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Closing Rice Yield Gaps in Asia

Innovations, Scaling, and Policies for Environmentally Sustainable Lowland Rice Production

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To the smallholder rice farmers, who are battling every day to provide food for billions of people.

Foreword

Rice is the staple food for some 4 billion people worldwide. The 90 million (harvested) hectares of irrigated lowlands in Asia represent 60% of the global rice area and produce 75% of the world's rice. Irrigated rice is Asia's most important agricultural ecosystem, and population increases require at least 1.5% annually to achieve food security. The gap between attainable yield as the mean yield of the top decile of farmers as a site and the actual yield of all farmers (yield gap) is considerable in Southeast Asia at some 2.5 tons per hectare in Asian rice granaries. To close these yield gaps, one must avoid the negative externalities that have led to environmental degradation in many agricultural landscapes since the Green Revolution. Sustainable intensification of rice production needs to be carried out while at the same time minimizing the load of agrochemicals (fertilizers, pesticides) in soil, water, and air and the emissions of greenhouse gasses that contribute to global warming. Increased environmental sustainability must also be accompanied by enhanced social and economic sustainability, which requires sustainable rice value chain upgrading. This requires an interdisciplinary approach with an innovation platform that facilitates the integration of the various disciplines, research topics, and the different stakeholders of the rice value chain and linkages to national programs to disseminate research results.

The Swiss-funded Irrigated Rice Research Consortium (IRRC) was initiated in 1997 to promote interdisciplinary research among rice-growing countries in Asia. Its main objective was to develop partnerships to facilitate national agricultural research systems research. The IRRC established linkages between the previously established research groups and networks. Activities were planned under six major workgroups: Integrated nutrient-pest management, hybrid rice, water saving, weed ecology, rodent ecology, and postharvest management. From 1997 to 2008, the IRRC led to exciting progress for a number of natural resources management technologies and processing, resulting in increased production by smallholder farmers in the irrigated lowland rice ecosystem. While outreach programs had been established in Myanmar, Indonesia, and Vietnam, a more integrative approach was needed to work with national partners to scale the research findings. This was facilitated through the Swiss-funded successor project Closing Rice Yield Gaps in Asia (CORIGAP), which was co-funded by the national governments of China, Indonesia, Myanmar, Sri Lanka, Thailand, and Vietnam from 2009 to 2023.

The Vision of CORIGAP was to continue to co-develop science-based tools to close yield gaps while protecting the environment; implement effective and widespread diffusion of project outputs, leading to improved production systems that increase the livelihoods of smallholder rice farmers; and meet the increases in rice production required to maintain food security in Asia. More emphasis was placed on sustainable rice production, biodiversity, and agri-food chains, developing and implementing the communication channels and knowledge products required for reaching the farmers as end users and other value chain actors, decision and policymakers. The indicators for sustainable rice production that are now part of the Sustainable Rice Platform (SRP) certification are based on initial work during the IRRC and were developed and verified with partners under CORIGAP.

This book contains key lessons learned from CORIGAP, such as detailed documentation of the implementation, dissemination, and impact of the CORIGAP project. It presents actionable research findings with the experience of bringing these findings into use. It provides a wide array of pathways to impact sustainable rice production in lowland irrigated rice-based agricultural systems.

The book was written by CORIGAP scientists and partners representing local actors of the rice value chain, researchers, and engineers working on a range of best management practices, climate-smart rice production innovations, knowledge translation, and dissemination, as well as decision-making and policy aspects. The contents of this book can be translated into messages that can help farmers, extension workers, policymakers, and funders of agricultural development decide on implementing best management practices and climate-smart technologies in their agroecological systems by presenting the technological/practical options along the rice value chain and partnerships and business models required for their implementation.

The book is aimed at practitioners, researchers, and engineers interested in information on current best management practices, sustainable and climate-smart rice production, and constraints that need further investigation. Furthermore, the book is also aimed at policymakers and agricultural development funders required by public opinion and legally binding agreements to reduce greenhouse gas emissions, conserve biodiversity, and increase agroecological practices, who are looking for research-based evidence to guide policymaking and implementation.

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Preface

Paradigms of development have changed over the last decades from being focused mostly on fast economic growth to sustainable growth including social empowerment and an environmentally friendly approach for agricultural development. Agricultural development in Asia has undergone multiple phases and adapted to new challenges emerging from changes in climatic conditions to sociopolitical imbalances. Currently, the United Nations (UN) 2030 Agenda with its 17 sustainable development goals (SDGs) aims to structurally fight poverty and emphasizes the promotion of environmental sustainability. In this context, Swiss foreign aid is striving for sustainable development aligned with the UN's goals. The main objectives of Swiss development cooperation are ending poverty and promoting peace. Therefore, one major area of work is agricultural development with a strong focus on smallholder farmers (farm size is less than 2 ha). These constitute the majority of the world's farmers who are particularly vulnerable to economic and environmental changes. Asia has the highest number of smallholders who predominantly cultivate staple crops, such as rice. Yields and profitability are generally low due to a lack of knowledge of new technologies and challenging access to innovations.

Although the Green Revolution has modernized agriculture in the world and contributed considerably to ensure food security, particularly in Asia, farmers today must deal with the negative effects of the unsustainable use of natural resources and new threats to food security such as the negative effects of climate change. Environmental degradation has become prevalent in many regions and Southeast Asian countries are especially affected. In addition, climate change is exacerbating the current challenges by accelerating sea-level rise and saline intrusion into waterways in coastal areas and deltas, intensifying extreme weather events, and changing climatic patterns. Hence, the adoption and diffusion of agricultural best management practices and technologies for climate-smart and sustainable farming are crucial for ensuring rural livelihoods and global food security. The Swiss-funded 'Closing Rice Yield Gaps in Asia with Reduced Environmental Footprint' (CORIGAP) project, which ran from January 2012 to March 2023, explored how to improve smallholder agricultural productivity and profitability in five major rice granaries of Southeast Asia and one of East Asia by disseminating sustainable farming practices and technologies.

The scope of the book is a detailed documentation of the implementation, dissemination, and changes brought by the CORIGAP project in Sri Lanka, Myanmar, Thailand, Vietnam, Indonesia, and China with spillover to Cambodia and the Philippines. The contributions pull together actionable research findings with the experience of bringing these findings into use. An impressive array of pathways to change for sustainable rice production in lowland irrigated rice-based agricultural systems is presented. The book was written by a combination of local actors involved in the rice value chain and researchers and engineers working on a range of best management practices, climate-smart rice production innovations, knowledge translation, and dissemination, as well as decision-making and policy aspects. The contributors distill key messages that can help farmers, extension workers, policymakers, and funders of agricultural development, decide on implementing best management practices and climate-smart technologies in their agroecological systems.

An important focus is the presentation of practical technological options along the rice value chain and the partnerships and business models required for their implementation. The book is aimed at practitioners, extension specialists, researchers, and engineers interested in information on current best management practices, sustainable and climate-smart rice production, and constraints that need further investigation. In addition, the outputs and outcomes of the CORIGAP project captured in this book provide policymakers, the private sector, agricultural extension specialists, and agricultural development funding agencies pathways based on evidence-based research to reduce greenhouse gas emissions, conserve biodiversity, and increase the acceptance of good agroecological practices.

The book is divided into seven chapters.

