responsible for crop yield gaps; they also suggest technological interventions considering the socio-economic and policy environments to help close those gaps. A robust analysis of yield gaps can help increase food production, meet food demand, reduce food import, and achieve food and nutritional security (Guilpart et al. 2016; Timsina et al. 2018). The application of crop simulation models, incorporating socio-economic and climate processes can contribute to

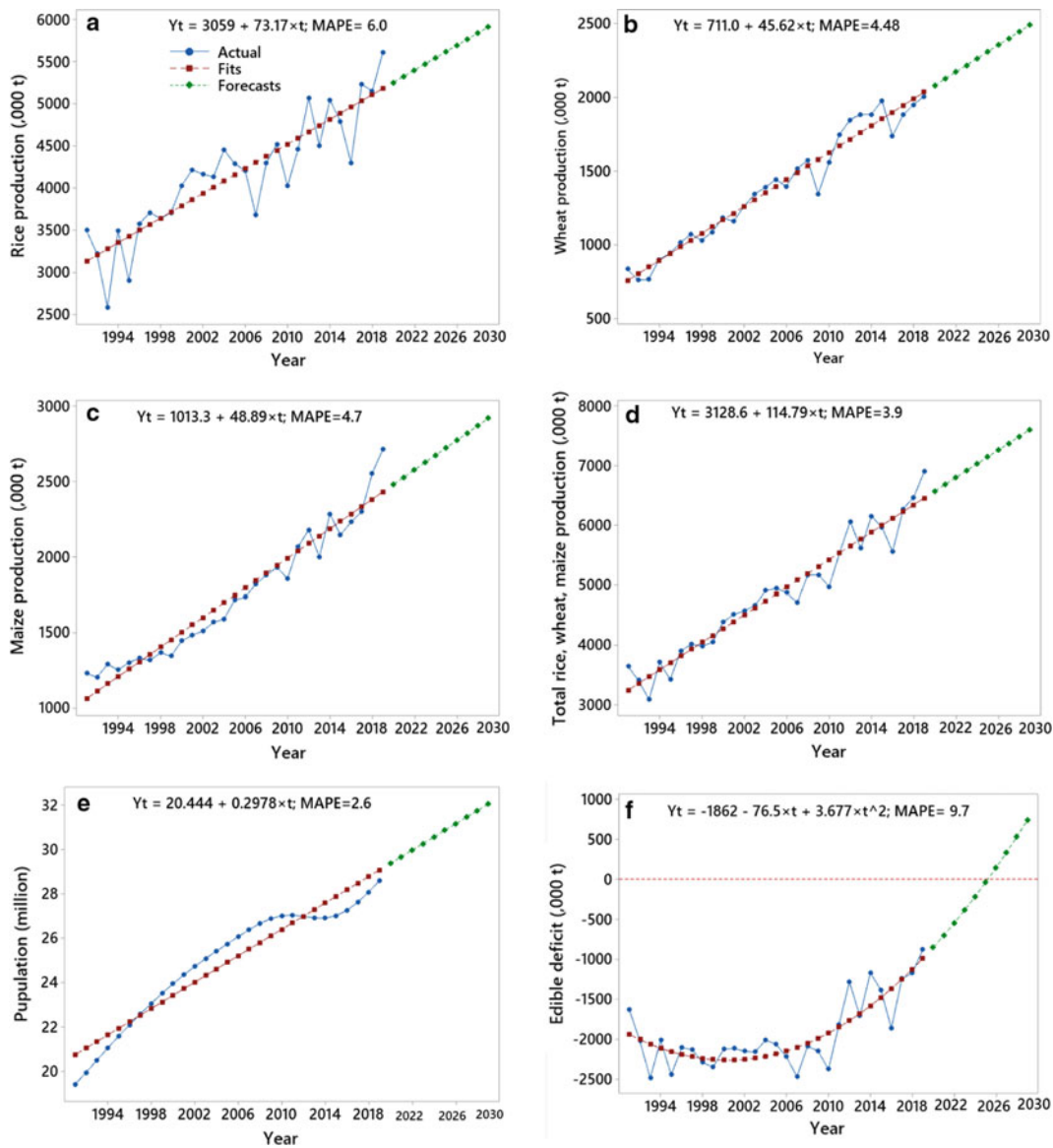


Fig. 23.2 Yearly and projected (for next 10 years; green dotted lines in all six figures between 2020 and 2030) trends of production of rice (a), wheat (b), maize (c), total rice, wheat and maize in terms of edible production (d), population growth (e), and deficit in food supply from these three crops for the current and future population. Figs. A, B, and C are harvested grain yields; D is the total edible product from rice, wheat, and maize. Edible yield is derived by converting 60% milling recovery from rice,

and 75% each for wheat and maize after reducing the losses during processing. F = deficit in terms of edible rice, wheat, and maize. Deficit computed subtracting demand from the supply (total edible rice, wheat, and maize). Demand was computed by multiplying each individual person by 272 kg for one year as suggested by Gauchan et al. (2021). MAPE = measure of the absolute percentage error in the model. *Data source* Recalculated and drawn from CBS (2019)

sustainable development goals (SDGs): poverty reduction (No. 1), zero hunger (No. 2), and climate action (No. 13). Since the three major staple cereals—rice, wheat, and maize—are vital for providing calorie and protein to the majority of smallholders and the urban population (Kumar et al. 2020), this chapter focuses on the application of simulation models for improving food and nutritional security in South Asia and in Nepal in particular.

Many of the crop simulation, econometric, and climate change models operate dynamically (Fig. 23.3). The biophysical information required for most of the simulation models is climate, soil, inputs used, and crop management practices. Such datasets can be derived from different sources, such as field experiments, household

surveys, web-based data sources, remote sensing, and published literature. Besides simulating yields and other input use dynamics, most crop and cropping system models have the option of simulating economic profitability and trade-offs using the per-unit cost of production of input and output variables. With such models, information about the impact of climate change and the alternative management practices (adaptation and mitigation strategies) for changing climatic conditions are generated. Such models are used to predict the impact of alternative soil, climate, genotype, management conditions, profitability, soil organic carbon sequestration, enhancement of biodiversity and ecosystem services, institutional pathway, and policy and subsidy from local to global scale.

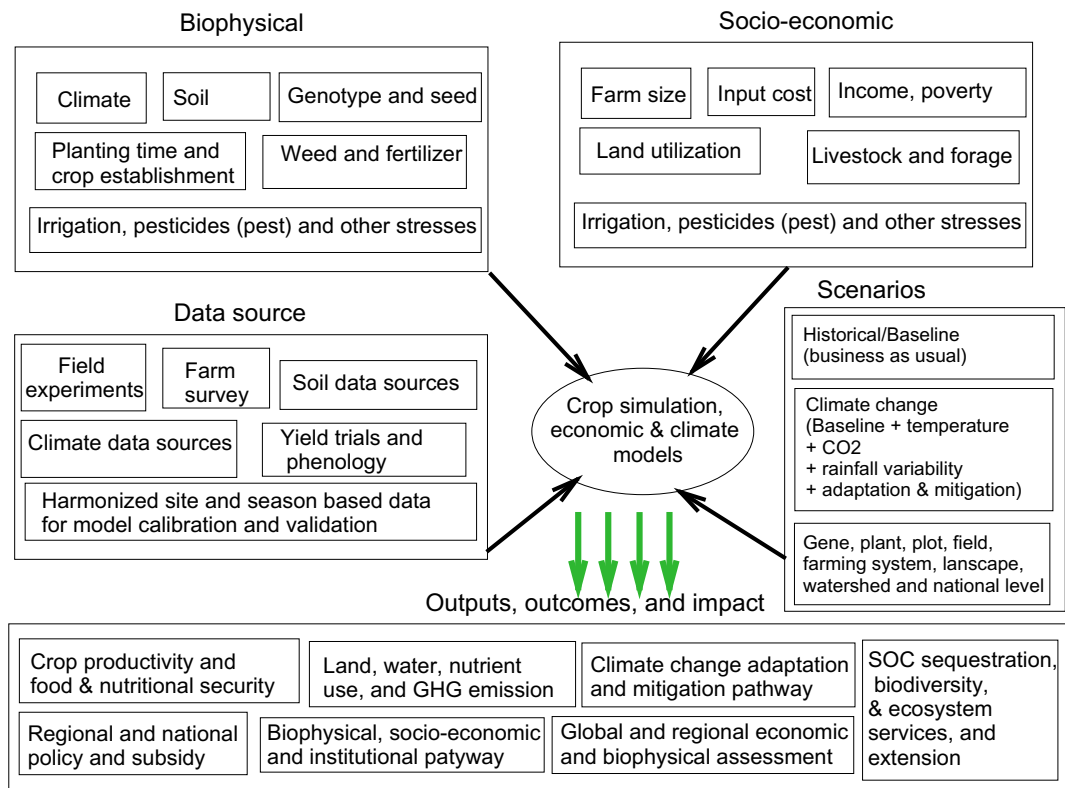


Fig. 23.3 Processes and application of simulation models (Source authors' own work). SOC = Soil organic carbon; GHG = greenhouse gas emission

23.3 Evaluations and Applications of Crop Simulation Models

23.3.1 Evaluations and Applications in South Asia and Nepal

Several aspects of cereal production have been simulated using cereal crop growth models for improved understanding of research and policy issues related to increase in productivity and combat the effects of climate change (Timsina and Humphreys 2006a; Maraseni et al. 2021). Cereal crop growth models such as CERES-Rice, CERES-Wheat, and CERES-Maize embedded within DSS for Agro-technology Transfer (DSSAT) (Jones et al. 2003), Cool-Farm Tools (Hillier et al. 2011), ORYZA2000 for rice (Bouman et al. 2001), model embedded within Agriculture Production Systems Simulator (APSIM) (Keating et al. 2003). Similarly, other popular models include Hybrid-Maize (Yang et al. 2006), Quantitative Evaluation of Fertility of Tropical Soils (QUEFTS) (Janssen et al. 1990), FAO developed soil, water and plant management model AQUACROP (Foster et al. 2017), IWMI developed CRAFT (Shelia et al. 2019), CROPSYST (Stöckle et al. 2003), EPIC (Izaurrealde et al. 2017), CROPWAT (Smith 1992), FARMSIM (van Wijk et al. 2009), World Food Studies (WOFOST) (van Diepen et al. 1989), Nutrient Expert (Pampolino et al. 2012), Rice Crop Manager (RCM) (Buresh et al. 2019), InfoCrop (Aggarwal et al. 2006), etc. for various purposes globally and in South Asia.

Several of these models are validated and applied in South Asia (Table 23.1), including Nepal (Table 23.2). Hence, they can be confidently applied in different agro-ecological zones (AEZs) for policy decisions in Nepal. Matthews et al. (2002), Reynolds et al. (2018), and Timsina and Humphreys (2006a) reviewed the application of CERES rice and wheat models for rice and wheat crops in Asia. These models have been applied mainly for crop genotype improvement,

identification of desirable plant traits, environmental characterization, genotype x environment interaction, yield gap and yield trend analysis, and optimization of tactical crop management practices. Moreover, these models are applied in selecting appropriate establishment methods, planting and harvesting time, water and nutrient management, and pest and disease management, designing new cropping systems, evaluating sustainability, improving farming systems and rural livelihoods, land use and irrigation planning, strategic decision-making, and aiding government policies (Tables 23.1 and 23.2). In addition, they are also applied to predict the effects of climate change on crop yields, greenhouse gas emissions from agriculture, and short- and long-term climate and crop yield forecasting (Jha et al. 2019a, b; Table 23.2).

23.3.2 Increasing Cereal Yields and Improving Food Security in Nepal

Most globally used crop simulation models are for strategic and tactical decision-making, and for yield forecasting purposes with the goal of maximizing crop productivity and profitability with reduced environmental footprints. Crop, soil, water, and climate simulation models have the ability to integrate the results of research from many different disciplines and locations and offer a new way of improving efficiency by reducing research costs (Stephens 2002). In Nepal and largely in South Asia, much of the modeling work has focused on understanding the interactions between the various factors of production influencing crop growth and development, such as climate, water, nutrient supply, crop management practices, biotic and abiotic stresses, optimizing crop calendar and management practices for maximizing yields with sustainability, and improving resilience to climate change (Tables 23.1 and 23.2).

Table 23.1 Summary of validations and applications of simulation models for cereal crops in South Asia

Model used	Crops	Validation and application country/regions	Validation and application	References
CERES rice and CERES wheat	Rice and wheat	India and Pakistan	Climatic potential yield, yield gap, sensitivity analysis, temporal and spatial simulated yield trend	Pathak et al. (2003)
CERES-rice	Rice	Bangladesh, India, China	Strategic decision-making and planning	Singh and Thornton (1992), Timsina et al. (1997)
CERES models	Rice, wheat, maize	Punjab, India, Nepal, Bangladesh	Tactical management strategies	Singh and Thornton (1992), Timsina et al. (1997)
CERES-rice	Rice	South Asia	Prediction of greenhouse gas emission	Matthews et al. (2000)
CERES models	Rice, wheat, maize, and other cereals	Nepal, India, Bangladesh, Thailand, Philippines, Japan, China, Pakistan, Indonesia, Taiwan, Vietnam	Phenology, biomass and grain yield trends, growth, nitrogen (N) and water balance, strategic decision, tactical management, climate change study, predicting greenhouse gas, pest and disease management, policy formulation	Timsina and Humphreys (2006a, b)
CERES rice and CERES wheat	Rice and wheat	Punjab, India	Phenology, water and nitrogen management, climate change	Amgain et al. (2004, 2008)
APSIM and DSSAT models intercomparison	Rice and wheat	Pakistan	Climate change projections, trade-off analysis for multidimensional impact assessment, adaptation strategies of climate change on sowing density, improved cultivars, increase in N use, and fertigation	Khalid Anser et al. (2020)
APSIM	Rice, wheat, maize, cotton, soybean, mustard	Philippines, Indonesia, India, Bangladesh, Sri Lanka, Nepal, Bhutan, Pakistan, Japan, China, Cambodia, Laos	Crop phenology, yield trends, water-use efficiency and balance, soil dynamics (water, organic carbon, N), crop CO ₂ response, soil salinity, sowing date, photoperiod	Gaydon et al. (2017), Timsina et al. (2021), Devkota et al. (2016)
INFOCROP, and STICS	Rice, wheat, maize, peanut	South Asia	Yield, impact of climate change	AgMIP (2012), Kaur and Singh (2020)

(continued)

Table 23.1 (continued)

Model used	Crops	Validation and application country/regions	Validation and application	References
InfoCrop	Rice, wheat, pearl millet, maize, potato, cotton, and mustard	Several locations of India	Crop yields, pests, and environmental impacts in tropical environments (location, seasons, varieties, nitrogen management, organic matter, irrigation, and multiple pest incidences)	Aggarwal et al. (2006)
ORYZA	Rice	Several Asian countries	Growth, development, potential yield, water- and nitrogen-limited yield	Devkota et al. (2021), Li et al. (2017), Sudhir-Yadav et al. (2011)
Rice crop manager (RCM)	Rice	India, Bangladesh	Field-specific nutrient management in rice	Sharma et al. (2019)
Cool farm tool	Rice, wheat	South Asia	Precision nutrient management, nutrient use efficiency, and environmental footprint	Sapkota et al. (2014)
QUEFTS	Wheat	South Asia	Site-specific fertilizer recommendation	Maiti et al. (2006)
Hybrid-maize	Maize	South Asia	Growth, phenology, yield, irrigation management, yield forecasting	Timsina et al. (2010)
Oryza-2000 and hybrid maize	Rice–maize system	Bangladesh	Yield potential and yield gaps in rice–maize system	Guilpart et al. (2016)
CERES wheat within DSSAT	Wheat	Punjab, India	Yield, phenology, water management, and water productivity	Timsina et al. (2008)
CERES rice and CERES wheat; sucrose rice–wheat rotation model	Rice–wheat system	Pantnagar, India	System productivity, long-term yield, nutrients and soil organic carbon trends	Timsina et al. (1994, 1995, 1996)
CERES rice and CERES wheat	Rice–wheat system	Dinajpur, Bangladesh	Phenology, system productivity, Long-term yield and nutrients trends	Timsina et al. (1997)
Oryza 2000, hybrid maize, CERES wheat	Rice, wheat, and maize	Bangladesh	Estimation of yield potential and yield gap analysis, projection of food demand and food security	Timsina et al. (2018)
CRAFT	Cereal crops	South Asia	Forecasting crop production, risk analysis, and climate change impact studies	Shelia et al. (2019)

Note These are just examples of some cereal crop models validated and applied in South Asia and is not the complete list of all models used

Table 23.2 Summary of validations and applications of simulation models for cereal crops in Nepal

Model used	Crops	Validation and application regions	Validation and application	References
CERES rice, CERES wheat, and CERES maize	Rice, wheat, and maize	Nepal	Phenology, yield, climate change effects; CA and N management in mid-hills	Amgain et al. (2019), Laborde et al. (2019), Timsina et al. (1997)
CERES rice	Rice	Nepal Terai	Crop yield forecasting	Jha et al. (2019a)
CERES maize	Maize	Chitwan, Palpa, Dailekh, Illam, Nuwakot, Kaski, Salyan, Surkhet, Tanahun, Bhojpur, Okhaldhunga, Doti districts	Yearly variability and impact of climate change in maize, maize yield gap, planting time, variety, N and phosphorus (P) fertilizers rate, growth and yield	Bhusal and Timsina (2010), Devkota et al. (2015), Devkota et al. (2016), Sapkota et al. (2008)
APSIM model and ground and satellite-based approaches	Wheat	Nepal Terai	Yield, soil-dependent crop yield outcomes	Campolo et al. (2021)
Nutrient expert	Rice, wheat, maize	Nepal Terai	Optimization of fertilizer recommendation using 4R stewardship	Amgain et al. (2021), Bhatta et al. (2020), Thapa et al. (2020), Timsina et al. (2021, 2022)
AquaCrop	Rice, wheat, maize	Chitwan district	Irrigation water and fertilizer management, yield response, closing yield gap	Shrestha et al. (2013a, b)
Poly-crop	Rice, wheat, maize	Solukhumbu and Kotang districts	Food security, climate change, crop yield, land use	Bocchiola et al. (2019)
DEED	Cereal crops and cropping systems	Nepal	Forecasting soil organic carbon and cereal crop yields	Adhikari et al. (2019), Acharya et al. (2019)
Climate forecasting	Cereal crops	Nepal Terai	Daily, monthly, and seasonal forecasting of temperatures, solar radiation and rainfall	Jha et al. (2019b)

Note These are few examples of some cereal crop models validated and applied in Nepal and is not the complete list of all models used

23.3.3 Estimating and Understanding Yield Potential and Yield Gaps

In irrigated system, yield potential (Y_p) is defined as the yield of a crop cultivar grown under non-limiting water and nutrient and crop

free of biotic stresses, where crop growth is determined by solar radiation, temperature, atmospheric CO_2 concentration, and genetic characteristics (Evans 1996). Y_p varies across genotypes and locations due to differences in climate, but not due to soil characteristics or any stresses such as nutrients, pests, and diseases.

Thus, Y_p (i.e., climatic potential yield) serves as the benchmark for yield gap analysis. In the rainfed system, water-limited yield potential (Y_w), the most relevant benchmark, is determined by rainfall events, soil water availability based on soil and terrain properties, and crop free of biotic and abiotic stresses.

The nutrient-limited yield gap is computed based on the economic sufficiency and deficiency of nutrients obtained from the farmers' practice (Devkota et al. 2018; Dobermann et al. 2004). The concept of yield gap (Y_g) is rooted in the production ecology and is defined as the difference between Y_p or Y_w and actual farm yield. Y_g provides a framework for contextualizing current farmer yields against Y_p in different production environments, including at the cropping systems level (Guilpart et al. 2016; Lobell et al. 2009; van Ittersum et al. 2013). Nevertheless, Y_g analysis will be of limited use for intervention prioritization in the context of agricultural development if the multiple causes of

lower productivity at the farmer's level are not identified; i.e., Y_g must be 'decomposed' by their constituent factors (Devkota et al. 2015, 2016, 2021; Lobell et al. 2009).