- Chapter 1 introduces the audience to Swiss foreign-development aid and how it benefits agricultural development in Asia. A retrospective historical documentation of the project development, the different phases of the CORIGAP project and agricultural development in Asia in general are introduced.
- Chapter 2 discusses the environmental, social, and economic challenges in lowland rice production. It introduces each of the CORIGAP countries, five in Southeast Asia (Sri Lanka, Myanmar, Thailand, Vietnam, and Indonesia) and China in East Asia. Discussed are respective rice-cultivation methods, the development of the rice sector as well as constraints and opportunities for the respective countries. The authors provide case studies of the respective countries with detailed descriptions of the individual specific circumstances.
- Chapter 3 adds an ecological dimension by presenting research findings on faunal biodiversity in rice-dominated wetlands, which is an essential contribution to sustainable lowland rice production. This chapter highlights the importance of wetlands by outlining the constant decline thereof over the last decades due to human activities and climatic changes. The authors provide case studies on the positive ecosystem services provided by amphibians, bats, birds, and rodents (impacts of native versus introduced pest species) living in and around irrigated rice cropping systems.

- Chapter 4 provides an overview of a range of best management practices and technologies that have been developed, introduced, and promoted as part of the CORIGAP project. The chapter reviews the main features and benefits of technology introduction and adoption and some barriers to adoption. A special focus is placed on 'One must Do—Five Reductions' (1M5R) in Vietnam, nutrient management in Indonesia, ecological engineering in Cambodia (which benefitted from CORIGAP technologies), and various mechanization technologies across all CORIGAP countries.
- Chapter 5 provides recommendations on managing the carbon footprint of flood-irrigated rice production. Different ways of reducing the carbon footprint are described in case studies from the CORIGAP countries. CORIGAP interventions have been implemented for almost a decade and have helped to substantially reduce greenhouse gas emissions. This chapter provides a synthesis of science-based evidence and knowledge about life-cycle assessment to quantify emissions and impacts on emissions from closing rice yield gaps.
- Chapter 6 reflects on pathways for scaling of CORIGAP technologies using a multi-level perspective. Impact at scale is one of the most desired outcomes in agricultural development. The authors evaluate the extent to which novel technologies and practices lead to wider benefits. Also highlighted is the importance of partnerships and local champions, and the involvement of a plethora of stakeholders. Case studies emphasize the process of partner engagement and ownership of CORIGAP. Furthermore, the authors highlight the benefits of linkages with other projects and how findings from farmer-participatory adaptive research inform a broad policy context that, in turn, aided outreach and impact.
- Chapter 7 addresses changes and lessons learned from the CORIGAP project. Several activities have taken place in multiple countries, each facing a variety of challenges that are presented as lessons learned. Furthermore, the authors harness and distill outcomes from the CORIGAP activities and studies and analyze a range of outcomes and associated pathways to impact that have been identified during the project cycle.

Nairobi, Kenya — Melanie Connor
Laguna, Philippines — Martin Gummert
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World Bank—VnSAT project, Vietnam
Project Coordination Unit, Agriculture Competitiveness Project, Vietnam
Sub-Institute of Agricultural Engineering and Postharvest, Vietnam
Faculty of Economics and Development Studies, University of Economics, Hue University, Vietnam
Hue Agricultural University, Vietnam
Nong Lam University, Vietnam

International and Private Sector

APV, Direct seeding equipment manufacturers in Austria
Australian Centre for International Agricultural Research (ACIAR)
CLAAS, Germany
Crop Tech Asia CTA, Thaus Co., Ltd., Thailand
DLG, German Agricultural Society
GrainPro, Inc., Philippines
Kellogg's Company (multi-national)
Nestle (multi-national) MARS (multi-national)
LEHNER Agrar GmbH, Germany
Trimble, Australia
Myanmar Rice Federation (Myanmar Rice Industry Association)
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Dr. Melanie Connor is a senior scientist at the International Rice Research Institute, specializing in behavioral science and international Development. Her research primarily focuses on decision-making in agriculture and rural development, specifically on food system transformation and crop diversification to address climate change challenges, biodiversity loss, the reduction of natural resources, and the triple burden of malnutrition. She has been part of Phases II and III of the CORIGAP project focusing on documenting the outcomes and impacts and harnessing the lessons learned.

Engr. Martin Gummert is an agricultural engineer and was a senior scientist leading the Postharvest and Mechanization Cluster of the International Rice Research Institute until 2022. He advocates for better postharvest management to improve the quality of rice and reduce losses caused by spoilage and pests. His time at IRRI centered on extracting more value from rice harvests through improved quality, processing, market systems, and new products. In 2020, he became the project coordinator for the Closing Rice Yield Gaps in Asia with Reduced Environmental Footprint Project (CORIGAP), funded by the Swiss Agency for Development and Cooperation (SDC). He supported all the knowledge management initiatives and impact documentation until the project closed.

Dr. Grant Robert Singleton was a principal scientist at the International Rice Research Institute until 2019, a visiting Professor at the University of Greenwich, UK, and an adjunct professor at Northern Arizona University, USA. He was the coordinator of the Irrigated Rice Research Consortium (IRRC) and the Closing Rice Yield Gaps in Asia with Reduced Environmental Footprint (CORIGAP) Project funded by the Swiss Agency for Development and Cooperation (SDC) until his retirement. A world expert in ecologically based rodent management, he is also involved in cross-cutting research in natural resource management.

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Abbreviations

$US	US dollar
1M5R	One must-do, Five reductions
3CT	Three Controls Technology
AC	Advisory Committee
AED	Agricultural Engineering Division
AFT	Axial Flow Thresher
AIAT	Assessment Institute for Agricultural Technology
APC	Agricultural Production Cooperatives
AWD	Alternate Wetting and Drying
BDM	Becker, DeGroot and Marschak
BPTP	Balai Pengkaijan Teknologi Pertanian
CAPI	Computer-Assisted Personal Interviews
CF	Carbon Footprint
CFL	Continuous Flooding
CH_4	Methane
CORIGAP	Project “Closing rice yield gaps in Asia with reduced environmental footprint”
CORRA	Council for Partnership on Rice Research in Asia
CROP	Cost Reduction Operating Principles
CRRC	Chainat Rice Research Center
DARD	Department of Agriculture and Rural Development (Vietnam)
DLG	German Agricultural Society
DoA	Department of Agriculture
DS	Dry Season
DSR	Direct Seeding
DSRC	Direct Seeded Rice Consortium
FAO	Food and Agriculture Organization of the United Nations
FP	Farmers’ Practice
GAP	Good Agricultural Practice
GDP	Gross Domestic Product
GDRRI	Guangdong Rice Research Institute

GHG	Greenhouse Gas
GHGEs	Greenhouse Gas Emission
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
GlobalGAP	Global Good Agricultural Practice
GRET	Professionals for Fair Development
GWP	Global Warming Potential
ha	Hectares
HACCP	Hazard Analysis and Critical Control Points
HRRC	Hybrid Rice Research Consortium
HYV	High-yielding Varieties
IAARD	Indonesian Agency for Agricultural Research and Development
ICFORD	Indonesian Center for Food Crops Research and Development
ICM	Integrated Crop Management
IFPRI	International Food Policy Research Institute
INS	Indigenous Nutrient Supply
IRRC	Irrigated Rice Research Consortium
IRRI	International Rice Research Institute
ISO	International Organization for Standardization
IWM	Integrated Weed Management
JICA	Japan International Cooperation Agency
K	Potassium
l	Liter
LA	Learning Alliance
LCA	Life Cycle Assessment
LKP	Layanan Konsultasi Padi
LLL	Laser Land Leveling
M&E	Monitoring and Evaluation
MAFF	Agricultural Engineering Department of the Ministry of Agriculture, Forestry and Fisheries (Cambodia)
MARD	Ministry of Agriculture and Rural Development
Mha	Million hectare
MoA	Ministry of Agriculture (Indonesia)
MoALI	Ministry of Agriculture, Livestock and Irrigation (Myanmar)
MRD	Mekong River Delta
MRDI/CESD	Myanmar Development Resource Institute's Center for Economic and Social Development
MRF	Myanmar Rice Federation
MSP	Multi-Stakeholder Platforms
MSU	Michigan State University
Mt	Megatons
N	Nitrogen
N_2O	Nitrous oxide
NAMA	Nationally Appropriate Mitigation Action (Thailand)
NARES	National Agricultural Research and Extension Systems
NUE	Nitrogen use Efficiency

OECD	Organization for Economic Co-operation and Development
P	Phosphorus
PAPI	Pen-and-Paper Personal Interviews
PGPR	Plant Growth-Promoting Rhizobacteria
PIPA	Participatory Impact Pathway Analysis
PPDG	Pioneer Postharvest Development Group
PPP	Public-Private Partnership
PPS	Plant Protection Services
PTT	Integrated Crop Management (Indonesia)
R&D	Research for Development
RAISA	Rawa Intensif, Super dan Aktual
RCM	Rice Crop Manager
SA	South Asia
SBD	Solar Bubble Dryer
SDC	Swiss Agency for Development Corporation
SDG	Sustainable Development Goals
SEA	South East Asia and the Pacific
SERASI	Selamatkan Rawa, Sejahterakan Petani
SFLF	Small Farmer, Large Field
SFMDP	Small Farm Machinery Development Program
SRP	Sustainable Rice Platform
SRR	Seed Replacement Rate
SSFFMP	South Sumatra Forest Fire Management Project
SSNM	Site-specific nutrient management
t	tons
TFP	Total-Factor Productivity
TOC	Theory of Change
TPP	Target Product Profile
TPR	Transplanting
UN	United Nations
UNEP	UN Environment Programme
UPJA	Usaha Pelaganan Jasa Alisintan (Agricultural Equipment and Machinery Service Business)
UPSUS	Special Efforts Program (Indonesia)
USAID	United States Agency for International Development
VietGAP	Vietnamese Good Agricultural Practices
VnSAT	Vietnam Sustainable Agricultural Transformation
WHH	Welthungerhilfe
WS	Wet Season

Chapter 1
Introduction—How Swiss Foreign Aid for International Development Benefits Agricultural Development Across Asia

Helena Wehmeyer, Grant Robert Singleton, and Melanie Connor

Abstract In most of South and South East Asia and the Pacific, (For geographical descriptions, CGIAR regions are used. https://www.cgiar.org/research/cgiar-regions/) rice is the staple food crop. It is predominantly cultivated by smallholder farmers. Although the Green Revolution has modernized rice agriculture considerably, farmers today face the consequences of decades-long unsustainable natural resource use. Environmental degradation has become prevalent and climate change is exacerbating the current challenges. In this context, the diffusion of agricultural best management practices and technologies is crucial for ensuring rural livelihoods and global food security. The 'Closing Rice Yield Gaps in Asia with Reduced Environmental Footprint' (CORIGAP) project (2013–2023) funded by the Swiss Agency for Development and Cooperation (SDC) aimed to improve rice farmers' productivity and profitability in five South East Asian countries and one South Asian country by disseminating sustainable agriculture practices and technologies. The Irrigated Rice Research Consortium (1997–2012), also funded by the SDC, provided a strong platform for the CORIGAP project with national partners already in place in five of the six countries. As of 2022, more than 780,000 farmers were reached through CORIGAP. Mean rice yield and mean income increased by more than 10% for smallholder families. Through CORIGAP, SDC provided a strong platform for farmers to adopt best management practices for producing lowland irrigated rice. These practices, in turn, significantly reduced the use of pesticides, increased the efficiency of nutrient and water use, and decreased postharvest losses.

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Keywords Agricultural development · Swiss foreign aid · Best management practices · Rice yield gap · South and South East Asia · Sustainability

1.1 Agricultural Development and Rice Cultivation in Asia

Agricultural development in Asia has undergone multiple phases and has experienced a remarkable evolution that also advanced general economic development. The region has become a major agricultural producer in the world due to the Green Revolution in the second half of the twentieth century (Hazell 2009). In particular, its rice exports have become essential for today's global food security (De Koninck and Rousseau 2013; OECD-FAO 2017). Asia is a net rice-exporting region accounting for 70% of the world's rice exports, and Africa's food security highly depends on Asia's ability to maintain its agricultural exports (FAO 2014). South Asian (SA)and South East Asian (SEA) countries are considerable contributors to local, regional, and global food security (FAO 2014). Today, most Asian countries are at a transitional stage of agricultural development that follow relatively modern farming practices (Seck et al. 2012; Lagerqvist and Connell 2018). In general, a dual-household economy in which subsistence agriculture combined with other income-generating activities within or outside the agriculture sector has become the norm (Lim 2004; Lagerqvist and Connell 2018). Nevertheless, traditional lowland and upland rainfed rice farming supplies over 20% of global rice production and is mainly located in South and Southeast Asia with relatively low yields, little input use, and high seasonal variability (Seck et al. 2012; GRiSP 2013).

New challenges have emerged due to environmental, social, and economic imbalances across Asia. These limit agricultural growth and threaten rural livelihoods. The negative effects of fast agricultural and economic growth materialize in environmental degradation, lingering food insecurity, increased disparities, and marginalized peripheral regions (Pingali 2012). Rice farmers often use excessive amounts of agricultural inputs, such as synthetic fertilizers and pesticides, seeds, and water. Thus, they have a particularly large environmental footprint because their intensive farming practices affect the environment due to unsustainable natural resources use (Čuček et al. 2015; OEDC and FAO 2017). Consequently, rice farming contributes to environmental degradation in Asia and plays a significant role in emitting greenhouse gases such as methane and nitrous oxide. Globally, rice accounts for about 11% of all anthropogenic methane emissions (IPCC 2013; Jiang et al. 2017). This poses a threat to human health, biodiversity, and global food security (Redfern et al. 2012).

1.2 The Green Revolution in Asia

Rice has been the preeminent crop in Asia for over 2,000 years. Traditional wet rice-farming practices were developed in southern China (Rigg 1991; GRiSP 2013). Since the late nineteenth century, agriculture in Asia has become industrialized due to land expansion and a significant rise in population (Boomgaard 2007). In the second half of the twentieth century, public investments, policy support, and research for modern agricultural development were initiated to transform global agriculture and avoid food shortages (De Koninck 2003; FAO 2004; GRiSP 2013). Between the 1950s and 1980s, the agricultural productivity of smallholder rice and wheat farmers in Asia and Latin America significantly increased due to a continuous process of change driven by an agricultural technology revolution known as the Green Revolution (Hazell 2009). New farming methods were introduced to developing countries through the implementation of agricultural modernization policies. In combination, these elements accelerated agricultural productivity growth and prevented millions of people from starving (Kaosa-ard and Rerkasem 1999; De Koninck 2003; FAO 2004).

A key element for the rise of the Green Revolution was the introduction of 'improved' crop varieties with a main focus on rice in Asia (FAO 2004; Hazell 2009). High-yielding varieties (HYVs) were developed with the aid of modern plant-breeding techniques starting in the 1950s (Kaosa-ard and Rerkasem 1999; De Koninck 2003; FAO 2004). These improved varieties were generally superior to traditional varieties. They had a higher yield potential, improved tolerance to pests and diseases, better adaptability to a broad range of latitudes, more insensitivity to the length of daylight, as well as faster responsiveness to fertilizer and irrigation (Kaosa-ard and Rerkasem 1999; Hazell 2009). Furthermore, the new varieties often required a shorter growth period. This made it possible to establish intensive cropping systems by increasing cropping ratios from one to at least two crops a year (GRiSP 2013). In most Asian countries, irrigated lowland rice cultivation became the standard (Hazell 2009; De Koninck 2003). HYVs were shown to reach 10 t/ha under ideal conditions in combination with synthetic fertilizers and pesticides (Hazell 2009; GRiSP 2013). This was a significant increase compared to the 2 t/ha average rice yields from local varieties (Kaosa-ard and Rerkasem 1999; Lim 2004; GRiSP 2013). Overall, in developing countries, rice yields rose by 109% between 1960 and 2000 with an average annual production increase of over 2% (FAO 2004; Rapsomanikis 2015).