The prediction made by Amgain and Timsina (2004) and Krupnik et al. (2021) from several districts of Nepal showed that large Y_g existed between simulated climatic potential yield, on-station yield, farmers' yield, and national statistics. The potential yield was exceptionally high, ranging from 8 to 13 t ha⁻¹ for rice, 6–15 t ha⁻¹ for maize, and 5–8 t ha⁻¹ for wheat (Fig. 23.4, Table 23.3; Devkota et al. 2021; Timsina et al. 2021; Amgain and Timsina 2004), while remarkably low national average yields of 3.76, 2.85, and 2.82 t ha⁻¹ existed respectively for rice, wheat, and maize (FAOSTAT 2021). Considering farmers' field yields of these crops, yield gaps ranged from 4.9 t ha⁻¹ for rice, 4.5–12.5 t ha⁻¹ for maize, and 3.1–6.9 t ha⁻¹ for wheat (Table 23.3). These data indicate the existence of huge yield gaps between climatically potential

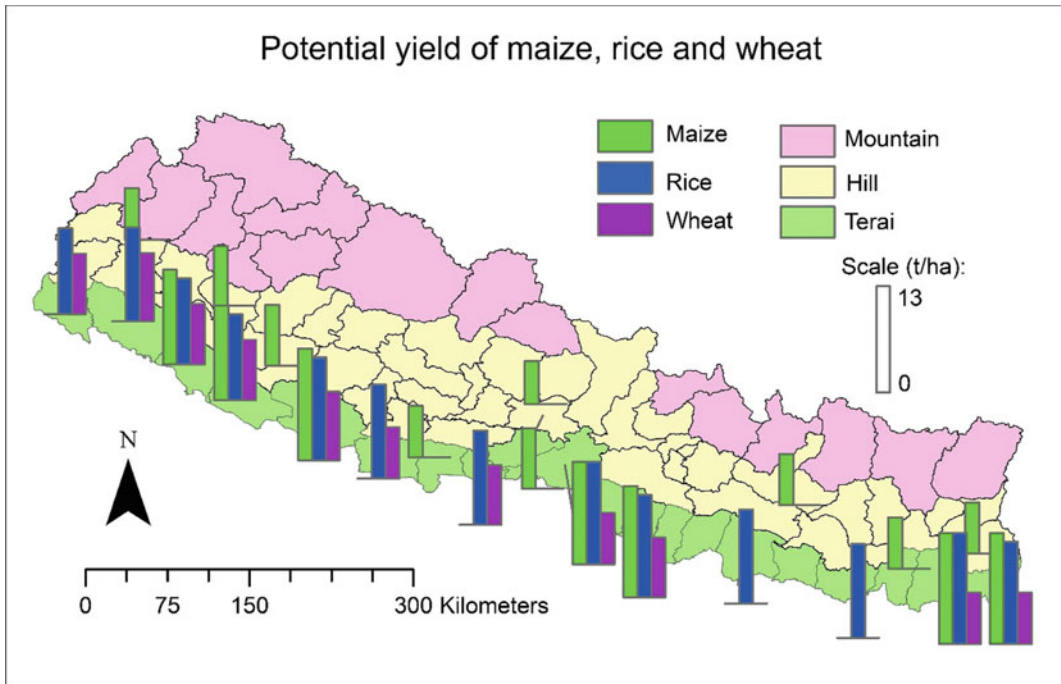


Fig. 23.4 Climatic potential yield of rice, wheat, and maize across Terai, hill and mountain agro-ecological zones (AEZ) in Nepal. Black arcs/lines represent district

boundaries. *Data source* Devkota et al. (2016, 2021); Timsina et al. (1997, 2021)

Table 23.3 Yields and yield gaps (t ha^{-1}) of rice, maize, and wheat crops in three agro-ecological zones of Nepal

Crop	Agro-ecological zones	Potential yield (A)	Research station yield (B)	Farmers' yield (C)	Yg1 ^a (A–B)	Yg2 (B–C)	Yg3 (A–C)	References
Rice	Terai	8.7	5.06	3.78	3.64	1.28	4.92	Timsina et al. (2021)
	Terai	8.1	3.40	2.74	4.10	0.66	5.36	Krupnik et al. (2021)
	Nepal	10–13	5.0	3.76	5–8	1–2	6–9	Fig. 23.4
	Terai	12	5.06	3.5	6.9	1.56	8.5	–
	Mid-hill	11	5.0	3.12	6.0	1.88	7.88	–
	High-hill	10	4.0	2.34	6.0	1.66	7.66	–
Wheat	Terai	5.5	3.06	2.39	2.44	0.67	3.11	Timsina et al. (2021)
	Terai	5.03	3.50	1.88	1.53	1.62	3.15	Krupnik et al. (2021)
	Nepal	6–8	4.0	2.82	2–4	1–2	3–5	Fig. 23.4
	Terai	8	3.06	2.61	4.9	0.45	5.39	–
	Mid-hill	8	3.5	1.07	4.5	2.43	6.93	–
	High-hill	7	3.0	1.64	4.0	1.36	5.36	–
Maize	Terai	13.4	10.11	5.76	3.29	4.35	7.64	Timsina et al. (2021)
	Terai	6.3	3.30	1.82	3.0	1.48	4.48	Krupnik et al. (2021)
	Nepal	11–13	8.0	2.85	3–5	4–5	8–10	Fig. 23.4
	Terai	13	10.11	4.15	2.9	5.96	8.85	–
	Mid-hill	15	11	2.53	4.0	8.47	12.47	–
	High-hill	11	7	1.94	4.0	5.06	9.06	–

^a Yg1 = Yield gap 1; Yg2 = Yield gap 2; Yg3 = Yield gap 3

and farmer's field yields. They reveal an urgent need for the implementation of the science-led approach to maximize cereal productivity for food self-sufficiency. This also suggests that Yg 1 (gaps between Yp and those typically obtained on research stations) was larger for rice than that for open-pollinated variety (OPV) maize and wheat, suggesting that the use of high-yielding rice varieties, good integrated soil and agronomic practices required to reduce these gaps. A recent study by Devkota et al. (2021) has shown rice Yg in the Terai region can be closed by 1.85 t ha^{-1} (48%) through the use of integrated agronomic management packages. Yg 2 (between research stations and yields obtained by farmers) was larger for wheat than the other two crops, suggesting that farmers' management for wheat was

poor; thus, the extension of recommended technologies to farmers and their adoption will help increase wheat yields and reduce Yg. The large Yg in maize can be closed through improved varieties (1.4 t ha^{-1}), fertilizer (1.75 t ha^{-1}), optimal plant population (0.9 t ha^{-1}), integrated weed management (0.87 t ha^{-1}), and with the package of best agronomic management practices from 2 t ha^{-1} (under farmers' practice) to 4.5 t ha^{-1} in the rainfed mid-hill region of Nepal (Devkota et al. 2016; Table 23.3).

Timsina et al. (1997, 2010, 2011) reported that the long-term mean Yp of rice (12 t ha^{-1}), maize hybrid (15 t ha^{-1}), and wheat (7 t ha^{-1}) estimated by ORYZA 2000, Hybrid-Maize and CERES models in Chitwan, Central Terai under optimal crop planting, suitable varieties, non-limiting

water and nutrient, and control pests and disease conditions. Sustainable intensification of crop production is required to feed the growing population. Sustainable intensification is associated with growing two or more crops with optimal inputs and management practices using short- or medium-duration high-yielding varieties, which can minimize the yield gaps (Devkota et al. 2021; Timsina et al. 2021; Amgain and Timsina 2004).

Farmers' decisions on resource allocation, prioritization, and crop management practices for closing the Yg depend on objectives, resource constraints, synergies, and trade-offs between different components/activities, thus requiring an in-depth analysis at the farm level (Silva, 2017). In this context, other methods of analyzing Yg, for instance, crop yields and resource-use efficiencies using stochastic frontier analysis (SFA) and determining technically efficient Yg (Dossou-Yovo et al., 2020; Silva, 2017). Similarly, Devkota et al. (2018, 2021) determined Yg using machine learning and categorizing farmers into different Yg groups.

23.3.4 Simulating the Impact of Climate Change on Cereal Productivity

The IPCC Third Assessment Report (IPCC 2001) projected that from 1990 to 2100, the average global temperature is likely to increase by 1.4–5.8 °C, with a substantial rise in intensity and frequency of rainfall and extreme events (floods, drought, cyclones, wildfire). The climate change scenarios for Nepal show an increase in the average annual mean temperature and rainfall; where temperature will increase by 0.9–1.1 °C in medium-term (2016–2045), 1.3–1.8 °C in the long-term (2036–2065), and 1.7–3.6 °C in 2100. Similarly, there will be an increase in rainfall by 2–6% in the medium-term, 8–12% in the long-term, and 11–23% in 2100 (MoFE 2019). The recent IPCC 6th report (Shukla et al. 2019), which consists of improved methodologies compared to the earlier reports, has projected an even higher (at least by 0.1 °C) increase in temperature. Furthermore, the projected effect of

climate change shows there might be a shift in bioclimatic conditions, which will affect the crop calendar, rainfall and temperature patterns, and glacial melting in Himalayan countries of South Asia including Nepal. Zomer et al. (2014) predicted that by 2050 over 76% of the total area may shift to a different stratum, 55% to a different bioclimatic zone, and 37% to a different ecoregion, with an upward shift in elevation of bioclimate (357 m) and ecoregions (371 m). Due to changes in those climatic factors, there will be a significant and substantial impact on the country's agricultural production, food security, and socio-economic conditions across the three AEZs (mountain, hill, and terai). Table 23.4 summarizes major projections related to climate change and its impact on food production in Nepal.

Besides the effect on grain yield, in all three AEZs, climate change impacts crop growth duration (APN 2005), planting time, and seasonal and spatial soil water balance. Such impacts result in increased disease and insect pressure and abiotic stresses, and increased demand for alternative crops and varieties (Krupnik et al. 2021). Because of the fragility, marginality, and small scale (~0.7 ha) nature of subsistence farming in Nepal, coping strategies and capacity for adaptation to climate change are also low (Bocchiola et al. 2019). Such conditions demand for the development of smart and climate-resilient agricultural practices for smallholders.

23.3.5 Simulation Models as DSS Tools for Adaptation Strategies and Input Optimization

With the current and predicted climate change conditions (IPCC 2013), an absence of appropriate adaptation strategies will exert further negative impacts on the livelihood and food security situation of the smallholder farming communities. Knowledge-driven field and landscape-scale DSS tools can provide guidance for developing adaptive crop production practices through the better choice of crops, varieties

Table 23.4 Projected climate change and its impact on cereal crops production in Nepal

Methodology/Study	Climate change scenario	Impact on cereal crops yield	References
13 general circulation models (GCM) from 67 meteorological stations in Nepal by Asia Pacific-network (APN)	Temperature increase of 2.89 °C in winter and 2.09 °C in summer in 2050 and 4.96 °C in winter and 3.67 °C in summer in 2080 compared to base year 1971–2005	Both positive and negative consequences across all three AEZs of the country	APN (2005)
Simulation using 13 GCMs by APN using DSSAT-CERES models	+250 ppm CO ₂ concentration	Rice yield: +9.5% in Terai, +5.9% in hills and +16.6% in mountains; Wheat yield: +41.5% in Terai, +24.4% in hills and +21.2% in mountains; Maize yield: +9.0% in Terai, +4.9% in hills and +15.5% in mountains	APN (2005)
	+250 ppm CO ₂ + 4 °C increase in mean temperature	Rice yield: –3.4% yield Terai, +17.9% in hills and +36.1% in mountains; Wheat yield: –1.8% Terai, +5.3% hills and +33.3% in mountains; Maize yield: –26.4% in Terai, –9.3% in hills and +26.8% in mountains	
	+250 ppm CO ₂ + 4 °C temperature +20% rainfall	Rice yield: –0.8% in Terai, –14.6% in hills, and +39.1% in mountains	
Using stochastic production functional model	Effect of climate change (rainfall and minimum, maximum and average temperature)	Rainfall variability worsen the effect of climate change. Decrease summer maize while increase rice and wheat yield	Poudel et al. (2014)
Climate–crop yield relationship and impact of climate change on rice, maize, and wheat yields in Koshi River Basin in eastern Nepal	Increased effect of temperature (disregarding CO ₂ fertilization)	In altitude <1100 m for rice, <1350 m for wheat and <1700 m for maize, crops suffer from high temperature. Flowering and yield formation processes affected. Rice, wheat, and maize yields decreased by –6 to 16%, –4 to 11%, and –12 to 3%, respectively	Bhatt et al. (2014)
	+1 °C increase in maximum temperature	–23.6 kg ha ^{–1} year ^{–1} maize yield; +44.9 kg ha ^{–1} year ^{–1} wheat yield; No effect on rice yield	
	+1 °C increase in minimum temperature	+68, +7, and +56 kg ha ^{–1} year ^{–1} increase rice, maize, and wheat yields, respectively	

(continued)

Table 23.4 (continued)

Methodology/Study	Climate change scenario	Impact on cereal crops yield	References
Poly-crop model using daily rainfall, maximum and minimum temperature, and solar radiation in Dudh Koshi river basin in eastern Nepal	Under three climate change scenarios provided by IPCC (2013) (RCP 2.6, 4.5, 8.5) during 2040–2050 and 2090–2100	Maize area increases at higher altitudes (1500–2500 m); wheat area increases between 500 and 1500 m altitudes; rice area decreases at the intermediate altitudes (250–1500 m), with some increases at 1500–1800 m altitude	Bocchiola et al. (2019)
The impact of climate change on rice production in Nepal using stochastic frontier model in 28 districts	+1 °C increase in average summer temperature	−0.48% (−4183 kg ha ^{−1} season ^{−1}) reduction in rice production	Rayamajhee et al. (2021)

and cropping systems, management practices, and inputs optimization for improved food and nutrition security.

23.3.5.1 Fertilizer Application and Site-Specific Nutrient Management

Crop simulation models can be used to optimize fertilizer and nutrient management in cereal crops and estimate their yields in cropping systems. Such models and the DSS tools and Nutrient-Expert (NE) for rice, wheat, and maize have been used for site-specific and crop demand-based fertilizer recommendations in cereal crops in Nepal. Balanced application of organic and inorganic fertilizers increases cereal yields in farmers' fields through improved soil quality and fertility and develops plants' resistance to insects and diseases. In addition, the application also improves soil nutrient balance, optimizes water application, and consequently improves the long-term sustainability of the cropping system (Devkota et al. 2016, 2018; Krupnik et al. 2021; Timsina 2018). In the recent studies by Amgain et al. (2021), Bhatta et al. (2020), Thapa et al. (2020), and Timsina et al. (2021, 2022), NE-based nutrient recommendations indicate that cereal yields, profits and energy- and water-use efficiency can be increased, energy use and GHG emissions can be reduced, and crop yield gaps can be narrowed in Terai and western mid-hills regions. A high disparity in Yp and district-specific attainable

yield exists, requiring domain-specific recommendations of N fertilizer rates varying between 65 and 208 kg N ha^{−1} (Devkota et al. 2016).

The optimal seeding date of maize is important but may vary in different locations. Seeding beyond optimal date causes prolonged growth and develops a high risk of crop failure due to temperature (hot or cold) (Devkota et al. 2015). Devkota et al. (2016) observed that the response of maize hybrids was significantly higher than OPVs to fertilizer and seeding date. In a western mid-hill district (Palpa), under rainfed conditions hybrids responded up to 180:60:60 kg N:P:K ha^{−1} while the plateaus were between 120–180 kg ha^{−1} for N and 30–60 kg ha^{−1} for P and K nutrients for OPV. Optimal fertilizer rates for both maize varieties differed based on seeding date (Devkota et al. 2016). Considering small-scale spatial soil and climatic variability, especially in hill ecology, improved understanding of farm-level nutrient management recommendations using the Nutrient Expert (NE) tool helps to make informed farmers and extensionists.

23.3.5.2 Irrigation Scheduling, Water Management, and Water and N Interaction in Cereals

Crop simulation models can also be used to optimize water management in cereals and estimate their yields under different soil and crop management practices. Application of supplementary irrigation through improved agricultural

water management, for example, water harvesting, crop demand-based irrigation scheduling, or efficient irrigation techniques helps improve and stabilize yields under the prevailing rainfall variability. In the context of Nepal, more than 65% of rice production is under the rainfed system; the application of supplementary irrigation might improve the sustainability of rice production. In a long-term simulation with ORYZA3 using historical rainfall data (where rainfall amount declined over time) in eight Terai districts of Nepal, Krupnik et al. (2021) showed that rice yield decreased by 21% under rainfed conditions, while it increased by 2% with supplementary irrigation. It indicates that with increasing rainfall variability (>27%) during the rice-growing season, the availability of irrigation facilities is the assured way for improving resilience and yield stability in the Terai region of Nepal. In the Terai region, it is possible to increase the availability of supplementary irrigation through: (i) increasing irrigated area either by building new irrigation structures and rehabilitation of old structures; (ii) constructing appropriate excess water harvesting small reservoirs for supplementary irrigation; (iii) improving on-farm agricultural water management practices; and (iv) reducing unproductive water losses through the adoption of crop demand-based irrigation scheduling and efficient application techniques (drip, sub-surface drip, sprinkler, furrow irrigation, etc.). It is envisioned that irrigation will remain a key policy and development intervention for the next few decades for the Nepal government.

From the experimental and simulation study using the AquaCrop model, Shrestha et al. (2013a, b) reported that for wet (monsoon) season, soil nutrient management is more important than water management, while for dry season (winter and spring) water management coupled with nutrient needs to be considered in central Terai region (Chitwan). They found that during the summer season, with improved nutrient management rice and maize yields could be increased by 65 and 58%, respectively; while in the dry season, with improved water and nutrient

management, wheat and spring maize yields can be increased by 197% and 100%, respectively.

23.3.5.3 Effects of Crop Varieties and Time of Planting on Simulated Yields

Maize yields in the mid- and high-hills regions of Nepal are judged to be intractably low, and few efforts have systematically assessed either the water-limited productivity potential or identified sensible entry points toward sustainable intensification that can be matched to the needs and constraints faced by farmers. Devkota et al. (2015) from the long-term simulation using CERES Maize found long maturity does not always mean high yield. The OPV maize had the lowest and the long-duration hybrids had the highest yield, with short-duration hybrids having the intermediate yield (Fig. 23.5). Devkota et al. (2017), with a rice simulation model, reported that across the AEZs of Nepal, rice can be planted starting from February up to the end of July based on the availability of irrigation water. Rice transplanting in June requires the lowest irrigation amount as it can utilize the rainfall effectively (Fig. 23.5). Varietal response, as well as the variety and seeding date interaction in yield differs significantly in rice as well. Under late planting, yield declined earliest for a long-duration variety (Swarna) but was the slowest for the short duration variety (Radha-4).

The long-term (1987–2013) simulation using CERES Maize (yearly simulation at every 10 days interval) was used to explore the opportunities for closing maize yield gaps with optimal seeding date and suitable variety for the mid-hill ecology of Nepal (Devkota et al. 2015). Authors reported that planting either before 25 April or after 20 May could reduce Yp by 19% in short-duration hybrid and by 11% in long-duration hybrid and OPV (Fig. 23.5). Fortunately, these optimum planting windows have the lowest level of intra-annual variability in Yp and the lowest risk of crop mortality before physiological maturity. In contrast, there was a sharp drop in Yp and a high risk of crop mortality with planting before mid-April due to

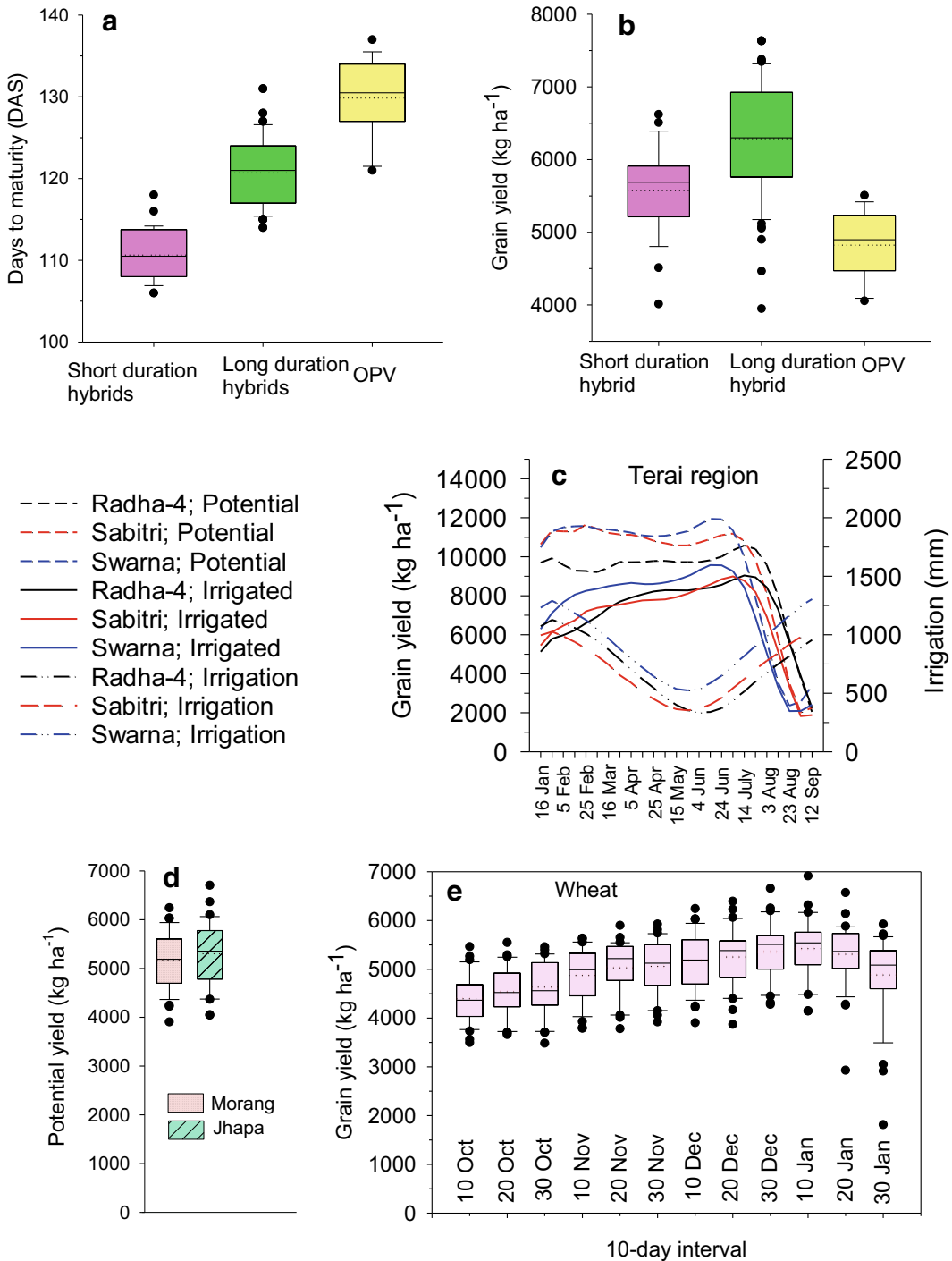


Fig. 23.5 Simulated maturity days (a) and grain yield (b) of three category maize varieties, and simulated potential and irrigated yields of three rice varieties for 13 seeding dates (spring and monsoon season rice) and the irrigation requirement (excluding rainfall) in Terai region (results from simulation for 8 Terai districts, c and

simulated potential yield for 10 January planting d and for 12 seeding dates at 10 days interval (e) for Jhapa and Morang districts. *Source* Devkota et al. (2015) for Figs. a and b, Devkota et al. (2017) for Fig. c and Timsina et al. 2021 for Figs. d and e. OPV = open-pollinated variety

moisture limitations. The implications of late planting (e. g., beyond 10 June; DOY 160) are less severe for maize Yp but come at the additional cost of delaying the establishment of the second crop in the rotation (Fig. 23.5). For wheat, Timsina et al. (2021) reported that its Yp across years ranged from 3.5 to 5.5 t ha⁻¹ (mean: 4.4 t ha⁻¹) for 10 October and from 4 to 7 t ha⁻¹ (mean: 5.5 t ha⁻¹) for 10 January planting. Further, Yp was lower, ranging from 4.0 to 6.5 t ha⁻¹ and from 4.0 to 7.0 t ha⁻¹ with a mean yield of 5.5 t ha⁻¹ in the two sites (Group 1: Babiya Birta and Itahara in Morang, and group 2: Damak and Gauradaha in Jhapa), respectively when planted on December 10th.