In Asia particularly, agricultural production has grown twice as fast as the global average since 1960 (De Koninck and Rousseau 2013). This rapid growth over the past five decades has been an essential characteristic of Asia's agricultural and economic evolution. Rural poverty has declined substantially and GDP per capita has grown strongly in Asia from the 1980s onwards (World Bank 2022). Furthermore, absolute poverty fell by 28% from 1975 to 1995, although the total population in the region grew by 60% over that same period (Fogel 2009; Hazell 2009). Reduced poverty resulted directly from increased farmer income due to higher outputs and improved profitability of smallholder farmers due to reduced prices of agricultural products. Indirectly, new employment opportunities in postharvest operations raised employee wages. Rapid rice production increases stimulated the demand and prices for land, labor, nonagricultural goods, and services (FAO 2004; Hazell 2009). Agricultural exports multiplied and countries' export performance was strengthened (De Koninck and Rousseau 2013). Furthermore, modern agricultural production systems required far less human labor. Consequently, migration to favorable areas where employment opportunities were higher bolstered rural incomes. This created new off-farm activities and led to more diversification of rural economies. A significant surplus labor force benefited the industrial sector. The new industrial labor force then profited from the reduction in staple food prices and rising incomes from 1960 to the early 2000s. In this regard, lower food prices with increased income levels changed salary spending ratios. This allowed for higher spending capacity, particularly for the poor, and hence for rapid economic growth. In addition, the impact on nutrition due to an increase in per capita food supply met the needs of millions in Asia (Hazell 2009; Pingali 2012).

Without the modern technologies and practices of the Green Revolution, world food prices would have been 35–65% higher today. Moreover, it has been estimated that without the creation of the CGIAR centers and national and international breeding programs, total food production quantities in developing countries would have been almost 20% lower (Pingali 2012). As a whole, the positive economic effects of the Green Revolution were especially beneficial for the poor. They gained relatively more from the agricultural productivity growth and decreasing food prices because they spend a higher share of their income on food (Kaosa-ard and Rerkasem 1999; McKittrick 2012; Pingali 2012). Thus, agriculture has shown to be an engine of economic growth, particularly for the rural nonfarm economy (FAO 2004; Hazell 2009). Today, Asia is a major producer of grains for the world and holds a global rice production share of 90%. This is mainly because more than half of the global rice production is concentrated in China and India (OECD-FAO 2020).

1.3 Current Challenges for Sustainable Agricultural Development in Asia

The impact of the Green Revolution on the environment is seen twofold. On the one hand, it is regarded as the crucial element to have impeded the conversion of millions of hectares of land, particularly forests, for agricultural use worldwide. Thus, it curbed deforestation and saved natural habitats. On the other hand, the Green Revolution is seen as an environmental failure due to unprecedented levels of environmental degradation that it is accused of causing (McKittrick 2012; Pingali 2012). The main reasons for today's environmental problems are (1) the extreme and inappropriate use of fertilizers and pesticides, (2) false irrigation practices that lead to high salinity degrees in soils, and (3) dropping groundwater levels because of bad irrigation practices (Rapsomanikis 2015). The improper management and overuse of modern inputs paired with a strong push in favor of cultivating rice as a monoculture have led to water and air pollution as well as soil nutrient depletion, desertification, biodiversity losses, and pest resistance (McKittrick 2012; Pingali 2012; Rapsomanikis 2015). Intensive irrigation and mechanization practices have reduced groundwater levels (Yu et al. 2021). This has accelerated soil degradation, such as loss of soil fertility, soil salinization and hardening as well as chemical runoff polluting soil and waterways resulting in yield decline (Yu et al. 2021). Consequently, this has led to severe environmental impacts beyond the areas cultivated in many regions of the world (McKittrick 2012; Pingali 2012; Rapsomanikis 2015) including impacts on biodiversity (Tilman et al. 2011). These issues have been intensified by inadequate extension services and institutional deficiencies. Furthermore, governmental policies have focused intensely on input pricing subsidies that made modern inputs cheap and encouraged excessive use (McKittrick 2012; Pingali 2012). Nevertheless, the environmental implications as such were not just caused by the technologies and practices introduced during the Green Revolution but also by a policy environment that promoted the excessive overuse of inputs (Hazell 2009; Pingali 2012).

Multiple risks concerning agriculture in Asia are expected to be tied to climate change and related extreme weather events. More frequent storms, droughts, flooding, and rising sea levels are significant threats to low-lying coastal areas. Coastal zones are particularly vulnerable to the impacts of climate change. Four types of primary physical effects are of major concern in SA and SEA: saline water intrusion, drainage congestion, extreme events, and changes in coastal morphology (Alam and Sawhney 2019). With regard to rice cultivation, climate change is expected to have a significant impact on yields and cultivation practices. GRiSP simulations for the main rice-growing regions of Asia forecasted that for every 1 °C rise in mean temperature, yield decreases of 7–10% will occur. In addition, the issues of water scarcity and salinity in the low-lying coastal areas are increasing, intensely hitting the SEA rice sector which is highly dependent on water for irrigation. GRiSP estimates show that 15–20 Mha of irrigated rice cultivation areas will suffer some degree of water scarcity by 2025 (GRiSP 2013). Hence, to counteract the adverse effects of climate change, the agriculture sector must also direct its effort toward mitigating the risks. Current policy environments, especially in SA and SEA, have not yet considerably changed their adaptation responses due to many conflicts of interest related to short-term economic goals. This could potentially exacerbate the negative impacts of climate change in the region (OECD-FAO 2017; Alam and Sawhney 2019).

Still, agricultural productivity in Asia is projected to increase during the upcoming years. This optimistic forecast is due mainly to improved total-factor productivity (TFP) over the past decades. TFP is growth from factors other than additional land, labor, capital, and material inputs (fertilizer, pesticides, etc.) (FAO 2017). Between 2001 and 2013, 60% of output growth was achieved by TFP growth due to farmers enhancing allocative efficiency. Hence, most of the agricultural output rise has been due to factors other than the higher use of conventional inputs. This was achieved by, e.g., crop diversification and intensification. This includes irrigation infrastructure expansion and the use of improved seed varieties (OECD-FAO 2017, 2020). An example is planting drought-tolerant varieties. Drought is a major problem because it is the most widespread and damaging of all environmental stresses. Thus, promoting adapted varieties can improve productivity more sustainably due to a reduced need for irrigation (IRRI 2018a).

In SA and SEA, the relative weight of the agricultural sector has been declining (Barichello 2004). Agricultural growth has stagnated since the mid-1980s in contrast to national GDP increases. Returns on investment have been declining, and fertilizer and seed prices have increased significantly since the beginning of the 2000s (GRiSP 2013). As the main technologies from the Green Revolution are based on fossil fuels, farmers have become more vulnerable to external forces, particularly price hikes in the global oil market (Kaosa-ard and Rerkasem 1999; GRiSP 2013). Up until today, the agriculture sector remains the primary source of employment for the increasing population in Asia and the widening of income discrepancies between rural and urban areas in most Asian countries is ongoing. Regarding poverty reduction since the Green Revolution, an overall increase of 1% in crop productivity reduced the number of people living in poverty only by 0.48% (De Koninck and Rousseau 2013; Pingali 2012; Rigg et al. 2016). Although significant progress in terms of improving food security has been achieved since the 1990s, wide discrepancies between Asian countries remain (OECD-FAO 2017). Agriculture and food security policy efforts focus mostly on rice. Rice self-sufficiency is the primary emphasis in policymaking for most Asian countries. Importing countries (e.g., Indonesia, the Philippines) use strategies such as price support, trade barriers, and input subsidies to boost domestic production. Exporting countries (e.g., Thailand and Vietnam) use policies that directly intervene in export markets through taxes, bans, or licensing arrangements and keep back a certain quantity of rice production to assure their food security (OECD-FAO 2017). As a consequence of the distortion of rice prices, overall agricultural resource allocation is affected. Farmers are pushed to continue low-productivity rice farming and avoid profitable diversification of cultivation. This in turn limits the production of higher-value crops and higher agricultural incomes which can enhance agricultural development. Furthermore, the elevated price for staple foods may hamper the possibility for low-income households to afford enough food in general. Subsequently, this increases the current levels of food insecurity in vulnerable households and limits the opportunity for a healthy diet (OECD-FAO 2017).

1.4 Swiss Foreign Aid for Agricultural Development in Asia

1.4.1 Switzerland's Efforts Toward Sustainable Development

The Swiss government has been actively involved in international development assistance for over 60 years. Since its beginnings in development assistance, Switzerland has remained focused on fighting poverty and providing humanitarian aid (Waldburger et al. 2012). Switzerland's budget for official development assistance (ODA) aid has risen considerably over the decades (Holenstein 2010; Waldburger et al. 2012). Today, the Swiss government's contribution to global development efforts is one of the highest in the world. It has risen from CHF 2.4 billion in 2010 to CHF 3.3 billion in 2020 (SDC 2021a). The central implementing entities are the SDC and the State Secretariat for Economic Affairs (FDFA 2017). Globally, Switzerland ranks in 12th place in absolute numbers for development cooperation expenditures and 9th place in its ODA to gross national income (GNI) ratio (SDC 2023). In this regard, the Swiss development activities directly impact international foreign aid strategies and have significant implications for advancing sustainable development worldwide.

SDC's current strategy focuses on alleviating poverty and promoting peace for sustainable development following the 2030 Agenda. It advances long-term solutions for enabling access to essential resources and services, namely employment, food, water, healthcare, and education (FDFA 2011; SDC 2019a, d). This is achieved by the SDC's 'Global Programmes' which address five global challenges: climate change, food security, water management, health, and migration (SDC 2021b). Thereby, the country actively engages in large-scale, worldwide advancements for achieving the Sustainable Development Goals (SDGs) by 2030. Through its 'Global Programme Food Security,' SDC seeks to improve production systems and rural services that favor the sustainable use of natural resources and fight hunger and malnutrition. By promoting sustainable agriculture, the aim is to provide a healthy and balanced diet to vulnerable and marginalized groups, preserve biodiversity, and secure constant food access to reach food security (SDC 2019c, d). The SDC works with multiple international, national, regional, and local institutions to ensure access to good-quality food in its priority regions. For example, it collaborates with CGIAR, a global association of 15 international agricultural research centers. There is a strong emphasis on increasing smallholder resilience with regard to the harmful effects of climate change. Improving adaptation to changing environmental conditions, specifically focusing on biodiversity, is a major focus. In this context, SDC works on six food and agriculture-related challenges (SDC 2019c, d): (1) access to food; (2) production, advisory services, and marketing for smallholder and family farming; (3) land rights; (4) biodiversity; (5) preventing desertification and soil erosion; and (6) food aid.

The largest number of smallholder farmers in the world is in Asia with around 420 million or 74% of small farms globally. The majority is located in China and India and 9% are in SEA (ca. 50 million) (Lowder et al. 2016; SDC 2019e). Smallholders in SA and SEA deal with multiple difficulties and threats to their livelihoods

(Reardon and Timmer 2014; Rapsomanikis 2015; Lagerqvist and Connell 2018). The major challenge lies in the economic balance between fair commodity prices for smallholder farmers on the one side and achieving affordable prices for low-income populations on the other side (Reardon and Timmer 2014; Lagerqvist and Connell 2018). In this regard, SDC's current strategy emphasizes that Asia is a critical region for expanding its long-term food security program strategy on planetary health and global environmental sustainability (SDC 2020f). Around 30% of SDC's budget is directed toward Asia, especially countries in SA and SEA. Technical cooperation for sustainable development in agriculture and climate change adaptation strategies are set as the key responsibilities (SDC 2019b, 2020a, b). Activities include disseminating low carbon-emission technologies, reducing agricultural input use, creating farmer business models, and introducing crop insurance schemes (SDC 2017, 2018).

1.4.2 History and Evolution of the CORIGAP Project (2013–2023)

The SDC-funded CORIGAP project aimed to improve rice farmers' livelihoods by promoting sustainable agriculture practices in six Asian countries (SDC 2020c). These were China, Indonesia, Myanmar, Sri Lanka, Thailand, and Vietnam. The project focused on reducing yield gaps and optimizing the productivity of lowland intensive rice cultivation to diminish farmers' environmental footprint and improve food security, advance gender and youth equity, and alleviate poverty. It did so by supporting farmers to optimize productivity, resource use efficiency, and sustainability of irrigated rice production systems. The three main targets were to increase farmers' rice yields by 10%, to raise their profitability by 20%, and to reach more than 500,000 farmers by 2022. Hence, the CORIGAP project addressing these issues was an important element in supporting the objectives of SDC's 'Global Programme Food Security' (IRRI 2017a; SDC 2020a, b, c, d, e, f).

The CORIGAP project built on the success of the Irrigated Rice Research Consortium (IRRC) (1997–2012), which was managed by IRRI and funded by SDC. The focus of the IRRC was the natural resource management of lowland irrigated rice systems. It began in 1997 with two discipline-based work groups, one on nutrient management and the other on integrated pest management. In 2005, the IRRC expanded to include work groups on best practices for fertilizer use as well as pest, water, and postharvest management and included a country outreach program that was led by country partners. Palis et al. (2010a) provide a brief history of the IRRC and its evolution. Palis et al. (2010b) present case studies on the impact of the IRRC. An external assessment of the impact of Phases I to IV of the IRRC covered economic, agronomic, and social-extension aspects of the project (Rejesus et al. 2014). An estimated return on investment (benefit–cost ratio) across the four phases was in the vicinity of 4:1. In addition, the project demonstrated substantial impacts on national policymaking in the 10 partner countries from SA and SEA (Rejesus et al.

2014). CORIGAP evolved from this platform of adaptive and inclusive research and outreach with a strong focus on understanding the needs of farming communities in each region and then established research trials in farmers' fields that addressed site-specific issues. In addition, CORIGAP used adoption-diffusion strategies to promote national policies on agricultural best management practices (BMP) adapted for each country in collaboration with country officials, regional leaders, and other development projects (IRRI 2017a; Flor et al. 2021). The project built on good agricultural practices that were environmentally sustainable and supported the development of science-based, quantitative tools and participatory methods. Multiple stakeholders, such as national agriculture departments, civil society groups, farmer cooperatives, the private sector associated with the rice value chain, and NGOs, partnered together (SDC 2020c). Based on the analysis of smallholder needs assessment, interventions to improve the management of lowland irrigated rice production were selected (Willett and Barroga 2016; Flor et al. 2016). CORIGAP's first phase began in 2013 and lasted until 2016. The second phase started in 2017 and ended in March 2023 (IRRI 2014; SDC 2020c).