23.3.6 Matching Productivity Required for Self-Sufficiency

Our long-term analysis (1991–2019) using a regression model, considering the amount of imported, current production, and actual area under respective crops revealed a deficit of 0.4, 0.23, and 0.42 t ha⁻¹ of rice, wheat, and maize grains in 2019, respectively. This deficit is equivalent to the deficit of 11, 8, and 15% respectively for these crops; in terms of edible products, it is a total of 1.3 million tons (Fig. 23.2). Currently, Nepal is meeting this deficit from import (Fig. 23.6). The regression models ($R^2 = >0.65$ in all cases) showed that this gap will be much higher in 2030, where for attaining self-sufficiency, the productivity of rice, wheat, and maize needs to be increased to 5.7, 3.9, and 4.9 t ha⁻¹ to sustain the current rate of population growth (Fig. 23.2; Fig. 23.6). If the productivity remained constant (as current; 4.4, 3.3, and 3.7 t ha⁻¹ for rice, wheat, and maize, respectively) by 10 years the deficit will be 38, 25, and 25% than the required. In this scenario, the import value will be three times higher than the current amount in 2030. This analysis has clearly shown that the current effort in agronomy, breeding, and other required sciences to increase cereal productivity for achieving self-sufficiency is largely inadequate and greater efforts will be

required. As shown by the various simulation results earlier, additional gains in cereal production should come from science-led and demand-driven knowledge and technologies.

23.4 Policy Implications and Recommendations, and Limitations in Use of Simulation Models

The findings of this review conveyed the role of crop simulation models in crop yield predictions and yield gap analysis, understanding the climate change effects on crop production, and addressing food and nutrition security which would help achieve SDGs 1, 2, and 13 in Nepal. The review identified the following limitations of model use and some suggestions for policy implications in South Asia in general and Nepal in particular.

23.4.1 Limitations in Model Use

Following are the major limitations for effective use of the simulation models for answering the questions related to research, crop management, and policy implications.

- **Inadequacy of quality input data:** Input data, for example, climate, soil profile characterization, crop management, and cultivar characteristics are generally incomplete, poor in quality, and not easily accessible for immediate use of crop modeling. Also, the field experiments focus more on yield and profits and less attention is paid to collecting data that are vital for simulation modeling (especially on seeding date, dates on phenological stages, biomass yield, etc.). Most of the data found on reports are available on a percentage of phenological stages and such data do not fit well into any model as they do not meet the requirement for the model input data format.
- **Poor in communicating the model application:** The uptake of the model outputs in research and policy is low due to limited

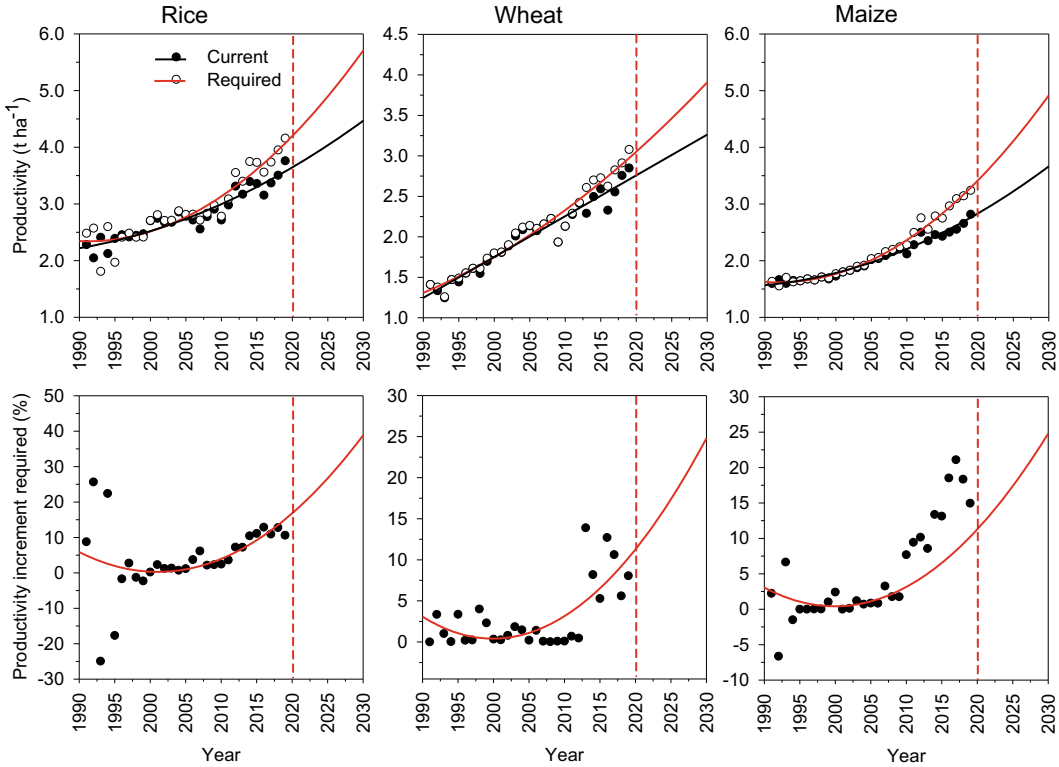


Fig. 23.6 Current and the required productivity (upper) and the percentage productivity (lower) to eliminate import and self-sufficiency in rice, wheat, and maize in 2030 in Nepal. The required productivity and percentage

are computed considering the current yearly import, the total area under crops, and yearly productivity. The lines after the vertical dotted line are the predicted trends for 2030. *Data source* FAOSTAT (2021)

exposure of model application, and insufficient appreciation and recognition by policymakers.

- **Limited availability of automated devices for continuous data:** Very limited numbers of automated devices (sensor-based soil and weather monitoring devices) are available to generate quality data required for crop modeling.
- **Lack of uniformities in the storage of weather and soil data:** There is a lack of uniformity in data management and storage. If data are available, there are tedious and bureaucratic steps to access/download and insufficient download tips and steps available publicly in an understandable way. The cloud-based secondary and remote sensing data are mostly provided as a link to big data and only a handful of researchers are familiar with such tools.

- **Poor or no capacity development for validation and applications of simulation models:** Low-capacity development for engagement and co-generation of scenarios and poor collaboration for sharing knowledge and outputs among stakeholders at different levels.
- Location-wise validation of the model demands costs and human resources.

23.4.2 Policy Implications and Recommendations

- In the context of Nepal, not much work on modeling is done so far while in the global context, simulation modeling has been used as a decision support tool, technology transfer,

and policy planning strategies. Those works have shown models have immense potential and more research work needs to be conducted on model validation and application to increase crop productivity, profitability, and achieve food and nutrition security under current and future climate change conditions.

- Development of storylines and exploration of intervention priorities at national, regional/province, and local levels for the sustainable development of the crop, live-stock, economics, climate, and land surfaces.
- Sensitivity of current agricultural production systems to climate change, the impact of climate change on future agricultural production systems, and the benefits of climate change adaptation can be better understood through risk and vulnerability assessment, and economic feasibility of adaptation strategies using simulation modeling.
- The earlier studies have indicated that except for hybrid maize, crop yields are low, and a large yield gap exists between potential and farmers' field yields. In this context, models can be a DSS tool for breeding climate resilient varieties, improved resistance against biotic and abiotic stresses, and agronomic research for improving resilience to stresses for all cereals.
- Site- and soil-specific technology development by conducting experimental and simulation studies across three AEZs to develop and evaluate smart-agricultural practices for staple cereal crops.
- Simulation models need to be applied to provide an evidence-based comprehensive methodology to support the adaptation plans at the country, regional, and local levels.
- Many models have been validated in South Asia and Nepal in different aspects. However, as of now, only a few model outputs have been utilized for the improvement of the economic, environmental, and resilience of cereal production systems.
- Most models consider only the climatic and other biophysical aspects. Future modeling works would also require combining the

socio-economic and farming systems perspective with biophysical aspects. Addressing bio-physical and socio-economic aspects would help address food and nutrition security under varying socio-economic environments.

- The application of simulation results can achieve self-sufficiency in rice, wheat, and maize to achieve the productivity target of 5.7, 3.9, and 4.9 t ha⁻¹, respectively for 2030.

23.5 Conclusions

Models are powerful, quick, and less expensive tools for quantification of yield gaps, a better understanding of integrated soil and crop management and crop diversification, and designing climate-smart agronomic practices considering climate, soil, and socio-economic interactions. These can serve as alternative and more efficient DSS tools for research and extension and in providing reliable guidance to policymakers in policy assessment and design. This review showed the potential application of crop models for improving the food and nutrition security of the country by closing the cereal deficits and improving self-sufficiency in Nepal. Models helped in recommending site- and crop-specific fertilizer rates, optimizing crop yields, developing sustainable crop and soil management practices to quantify and close yield gap, and understanding the effects of climate on cereal yields. However, potential applications of crop models addressing socio-economic issues or interactions for better policy formulation and application are lacking in Nepal and South Asia in general. Rigorously calibrated and validated crop models have great potential to improve decision-making, assist policy, reduce imports, and achieve the food and nutrition security of the country. The future of crop modeling relies on the availability of quality input data, the strength of modelers to synthesize and standardize the data, and potential user groups' ability to communicate and implement the modeling results at different levels. Though this study focuses on the

applications of simulation models in Nepal, the lessons learned here could equally be useful in other South Asian countries facing similar socio-economic and environmental challenges.