Closing rice yield gaps, increasing farmers' incomes, providing evidence-based input into national policies on rice production, and improving environmental sustainability were the main projected outcomes. Yield gaps are the difference between the maximum potential yield and the actual farm yield (Rabbinge 1993; Lewandowski et al. 2018). Potential yield is only constrained by genotype and environment. The larger the gap between potential yield and actual farm yield, the higher the opportunity to improve farming practices to increase production quantities. In rice production systems, the economically attainable yield or exploitable yield is defined as 80% of the potential yield (Rabbinge 1993; Stuart et al. 2016). Exploitable yield is limited by the same factors as potential yield and additionally by agronomic practice, socioeconomic and institutional factors as well as access to inputs and technology (Stuart et al. 2016). To reduce yield gaps in rice production, concentrating on the gap between actual yield and exploitable yield is essential. In this regard, focusing on smallholder farmers is crucial. They produce most of the food consumed in the developing world and, specifically, rice in SA and SEA (Rapsomanikis 2015). However, productivity growth has been stagnating, particularly for small farms. There are multiple reasons for this current situation. One major factor is the suboptimal use of inputs. Also, insufficient adoption of best management practices and technologies slows the improvement of agricultural efficiency. Therefore, it is crucial to assist smallholders in adopting innovations to reduce their yield gap. Furthermore, enhancing labor productivity is of particular interest because it pushes food production and employment opportunities. Increased labor productivity through optimal technology use strengthens the demand for skilled labor and thus raises rural wages (Rapsomanikis 2015).

1.4.2.1 CORIGAP Phase 1: 2013–2016

The main objective of CORIGAP Phase 1 was to assess farmers' agricultural practices. This gave a better understanding of rice yield gaps and their contribution to food security. Two key studies early in the project were those by Stuart et al. (2016) on yield gaps in rice production at a country level and by Devkota et al. (2019) on economic and environmental indicators of sustainable rice production. Findings from these studies set a platform for collaborative research in each of the six CORIGAP countries on closing yield gaps by targeting country-specific best practices for rice production that reduce negative environmental impacts including the carbon footprint of rice production (see Chapter 5, this book). Case studies highlighting the successful outcomes and impacts of CORIGAP are provided in this book.

Through strong in-country partnerships and tools, such as participatory methods (e.g., learning alliances and farmer-participatory research), CORIGAP fostered collaborations and outreach. Hence, in its first phase, the project was able to generate evidence on farming practices through an integrated approach to crop management and natural resource management. Furthermore, it guided dissemination strategies for sustainable rice production with the goal of reducing rice yield gaps. These achievements positively impacted national policy decisions in the CORIGAP countries (Willett and Barroga 2016).

The following activities were conducted in six irrigated rice granaries in Asia (SDC 2020c; IRRI 2020):

- Assessment of needs and constraints of farmers and other stakeholders along the rice value chain in six rice granaries to create appropriate monitoring and evaluation systems for improved rice production by introducing innovations.
- Development of a 'field calculator,' a computational framework to evaluate integrated, high-yielding and profitable rice production systems with minimum environmental footprint.
- Use of adaptive research concepts to establish an iterative process between farmers, extension agents, and relevant rice value chain partners to test cropping systems and technologies in two major rice granaries by 2016 and in six granaries by 2020.
- Development of mechanisms for outreach and scaling up of best management practices to be effectively used by 10,000 smallholder farmers in Vietnam, China, and Thailand. This includes farmer-participatory videos, business model development, and strengthening the market integration of farmers.
- Improvement of national extension partners' capacity and stakeholders' abilities to use the developed tools and methodologies and increase knowledge on sustainable rice production to generate changes at the policy level.

In Table 1.1, the technologies introduced during the CORIGAP project in the six project countries are described. These technologies serve as tools for farmers to support their development toward more sustainable rice cultivation. Different technologies were recommended for each country as farmers have different needs and are at different levels agronomically. Furthermore, environmental conditions also determined the introduction of a technology to a specific region or not. Overall, alternate wetting and drying (AWD), drum seeder, and laser land leveler are the technologies that were introduced in most CORIGAP countries.

In the following, the progress of CORIGAP Phase 1 is demonstrated year by year from 2013 to 2016.

2013. In the first year, progress in China and Vietnam was strongest due to the previous implementation of national policy programs during the IRRC Phase IV, namely three control technologies (3CT) in China and 'One Must Do, Five Reductions' (1M5R) program in Vietnam. A baseline survey and needs analysis in Guangdong Province was conducted interviewing a total of 248 households. Additionally, focus group discussions with 34 farmers in four villages took place. The results showed that rice farmers have the potential to increase their grain yield by reducing fertilizer input. In Vietnam, the adoption of 1M5R was already widespread as training in eight provinces of the Mekong River Delta had taken place during the IRRC Phase IV. In total, an estimated 240,000 farmers already implemented 1M5R in 2013. However, farmers were still dealing with several constraints including the need for improved market models for selling rice, inconsistent quality of seed, problems with straw management, and pest infestations. In Thailand, Indonesia, and Sri Lanka, data collection and training activities for local staff were the major outputs (IRRI 2014). Furthermore, the field calculator was developed as a decision support tool based on a program by Wageningen University for other crops (Wageningen University & Research 2012). For CORIGAP, the field calculator was developed and tested for rice using field data collected in Can Tho and An Giang Province in Vietnam. The field calculator summarizes data collected for rice production to indicate the environmental and economic impacts of different technological packages such as 1M5R (IRRI 2014).

2014. Continued progress in China, Vietnam, and Thailand was made. In China, research and outreach work on reducing water consumption and GHG emissions took place. Participatory demonstration trials for farmers and partners in three counties of Guangdong Province to promote 3CT and AWD were organized (IRRI 2015). Activities in Myanmar and Indonesia were aligned with national priorities for rice production. In addition, market chain studies through focus group discussions with multiple stakeholders were carried out in Indonesia, Thailand, and Vietnam. Learning alliances, a network of multiple stakeholders to promote learning on innovative practices and technologies at the community level, were established in Myanmar and Vietnam (IRRI 2015, 2017a). Particularly in Vietnam, the field calculator was further refined by comparing three different management approaches, namely 1M5R, SFLF (Small Farm, Large Field), and regular farmers' practice. Furthermore, business models for better management of rice straw were developed by the national partners to strengthen extension on market integration of mushroom production (IRRI 2015).

2015. The CORIGAP countries showed progress in identifying the causes of yield gaps. They continued to demonstrate the integration of technologies for reducing agricultural inputs. Field-tested interventions resulted in increased profitability mainly due to diminished input costs for farmers in Vietnam, Indonesia, Thailand, and China.

Table 1.1 Technologies and practices introduced and supported by the CORIGAP project

Technology	Countries introduced	Description
Alternate wetting and drying (AWD)	China, Indonesia, Sri Lanka, Thailand, Vietnam	A water-management technique where irrigation is applied at intermittent intervals resulting in alternating wet and dry soil conditions. Hence, the soil is allowed to dry out for one or several days after the disappearance of ponded water before it is flooded again. This mitigates GHG emissions from rice production as the field is not continuously flooded[a,b]
Support to introduce combine harvester	Indonesia, Sri Lanka, Thailand, Vietnam	Mechanical harvesting machine that reduces postharvest losses and promotes sustainable mechanization as well as supports direct and indirect reduction of GHG. It combines several operations into one: cutting the crop, threshing, and cleaning[a,c]
Drum seeder	Indonesia, Myanmar, Sri Lanka, Thailand, Vietnam	A machine that plants rice seeds, preferably pre-germinated, directly in neat rows. It supports an efficient cropping process and sustainable mechanization[a]
Ecologically-based rodent management	Indonesia, Myanmar, Thailand, Vietnam	Practice based on the principles of IPM that integrates a range of ecological management practices. They together provide more effective management of pest species such as rodents[d]
Flatbed dryer	South Sumatra (Indonesia), Myanmar, Vietnam	A mechanical dryer that removes water from wet grains by forcing air through the grain bulk[e]
High-yielding varieties (HYVs)	Indonesia, Myanmar, Sri Lanka, Vietnam	Improved rice varieties that are well adapted to soil conditions, tolerant to droughts, floods, and salinity, and achieve higher yields. They show a high response to chemical fertilizers, are shorter with stiff straw compared to traditional varieties, and mature faster. This enables farmers to grow two or three crops in a year[f]
IRRI super bag	Indonesia, Myanmar, Thailand, Vietnam	A hermetic storage bag for cereal grains to be stored safely for extended periods. It extends the germination life of seeds from 6 to 12 months, controls insect grain pests without chemicals, improves head rice recovery, and provides quality seeds[a,g]
Laser land leveler	Indonesia, Myanmar, Sri Lanka, Thailand, Vietnam	Laser leveling is a process of smoothing the land surface (±2 cm) from its average elevation using laser-equipped drag buckets on a four-wheel tractor. Laser-assisted precision land leveling saves irrigation water, nutrients, and agrochemicals. It can also enhance environmental quality and crop yields[h,i]

(continued)

Table 1.1 (continued)

Technology	Countries introduced	Description
Lightweight thresher	Myanmar	A technology that helps to save labor costs, accelerates postharvest processes, and reduces yield losses when separating the grain from the straw. Many farmers use a power thresher technology to replace manual threshing[j,k]
Mechanical rice transplanter	Indonesia, Myanmar, Sri Lanka, Vietnam	A mechanical rice transplanter is a manually operated machine that transplants rice seedlings in rows. Mechanically transplanting rice reduces fuel, labor costs, and water. It also supports direct and indirect reduction of GHG[a,l]
Solar bubble dryer	Indonesia, Myanmar	A low-cost drying technology developed by IRRI, Hohenheim University, and GrainPro. It is superior to the traditional sun drying process because it eliminates the re-wetting of grains during rain and losses due to animals, spillage, and cars running over the grains if they are spread on roads[m]
Three Controls Technology (3CT)	China	Nitrogen fertilizer-saving technology that includes the control of nitrogen application timing and quantity, limits the number of tillers, and controls for pesticide applications[n]
Direct seeder	Vietnam	A tractor or transplanter drawn direct seeding implement using the drill seeding principle adapted for seeding in dry soil and in wet, puddled soil

Sources [a] Connor et al. (2021a), [b] Sustainable Rice Platform (2019), [c] IRRI Rice Knowledge Bank (2021a), [d] Singleton and Labios (2019), [e] IRRI Rice Knowledge Bank (2021b), [f] Grigg (2001), [g] IRRI Rice Knowledge Bank (2021c), [h] Chandiramani et al. (2007), [i] Jat et al. (2006), [j] IRRI Rice Knowledge Bank (2021d), [k] Adri et al. (2020),[l] University of the Philippines Los Baños (2018), [m] IRRI Rice Knowledge Bank (2021e), [n] Wehmeyer et al. (2020)

Potential could be seen in Sri Lanka and Myanmar, where the balanced use of fertilizer remains a challenge. Further, CORIGAP was able to achieve community-level impacts through supportive activities, such as postharvest grain protection, learning alliances, and capacity-building activities as well as local and national policy support. In total, a network of 65 farmer groups was working with local partners to transfer research outcomes into community benefits. However, the progress of CORIGAP was uneven between the countries, particularly with regard to establishing integration of systems to support changes in on-farm practices. For example, China and Vietnam demonstrated higher rates of technology adoption and environmental improvements. In Vietnam, Myanmar, and Thailand, private-sector linkages were established of which some were impressively successful, for example in Myanmar, for dryer fabrication as well as setting up supply chains for laser leveling equipment in combination with providing training. These represent models that could be applied to sites in the countries that are less advanced (Willett and Barroga 2016).

2016. The results of the yield gap analysis in four CORIGAP countries demonstrated that the exploitable yield gaps ranged from 23 to 42% (1.4–3.8 t/ha) (IRRI 2017b; Stuart et al. 2016). With 37%, Myanmar had one of the highest yield gaps out of the CORIGAP countries and hence a great potential to increase yields through best management practices (IRRI 2017b; Stuart et al. 2016). The field calculator approach provided a fascinating comparison of the economic and environmental indicators of sustainable rice production across the six partner countries (Devkota et al. 2019). Linkages between farmers and markets that pay a premium for better quality rice and the adoption of best management practices were implemented through a learning alliance. This included the adoption of mechanized drying combined with inventory storage, the development of suitable business models for farmers, and exchange visits for farmers to premium markets. In addition, awareness at the private-sector level was created regarding the effect of grain quality on farmers' practice during production and postharvest (IRRI 2017b). In China, the extension activities of 3CT through demonstration sites were the main activity. 3CT was showcased at 68 demonstration sites in Guangdong, Jiangxi, Guangxi, Hainan, and Zhejiang provinces. Furthermore, the findings of a gender study showed that there is a research gap regarding the state of gender equality in Southeast Asian agriculture (Akter et al. 2017). Regarding adaptive research strategies and multi-stakeholder learning alliances, efforts were intensified and the approaches in each country were aligned with national initiatives on food security. Overall, 125,000 households were reached during CORIGAP Phase 1 (IRRI 2017b).

1.4.2.2 CORIGAP-PRO (Phase 2): 2017–2020

In the second phase, the project focused on the intensified integration of country-specific best management practices to further reduce yield gaps. CORIGAP-Pro aimed to reach 500,000 smallholders in six granaries. Increases in yield (10%) and profits (20%) for 20,000 households in East and Southeast Asia were targeted by 2020 (SDC 2020e). Consequently, the priorities in Phase 2 were scaling out and scaling up the outcomes of Phase 1. The main activities included outreach to farmers and the private sector. Also, a key activity was regular updates to policymakers on the integration of sustainable management practices based on evidence-based findings of CORIGAP farmer-participatory field trials. The alignment of activities with national extension programs was crucial to guide national policy developments. Learning alliances and the inclusion of the private sector and NGOs helped foster this goal (Flor et al. 2017). At the end of this phase, the adoption of best management practices demonstrated environmental benefits, improved gender- and youth-positive developments, and provided opportunities for smallholders in the rice value chain (IRRI 2017a).

In Phase 2, the following activities were conducted in project countries (IRRI 2017a; SDC 2020e):

- Increase the capacity of national extension partners and intensify public–private partnerships via learning alliances for strengthened linkages with the private sector for outreach purposes.
- Adoption of a more integrated approach to mechanization to increase environmentally sustainable irrigated rice production in all CORIGAP countries.
- Closer contact with policymakers to provide evidence-based recommendations on natural resource management in rice farming and assessment of strategies for inclusive value-chain upgrading.
- Expansion of best management practices and technology-dissemination activities in Myanmar and Sri Lanka with the start of the field calculator.
- Improvement of profits of smallholder farmers in a gender-inclusive manner.

2017. Large-scale diffusion of best management practices continued in Indonesia, China, and Vietnam. Overall, 379,000 smallholder farmers were reached in the CORIGAP countries. Additionally, more than 86,000 smallholders increased yields and profits by more than 10% on average. A survey was conducted in Indonesia and Myanmar to assess the influence of CORIGAP technology adoption on the income and spending power of smallholder families (IRRI 2018b; Connor and San 2021; Connor et al. 2021a, b). In China, the large-scale promotion of 3CT with the addition of AWD was expanded across seven provinces through training events for extension specialists and key farmers. In total, 5,399 new farmers were reached. 3CT was adopted by more than 200,000 farmers in Guangdong Province. Farmers increased grain yields by 11% and profits by 14%. In Vietnam, more than 51,000 farmers across eight provinces adopted 1M5R-recommended practices in addition to the 85,000 farmers reached during CORIGAP Phase 1. Field trials in Can Tho Province demonstrated that farmers who adopted the recommended practices and technologies had a mean profit increase ranging from 14 to 30%; however, there was no yield gain (Stuart et al. 2018). In Myanmar, activities included conducting multiple surveys on household farming data and on the financial benefits of those who adopted recommended practices as well as farmer interviews on livelihood changes. Learning alliance meetings and cross-site learning activities were conducted on topics such as mechanization of land preparation through laser land leveling. Two demonstrations were conducted to increase awareness of the benefits of this technology (IRRI 2018b).