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Agrobiodiversity Management for Gender-Equitable Adaptation to Climate Change: Investigating the Gendered Roots of Vulnerability in the Nepal Himalayas

Basundhara Bhattarai

Abstract

The Himalayan region has a long history of managing agrobiodiversity as a source of livelihood, a practice that has withstood multiple forms of climatic, social and ecological risks. In the recent decades of agricultural modernization, research and development projects have sought to improve productivity of agriculture focusing on high-yielding varieties and other modes of technical efficiencies, while agricultural landscapes are undergoing rapid transformation such as rural to urban migration. In such context, there is a dilemma as to how agricultural development can be adapted to tackle climatic and socio-economic drivers, in a way that can lead to gender equality and social justice. Combining social-ecological systems approach with feminist political ecology lenses, this chapter examines the interplay between gender equity and adaptation in the Nepal Himalayas. A case study of farm-level practices with a focus on rice cultivation in a mountain village in Nepal shows how gender roles and relations are influenced by wider socio-economic changes and discusses how gender roles shape adaptation practices as households

adopt high-yielding low land rice variety and abandon upland rice cultivation. The chapter concludes that agricultural modernization has not only exacerbated gender inequality but also made the farming communities more vulnerable to climate change. It is argued that a more holistic approach to agricultural research and development is needed, with full appreciation of gender-based differentiations in knowledge, management and policy, so that agriculture can withstand the impact of climate change and the socio-economic changes that the Himalayan region is undergoing.

Keywords

Gender roles and relations • High-yielding upland rice • Lowland rice • Climate change adaptation • Nepal

24.1 Introduction

It has been over four decades since concerns for gender inequality in agriculture and rural development were raised (Arora-Jonsson 2014a, b). While some achievements have been made in different parts of the developing world, gender inequality persists in South Asia when it comes to agriculture and rural development. In Nepal, this challenge is likely to be even more complicated in the context of climate change and rapid social and economic transitions taking place in

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the country (Bhattarai et al. 2015; Paudyal et al. 2019; Paudel Khatiwada et al. 2019; Bhattarai 2020).

A large body of literature on gender and environment consistently highlights that women are denied equal access to, and control over, resources including the management of agriculture farms and crop selection (Agarwal 1994; Howard and Nabanoga, 2007; Rocheleau 1995; Rocheleau and Edmunds 1997; Rocheleau et al. 1996, 2006; Wooten 2003). This situation can negatively impact on women's decision-making capacity to choose the crops they want to grow (Chen et al. 2011) and get the needed support from the agricultural development and extension services (FAO 2011).

Despite huge investments in Nepal's agricultural development and agrobiodiversity conservation, coupled with intense efforts and policy reforms on inclusive development and gender equality, what is being done is not enough to ensure gender-based inclusion and agrobiodiversity resilience to climate change (Paudyal et al. 2019; Sujakhu et al. 2019; Nagoda and Nightingale 2017; Bhattarai et al. 2015). Even the research and development community work has too often failed to recognize the complexity of the challenge. What concerns, in particular, is that due to the lack of understanding of the dynamic interplay between gender and complex social-ecological systems among policymakers, scientists, development agencies providing extension services, local people—particularly women, poor and other marginalized—are not likely to benefit from the current adaptation strategies and practices that are being promoted at the local level. Studies consistently show that despite several technical innovations in agricultural crops management, traditional gender-based power relations have hardly changed, with women continuing to play the subordinate role, as the deeply internalized frame of hegemonic masculinity does not normally allow gender-transformative practices (Tamang 2011; Bhattarai 2018). Moreover, the achievements on the ground are limited with the possibility of widening the existing gender gap.

A huge body of literature on gender and the environment highlights that women are denied equal access to, and control over, natural resources, including crop selection and management (Agarwal 1994; Buchy and Rai 2008; Howard and Nabanoga 2007; Rocheleau 1995; Rocheleau and Edmunds 1997; Rocheleau et al. 1996; Wooten 2003). Such situations can undermine women's capacity to make decisions and choose resources in agriculture and natural resources management (Chen et al. 2011; Khadka et al. 2014).

There is also a growing body of literature that highlights that climate change impact is differentiated by gender and women are disproportionately more affected by the impact of climate change (Alston 2013; Djoudi and Brockhaus 2011; Eakin 2005; MacGregor 2010; Terry 2009).

In addition to climate change, a variety of global and local-level socio-economic changes impacting increased rate of men's out-migration leading to the feminization of agrobiodiversity management practice (Desai and Banerji 2008), shortage of farm labour (Maharjan et al. 2012) due to men's out-migration coupled with increased enrolment of girls in school, increased access to remittance, and increased access to market and road transport that allowed households to buy cheap food substitute instead of growing by themselves (ISET-N 2009). However, there is limited research knowledge on how the climatic and socio-economic changes influence gender roles and relations in the management of agrobiodiversity of the farming communities who are least mechanized—acutely dependent on manual labour and monsoon rain. Gender inequitable mindsets permeate through decisions and practices at households, community, government and even the development support community. This masculine hegemonic mindset is also vividly demonstrated in the way scientists and policymakers underestimate the local processes of change (climate change, labour shortage, transport facilities to provide cheap substitutes) and its impacts on people's livelihoods.

A few terms need defining for the purpose of this chapter. The term agrobiodiversity covers agricultural crops' biodiversity but also includes 'species diversity of crops, trees, herbs, shrubs and livestock that are part of food production, supply of nutrients in regular diet and livelihood systems at a local level. Often forest biodiversity and its management are directly or indirectly linked to the agriculture production systems including those services of crop pollination, livestock fodder production, source of water and cooking fuel. This encompassing view of agrobiodiversity builds on Brookfield (2002, p. 12), who defines agrobiodiversity as 'whole ecosystems (scale) with agriculturally managed components or the landscape, areas beyond the crop field, wild wildlife and plants other than the wild relatives of the crops'. These crops and wildlife are part of the local agro-ecosystem which provides harvestable goods to people and provide services to agriculture such as pollination Brookfield (2002, p. 12). This way they support human livelihoods and ecosystems (Brookfield 2001).

The management of these agrobiodiversity components are inextricably linked to gender relations, and any adaptation or resilience-building efforts cannot progress without tackling any gender-based inequalities (Bhattarai 2020). In order to analyze the gendered nature of agrobiodiversity management and its relationship with climate change adaptation, this chapter combines feminist political ecology (FPE) and a critical approach to social-ecological systems (SES). The analysis integrates FPE lens to interrogate heterogeneous social structure of society (Meinzen-Dick et al. 1997; Nightingale 2006; Rocheleau et al. 1996). FPE lens (Rocheleau et al. 1996) can help differentiate how men and women bring different views of problems and solutions to agrobiodiversity management. Complementing this approach, SES allows us to see the social and natural aspects as constituting the same social-ecological system. The chapter then looks at the gender-based practices, mindsets and institutions as situated in the SES, which can be exposed through the critical analysis approach offered by FPE.

The chapter is based on some recent papers (Bhattarai et al. 2015, 2018, 2020, 2021) and other ongoing studies; it discusses how gender relations and agrobiodiversity management practices are interrelated and shaped by the emerging changes and practices of agricultural development including those driven by modern science and technology in the subsistence based agrarian context of Nepal and other parts of the world similar to this. The chapter concludes that agricultural modernization has not only exacerbated gender inequality but also made the farming communities more vulnerable to climate change. The chapter argues that a more holistic approach to agricultural research and development is needed, with full appreciation of gender-based differentiations in knowledge, management and policy, so that the Himalayan agriculture can withstand the impact of climate change, reduce gendered roots of vulnerability and also lead to equitable and inclusive development outcomes.

24.2 The Himalayan Context of Agriculture, Climate Change and Gender-Based Inequalities

In Nepal, agriculture and forest sectors contribute 26% of the gross domestic product (GDP) of the country's economy (MOF 2020). Nepal's agriculture is largely a subsistence level activity of small farmers, with slow rate of commercial farming. Diverse agro-ecological zones—from sub-tropical Terai region to alpine Himalayan slopes and valleys—exist in Nepal, supporting diverse agricultural practices. In terms of society and culture, Nepal is a very diverse society, with over 100 languages and ethnic groups. In the recent years, rural to urban and overseas migration has accelerated with declining agricultural yield and increasing access to opportunities in urban areas and other countries. Subsistence agriculture is also changing as commercial farming albeit of small scale proliferate, alongside the expanding road network in rural Nepal.

Gender inequality is historically entrenched in Nepal (Bennett 2008). More recently, new socio-

economic drivers have exposed traditional gender relations, yet new studies suggest that gender inequality is being reproduced in new forms as society changes from rural to urban (Bhattarai et al. 2021). As the majority of male youths migrate out of the villages and overseas for jobs, women are taking over public roles at community levels and becoming de facto heads of the families.

Intensifying impacts of climate change have also forced people to migrate outside of the rural region. The Himalayan region is already facing the impact of climate change (Shrestha et al. 2012; Stocker et al. 2013; Gupta et al. 2019). The Himalayan region is noted to be a major 'hot spot' for climate change (Stocker et al. 2013). Climate scholarships predict that climate change will bring more droughts and shortage of water supplies in the next decades (Barnett et al. 2015, p. 306). In such situations, socio-economic realities and the underpinning societal willingness to change centuries' old caste-based hierarchies and gender inequalities will continue to impact adaptation practices, as here in Nepal, where women are increasingly taking more responsibilities for agrobiodiversity management. Despite evidence of the growing impact of climate and socio-economic drivers, there appears to be little consideration of gender-differentiated local adaptation practices at a national level (Bhattarai et al. 2015). Rather, policies and practices continue to ignore the gender-differentiated nature of agriculture and development (Paudyal et al. 2019). As a consequence, the agrobiodiversity management system in the Nepal Himalayas is likely to be more vulnerable.

24.3 Research Methodology, the Overall Context and the Study Site

The chapter draws on local-level case studies as well as wider review of literature. The case study is designed to offer important insights into multi-scale systems and practices, including how agrobiodiversity management knowledge, science, resource control and preferences to grow

different types of crops are embedded in everyday adaptation practices, and how these are linked to gender relations. These occur at household, community, national and international levels and reflect both internal and external drivers associated with wider political, economic and environmental changes, impacting the study region and other parts of the developing world. The primary data for this study were collected between 2012 and 2015 and then updated in 2019. Purposive sampling was applied to select research respondents. In-depth interviews and focus group discussions were the main tools used to collect data from men and women farmers and the representative of the government and non-government service providers including research organizations.

Nepal derives 26 of its GDP from agriculture and forest sector (MOF 2020). The sector employs more than 60% of the workforce of the country and women make more than 70% of this workforce (CBS 2007; MOF 2020). Farming is mostly subsistence-based and rain-fed meaning that the majority of the farms are not linked to irrigation infrastructure. Rice, maize, millet and barley are the major staple agricultural food crops grown (MOAD 2020) in Nepal. Average land-holding size is low, with 0.7 hectares per household (CBS 2007; NLSS-III 2011). Land ownership is usually male-centric and women own only about 20% of the total land throughout the country (CBS 2007) and the trend is increasing with a government policy of a 25% and 30% discount on the revenues (during new registration) in urban and rural areas, respectively if the land is registered/shared in a woman's name (Khanal 2019).

Livestock raising is one of the major and intrinsic components of agriculture production system (John and Sthapit 2004). Community forests are a major source of livestock fodder supply, cooking fuel (firewood), soil nutrients (humus), agricultural implements, timber and medicinal herbs. Hence, the supply of these products from forests directly impacts the livestock and crop production as well as other services that households require for their everyday livelihoods and survival.

The Himalayan region has already witnessed the impact of climate change and this change is expected to bring frequent drought, flood and erratic rainfall in future (Shrestha et al. 2012; Stocker et al. 2013; Gupta et al. 2019; Barnett et al. 2015). With rapid rate of men's out-migration and other national and local-level changes, women are taking increasingly more responsibilities of household and farm management.

The study site, the Hanspur village of formerly Hanspur Village Development Committee is located in Kaski district of Nepal in Gandaki Province. The population size of the study village is 1014 with 145 households (Community Forestry Management Plan 2012; Village Profile 2010). The main market centres are Gagangauda, Sisuwa and Begnas Lake, all on the way to Pokhara and Pokhara itself, one of the most popular tourist destinations in the country. For the last 20 years, the village has been connected with a motor-able gravel road (from the Hanspur village to Begnas Lake market centre). Hanspur village was selected from the larger Rupa landscape for its mixture of farming households of different caste and ethnic groups, with male out-migration common. Major caste and ethnic groups residing in the village include *Dalits* (low caste), *Brahmin* (high caste) and *Bhujel, Magar* and *Gurung* ethnic groups (Janjati). For the last 20 years of so the village has had electricity and a piped water supply.

Community forests are a major source of livestock fodder supply, cooking fuel (firewood), soil nutrients (humus), agricultural implements, timber and medicinal herbs. Cropping land is differentiated by function as either upland farming (*bari*) or irrigated rice fields (*khet*). In *bari*, *Ghaiya*, upland rice is cultivated along with other staple crops like maize, millet, beans, taro and green vegetables. In *khet*, mostly rice is grown. Due to increased access to road transport, the consumption of rice is increased by many folds as compared to earlier times.

A reciprocal labour sharing system (locally called as *parma*) is the principal strategy for managing farm labour. According to the respondents, there is a big shift to consume more rice compared to earlier times.

In recent years, in *khet*, farmers have replaced traditional rice varieties by high-yielding improved rice varieties, which are believed to be drought-tolerant as well. With increased incidence of drought and changes in rainfall pattern one of the traditional major crops called *Ghaiya*, grown in *bari* land have been completely abandoned from cultivation.

Livestock is an integral element of the agricultural production system for the residents, providing a source of farm manure, draught power (ploughing), income and a dietary supplement for households (John and Sthapit 2004). Main types of livestock raised by the residents include buffalo, oxen, goats and pigs. Farmers of the study site reported that they have already reduced the number of buffaloes and goats because of the shortage of livestock feed coupled with an increased shortage of household labour. With reduced flow of fodder from community forestry and reduced amount of land for pasture as all barren land used for grazing livestock are converted to forest land through new tree plantation, smallholders are facing hard time to manage their livestock feed as community forests are the major source of fodder supply.

Out-migration of youth (mostly men) under the age of 40 is another big socio-economic change happening in the research site. Local residents estimate that on average, one man per household has migrated to the Gulf countries, Malaysia, or elsewhere for work and these young men are mostly from scheduled caste groups, locally known as *Dalits*.

Remittance has brought several changes in people's life and livelihood systems in the study village. *Dalits* have invested major part of their remittance in purchasing agricultural land, mostly in the village and with this *Dalits* have become new landowners. Historically, most of the *Dalits* used to have no or nominal land ownership. The next priority thing they used their remittance is for their children's education, including the schooling of their girl child. Increased enrolment of girls in school is seen as an important social change in the village.

On the other hand, men's out-migration has significantly increased women's workload.

Managing previously male jobs like ploughing land has been a major challenge for women, as this task is culturally and physically considered men's work. Increased enrolment of girls in school also resulted in the shortage of agricultural labour in the study village.

24.4 Analysis of Changing Agrobiodiversity Management Practices and Gender Relations

Over the past 40 years or so the study site is undergoing a variety of changes in managing agrobiodiversity. Such changes have mixed implications on gender relations: some are positive and some are reinforcing existing gender inequitable relations.

This chapter presents two stories to demonstrate how farmers have changed their crop varieties to respond to climate variability and concurrent socio-economic changes. The first story is about abandonment of *Ghaiya* (upland rice) and Foxtail millet, which has positive implications on reducing women's workload but has negative implications on ecological diversity and food diversity in the local diet. Because of the hilly terrain and lack of mechanization, both crops used to be highly labour-intensive, consuming women's labour tremendously during weeding and intermittent operations. The second story is about growing drought-tolerant, high-yielding rice variety (HYV) in *khet* (low land with access to irrigation). This has increased yield but has added women's work to manage livestock feed as these improved varieties produce less amount of straw—main source of livestock feed for dry season.

24.4.1 Abandonment of Upland Rice and Foxtail Millet and Impacts on Livelihoods and Gender

In the research site, abandoning the cultivation of some traditional crops including *Ghaiya* (upland rice) and foxtail millet (*Kauno*) has been one of

the response strategies for managing agrobiodiversity in the face of changing climatic patterns and household labour shortage. Traditionally, *Ghaiya* used to substitute for rice grown in *khet*. Indeed, locals reported that farmers had begun to abandon *Ghaiya* from cultivation some 20 years ago. Frequent delays in monsoon and pre-monsoon rainfall, or no rainfall, during the pre-monsoon season, resulted in a sharp decline in crop yield and these factors drove farmers to abandon these crops. One of the farmers' interpretations was like this:

We never know when the monsoon starts. Despite this uncertainty we keep sowing *Ghaiya* every year at the same time with the hope of getting rain at the usual time. In some years, when the rain is delayed, we hardly get any produce but spend tremendous amount of labour and other inputs. [(Small landholder *Dalit* man 1)]

Along with uncertainty and lack of rainfall during the cropping cycle of *Ghaiya*, there were other drivers including the shortage of household labour, increased flow of remittance and availability of cheap substitutes in the market due to the expansion of the road network to the village. These contributed to abandoning the *Ghaiya* which otherwise weighing the cost of production over benefits. One woman narrated her experience on why she abandoned *Ghaiya* in the following way:

I do share-cropping on others' land as my family own little amount of land. I stopped cultivating *Ghaiya* as it started to sharp decline in yield as compared to earlier years. Some years with the occurrence of long period of drought, it declined almost by 50 percent. This situation prompted me to stop growing *Ghaiya* and investing in labour, seed, and fertilizer instead started to work as a daily wage labourer which I feel more secured than growing *Ghaiya* myself. Good thing is that because of the proximity to market I can easily buy rice from the local shop using my wage money. [(Small landholder *Dalit* woman 4)]

Another crop that farmers almost abandoned is *Kauno* because of the frequent delays in pre-monsoon rain that affect its germination and harvest cycle. Usually, the cropping cycle of *Kauno* starts during pre-monsoon rain and its harvest time is just before low land rice planting

time so landowners can avail the same land for rice planting. When there is a delay in pre-monsoon rain, the germination of *Kauno* seed is also delayed, resulting in delayed ripening. In this case, the majority of the farmers tend to destroy the whole *Kauno* crop just before it ripens in order to prepare the land for rice planting. Rice being major staple crop and gets preference over *Kauno*. When all these factors interact, farmers reached to the decision not to grow *Kauno* and this way they can save the cost of seeds, labour and other inputs in anticipation of an unpredictable monsoon season.

Despite the reduction of crop diversity (ecological diversity) and people's diet, abandoning *Ghaiya* and *Kauno* has positively contributed to reducing women's workload. The cropping technology for both of these crops was highly labour-intensive and this task is carried out primarily by women. Respondents reported that women used to spend almost two months in the

hottest months of the year undertaking the tedious and difficult task of weeding these crops, working with a tiny trowel—locally called *kuto*. In addition, post-harvest food processing technology for *Kauno* was also found to be too laborious. A man respondent commented that:

Abandoning *Ghaiya* and *Kauno* has, in fact, liberated women from such a laborious job. By abandoning these crops women could save their time and could use their labour for other works [(Large landholder, high caste man 2)]

These narratives clearly indicate that with increased incidence of climate variability and changes in socioeconomics prompted household decision-making processes of abandoning the above crops from cultivation as shown in Fig. 24.1. Despite positive changes in women's drudgery, abandoning these crops contributed to reduce crop diversity hence reducing food diversity in the diet. Reduced diversity can compromise ongoing ecological functions of the site.

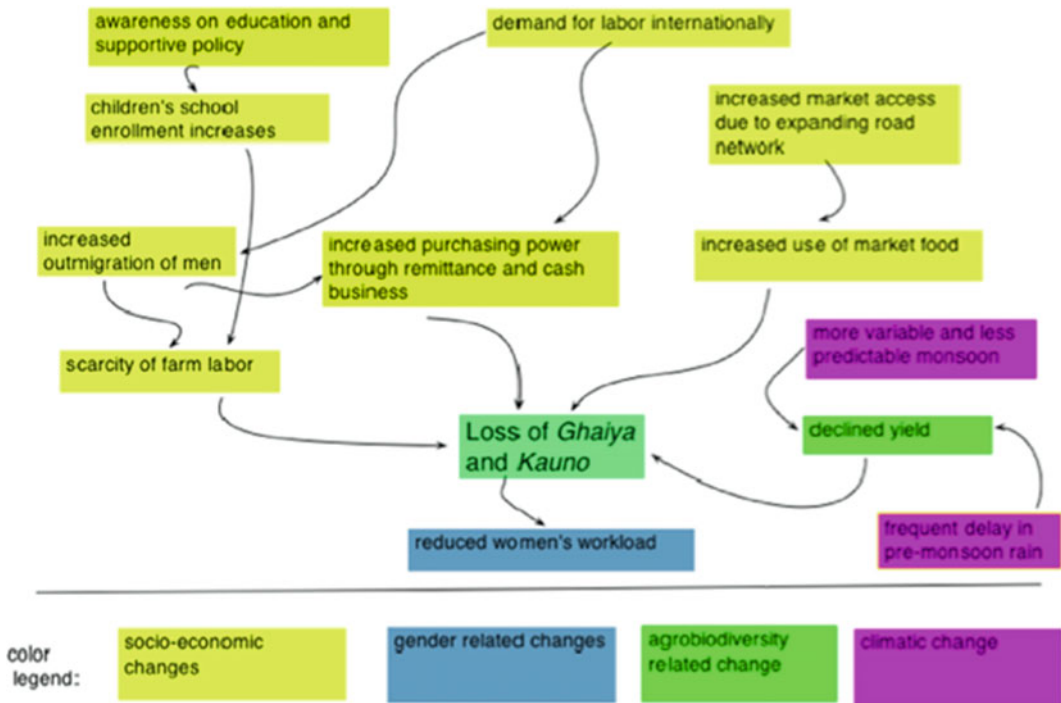


Fig. 24.1 Complex interaction of climatic and socio-economic drivers led to the abandonment of upland rice (Source Bhattarai et al. 2015)

24.4.2 Adopting High-Yielding Rice Varieties, Gender Equality and Scientific Knowledge

The majority of the farmers, specifically of the smallholders, from the study village, own *khet* but rarely connected to irrigation channels, which means that they acutely depend on monsoon rainfall. With increased uncertainty of monsoon rain and increased incidence of dry periods and shortage of winter rainfall, a large number of farmers from the study site have started growing high-yielding improved rice varieties in their *khet* land. These seeds and associated cropping technologies are also easily available to the farmers. These varieties not only have greater drought tolerance capacity but also have shorter harvest cycle (MOAC 2010). As the harvest cycle ends before the start of winter, the yield cannot be compromised because of possible winter drought.

Despite high-yielding attributes, these rice crops have some negative effects too. These crops produce little amount of straw to feed livestock which otherwise used to be the main source of livestock feed during winter. Clearly, this has increased women's workload to find alternative ways of organizing, harvesting and transporting livestock feed.

Once these seeds were available, we could get more yield but the reduction in rice straw has increased women's burden in managing livestock feed. These days, my wife needs to visit distant forests more frequently to get fodder/grasses for our buffaloes. [(Small landholder *Dalit* man 1)]

The choice of improved rice crops resulted in from the combination of high yield potential of the crops that can grow on poor quality land that most of the smallholders own. Most of these smallholders are from Dalits who recently bought these *khet* from other caste groups, who are migrating to cities.

The selection of high-yielding varieties may contribute to increased yields, but it has also increased women's work in other aspects of their livelihoods. The innovation and production of such improved seeds do not align with women's

other responsibilities, including managing live-stock feed. The farmers could choose these rice crops when seeds of these crops were available from the government research centre called National Agricultural Research Organization (NARC). These crops produce lower yield of straw, which is used as important livestock feed for use in the winter and dry seasons. Because of the reduced supply of livestock feed and labour shortage, farmers seemed to reduce the number of large livestock and this livestock were an important source of bio-fertilizer.

Besides, the adoption of high-yielding improved seeds produced by the NARC, and disseminated by the agricultural extension services, it is also likely to make the agrobiodiversity-based livelihoods of the small landholders more vulnerable (maladaptive). Furthermore, the potential reduction in the flow of bio-fertilizer (through the reduction in numbers of large livestock) is further likely to reduce crop yields in the longer term, because smallholders have limited capacity to buy chemical fertilizer and the other alternative inputs that these HYVs require. As a smallholder *Dalit* woman said:

We grow high yielding improved rice both in our (family) owned and share-cropped land to get more yield, but in return we get little straw to feed our buffalo. Keeping at least a buffalo and a pair of oxen is necessary for the supply of bio-fertilizer, dietary supplement for family members and for ploughing. It is becoming very hard for smallholders like my family to keep these livestock as we are already experiencing a reduction in the supply of fodder from other sources as well e.g., community forests. [(Small landholder *Dalit* woman 1)]

Continued focus on the production of such improved seeds undermines other livelihood options. For example, livestock are not only the main source of bio-fertilizer but also important for land preparation (ploughing) and the important source of family income.

When discussing with government extension worker on why such low straw-yielding seed varieties were produced, he opined that

Our researchers hardly carry out any consultations with the farmers before producing a new agricultural variety. I, as an extension worker, had to face

a hard time when the farmers asked whether agricultural research could produce a high straw yielding improved variety. [(Government male field extension officer 1)]

The problem lies with the narrow thinking of the scientists who seemed less capable or seemingly ignored the local livelihood systems of the communities. Narrow understanding of these scientists who tend to solve food security problems by just one means by availing improved rice seeds and could not think about follow-on effect of these practices to the overall wellbeing of the people and livelihoods associated with.

An important interpretation of such practices is that the production of high straw-yielding variety was not prioritized or even thought of, because women's need is not adequately recognized and the mindsets of the agricultural scientist and associated agricultural development services may think the implications as less significant. This seems very narrow definition of efficient production focusing only on aspects of human diet, ignoring other important dimensions of human diet when the production system was not feasible to raise livestock—source of regular protein (mainly dairy products), source of family income (sale of meat and dairy). More importantly, the practice has undermined the intrinsic elements of agri-based production systems.

24.5 Exploring Gender and Adaptation Link: Three Key Themes

Taken together, the two examples illustrated before show complex interactions between agrobiodiversity management practices and gender roles and relations. The combined effects of changing climate and wider socio-economic conditions are linked to impact on local agrobiodiversity and gender in the study site. The following three analytical points offer further analysis of how the above-mentioned choice of crops for cultivation has impacted gender roles and relations.

First analytical thread is derived from adoption of high-yielding rice variety is that gender

inequality is exacerbated in the study village. This is because the scientific knowledge of producing high-yielding rice pays little attention to women's livelihood needs. Feminist policy ecology literature highlight, women's increased access to formal scientific knowledge can address existing gender inequalities (Howard 2007; Rocheleau et al. 1996). In the study village, all the farmers including women have access to this knowledge irrespective of social categories. Women are often not regarded as farmers and easy access of such knowledge by women can be seen as progressive step toward gender equality. Even with reduced level of extension services, multiple socio-cultural factors might have contributed to acquire such knowledge by women. These factors include increased access to road networks; communication technology (mobile phone, radio and TV); a culture of exchanging seeds and cropping technology within expanded families, principally sourced in the women's natal villages; and the continued practice of *parma* (labour sharing), which used to be one of platform of sharing such knowledge and information.

Despite women's increased access to knowledge—availability of improved seeds and cropping technology, gender inequity is exacerbated because the science used for the production of improved rice varieties ignored women's roles in the larger food production systems. First, this has tremendously increased women's workload in managing livestock feed from alternative sources such as community forests. Women's workload is further exacerbated with reduced supply of fodder from community forests (Bhattarai 2020). Second, as mentioned, here the reduction of rice straw has multiple and chain-like effects such as reduced supply of rice straw contributed to reduce the number of large-sized livestock and this reduction in livestock reduced family income (important family income buffer) and reduced the supply of people's diet noting that dairy is the most common source of protein in the villages of Nepal. Third, farmers might not be able to harness the full potential of high-yielding varieties with reduced flow of locally produced bio-fertilizer. This means farmers have to depend

on imported chemical fertilizer, which is often short in supply when farmers need, and poor farmers might not be able to afford too.

Second thread is cross-scale interactions between crop selection, livestock raising, access to irrigation infrastructure for rice planting, flow of remittance and agricultural development services such as producing high-yielding rice varieties as way to adapt to drought and food security continue to penetrate and reproduce particular forms of gender inequality in the agrobiodiversity management of the study village. This is consistent with cross-scale dynamics, as argued by SES scholars (Berkes and Folke 1998; Walker and Salt 2006; Walker et al. 2004) and as demonstrated above in the example of high-yielding improved crops, gender-equitable adaptation is the outcome of scientific knowledge (innovation of high-yielding rice in this case), and access to this knowledge at multiple scales of management. For example, national research organizations produced improved seeds to enhance the productivity. For example, despite increased yield from improved crop varieties, national research organizations produce improved seeds that created high costs for women, particularly in small land-holding households, in the management of livestock feed. This analysis clearly shows gender-equitable practices are not only confined to household level processes, but the processes operate at higher scales, including those of support organizations' approaches in the production of knowledge.

Third thread shows that increased levels of agrobiodiversity are generally considered to be a property contributing to a social-ecological system's resilience. In general, rich biodiversity is assumed to be helpful in maintaining ecological resilience which can be maintained by low-input production processes (Johns and Sthapit 2004). However, critical systems thinking and the analysis of FPE literature do not necessarily help address subsequent social resilience. Often social resilience depends on power, access to resources and possession or access to knowledge. Here the argument is that increased agrobiodiversity can offer more options to local livelihoods (Adger 2000; Walker and Salt 2006), if the adaptation

interventions are not maladaptive—improvement in one aspect costs to other. Also, speaking from social resilience (gender equity in this case) point of view we can't make a conclusion that increased level of agrobiodiversity will bring positive impacts on women's roles and vice versa. As shown in this research abandonment of crops such as *Ghaiya* and *Kauno*, means reduced agrobiodiversity, contributed to reducing women's workloads as the cropping and post-harvesting work used to be highly labour-intensive. Instead, the findings of the research partly resemble with the findings Isakson (2011, p. 1444) who found that 'quality of land owned by the farmers can have positive correlation with crop diversity'.

In summary, the study found that the simultaneous interaction of climate variability and socio-economic conditions provided the 'multiple shocks' that led to the potential reduction in agrobiodiversity, and mixed outcomes for women's workloads. Alongside, with men's increased out-migration together with the enactment of government policy for girl's compulsory enrolment in school, both contributed to increase women's workload. On the other hand, flow of remittance and increased access to market to buy cheaper substitutes contributed to abandon the crops which are no longer feasible to continue. Scholars also argue that despite the loss of crop variety from the system, in the longer term, investment on girl's education can enhance their power to speak up against gender discriminatory practices (Quisumbing and Pandolfelli 2010).

These three analytical threads clearly indicate the need for a more nuanced analysis of the challenges and opportunities for gender-equitable agrobiodiversity management while the study village undergoing climatic and wider socio-economic changes.

24.6 Conclusions

Agrobiodiversity resources in Nepal Himalayas are the mainstay human survival and livelihoods. This chapter has discussed how the persistence of gender inequality in agrobiodiversity management

has led to the vulnerability of local communities to climate change, especially women. It has identified masculine mindsets in agricultural research, development and policy that ignore or underestimate climatic and socio-economic challenges which agrobiodiversity-dependent households and communities are facing. As climate change and socio-economic drivers impact agrobiodiversity systems, gendered roots of vulnerabilities have become critical in enhancing inclusive adaptation. The adaptive capacity of households and communities is contingent, to a large extent, upon how and to what extent gendered forms of knowledge and power are linked or disconnected in management practices, research and technology development and policy.

Overcoming gender inequality is critical to the achievement of Sustainable Development Goals (SDGs), mainly gender equality (SDG 5) and food security (SDG 2). Any attempts to enhance gender-equitable adaptation in agrobiodiversity management must consider the dynamic links between social, ecological and agrobiodiversity management systems, as well as the agency of women and men to reshape mental models, behaviours and practices that entrench inequitable gender relations. Research and development practices must take a systems approach considering both biophysical and social components. Agriculture and rural development need to be supported by a nuanced view of the interplay between gendered forms of knowledge, power and decision-making practices in specific social, political and environmental contexts. It is also important to address gender inequity through the analysis of intersectionality based on caste, ethnicity and class.

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