2018. Progress in all six CORIGAP countries was strong. In total, 7,520 national extension partners were trained on the promotion, application, and management of best management practices. More than 600,000 farmers were reached and 118,000 farmers adopted recommended practices and technologies. An in-depth analysis of yield gaps in Vietnam, Thailand, and Myanmar revealed that they were mainly due to unsuitable management practices. Farmers' rice variety selection was also shown to have an impact. The potential to close yield gaps by optimizing the sowing and planting dates was high. Consequently, the next step was to understand the importance of various factors toward the management of the yield gaps and to comprehend how socioeconomic aspects influence farmers' management choices (Stuart et al. 2016; IRRI 2019).

In Thailand, in 2016–2018, new management practices plus existing national priorities for natural resource management of rice were promoted to farmers in the Central Plains under Cost Reduction Operating Principles (CROP). Farmer groups reduced costs by an average of 17% and increased income by an average of 79% (Stuart et al. 2018).

In Vietnam, a survey on farmers' trust in institutions, perceptions of risks, acceptance of the methods, and knowledge about climate change regarding different rice-straw management options was conducted. The findings showed that farmers burned their rice straw although they perceived high risks, few benefits, and low levels of acceptance. However, farmers were aware of climate change, but their sustainable behavior depended on the acceptability, feasibility, and perceived benefits of the sustainable options for straw management (IRRI 2019; Connor et al. 2020a, b).

In China, outreach activities in Guangdong Province were supported by the World Bank project on nonpoint source pollution. More than 300,000 farmers participated in training and promotion events on 3CT, AWD, and conservation agriculture. Results of field trials on water use for rice cultivation showed a reduction of more than 20% and a substantial decline in methane emissions. Fertilizer rates dropped by 36%, pesticide use decreased by more than 50%, and yields increased by 8% after 4 years (IRRI 2019).

In Myanmar, survey results showed that farmers adopted various best management practices and technologies. They also experienced increased yields and higher incomes. In addition, interviews were conducted to investigate farmers' perceived changes by adopting best management practices for rice farming. Farmers mentioned that their living conditions and livelihoods had improved and that they were able to expand their farm business as well as produce rice more sustainably (IRRI 2019; Connor and San 2021; Connor et al. 2021b).

2019. In total, more than 750,000 farmers had been reached since the beginning of the CORIGAP project in all six countries (IRRI 2020; SDC 2021c). Over 130,000 farmers adopted the recommended practices and technologies, and farmers increased rice yields and profits. Training events in China, Myanmar, and Vietnam were co-funded by World Bank projects that promoted best practices. This also enhanced CORIGAP's outreach (IRRI 2020).

In China, the out-scaling was mostly achieved as part of a World Bank project. Overall, more than 300,000 farmers participated in activities promoting 3CT, AWD, and conservation agriculture. First evidence from farmers' field diaries showed that those who adopted the technologies improved yields by more than 10% and profits by more than 13% compared to the standard farmer's practice. Additionally, a survey on farmers' perceptions of 3CT with 142 participants was conducted in three townships of Guangdong Province (IRRI 2020; Wehmeyer et al. 2020).

In Vietnam, the main CORIGAP activities took place in Can Tho Province. Continued extension activities of 1M5R were the main focus. This was achieved by working closely with the national partners on SFLF to better align farmers with traders and millers. The demonstration of farming techniques for mechanization of sowing, a field day that included a series of seminars with participants from the public authorities, the private sector, and many farmers, as well as technicians, were organized. The outreach of best management practices was further facilitated by the World Bank VnSAT project, which reported more than 800,000 beneficiaries, which included all people residing in a rural household. Additionally, a survey on farmers' perceptions of 1M5R with 465 participants was conducted in the provinces of An Giang and Can Tho (IRRI 2020; Connor et al. 2020a).

In Myanmar (Htwe et al. 2021), Indonesia (Lorica et al. 2020), and Sri Lanka (Htwe et al. 2021; Jayasiri et al. 2022), there was strong progress on rodent, weed, and pesticide management, and during the life of the CORIGAP project, ecologically-based pest management was strongly promoted in these countries with a spill-over to Cambodia (Castilla et al. 2020; Stuart et al. 2020).

2020. The COVID-19 pandemic challenged the research activities. Planned documentation of some project outcomes and impacts was impeded. Furthermore, working directly with the research partners in the countries became impossible and some activities were subsequently delayed, especially field surveys. Work shifted to online meetings and webinars as a response to the challenge. The CORIGAP countries were affected differently by the pandemic. Hence, research opportunities were impacted differently in the project countries. In Vietnam, the situation was managed well, allowing for a continuation of most of the field activities. Activities in China and Myanmar were paused. New research addressing some of the effects of the crisis was initiated by CORIGAP. For example, a study on farmer inclusiveness in the context of the COVID-19 pandemic and how it affects the rice value chain was launched. In Myanmar, the fragile political situation since February 2021 halted the project. In-country colleagues were unable to continue their research activities. Some activities planned for Myanmar including field surveys for designing pathways for the agroecological transition toward sustainable food systems were moved to Indonesia.

2021–2022. The final phase of the CORIGAP project consisted of a 2-year wind-down phase that documented the main outcomes and disseminated the key learnings of the project. This included sharing the lessons learned with policymakers and donors as well as aligning with national project leaders and stakeholders to support further scaling out of CORIGAP outputs beyond 2022. The main CORIGAP learnings were also integrated into the national programs of two associated project countries, the Philippines and Cambodia. Furthermore, opportunities were explored to transfer the key findings to other global regions, e.g., to Africa, by producing policy briefs to facilitate sustainable adoption at scale (IRRI 2022).

As of 2022, more than 780,000 farmers were reached through the CORIGAP project, and the project was successful in incentivizing farmers to adopt sustainable rice-farming practices and technologies long term. Mean yield and mean income increased by more than 10%. This demonstrates a considerable achievement of Swiss foreign aid. The lessons learned foster South-South cooperation and serve as a blueprint for successful long-term development assistance incorporating beneficiaries' perspectives (SDC 2021c; IRRI 2022).

1.5 Overview of Chapters 2–7

The book is divided into seven chapters that provide a wide array of pathways to change for sustainable rice production in lowland irrigated rice-based agricultural systems. Each chapter focuses on a specific area of research and outreach that the CORIGAP project targeted. The aim is to provide not only a reflective process of actions and lessons learned but also to give detailed information to the readership on how to implement different activities.

Following the general overview of agricultural development in Asia and the historical development of the CORIGAP project in this chapter, Chap. 2 provides an introduction to the six CORIGAP countries (China, Indonesia, Myanmar, Sri Lanka, Thailand, and Vietnam). We focus on environmental, social, and economic challenges in lowland rice production. Therefore, several country-specific sustainable best management practices were introduced by the project including nutrient management, pest management, water management, and several postharvest technologies among other very specific practices. This chapter introduces each country and its respective challenges to rice production. It outlines cultivation practices, historical developments, and their impacts on opportunities for the development of the rice sector. This is accompanied by case studies from the CORIGAP activities that highlight the adoption of specific technologies and practices.

The case studies encompass:

- The adoption of various best management practices in Myanmar and Thailand, especially postharvest technologies;
- The outreach of 'One Must Do, Five Reductions' in Vietnam;
- The development and implementation of the 'Three controls technology' and alternate wetting and drying (AWD) practices in China;
- Rodent pest management in Indonesia and Myanmar;
- The introduction and changes due to best management adoption in Myanmar; and
- Water management (quality and quantity) and weed management in Sri Lanka.

Most of these case studies identified positive agronomic, social, and economic changes. The chapter concludes by harnessing the agricultural development strategies in each country.

Chapter 3 focuses on faunal biodiversity in rice-dominated wetlands as an essential contribution to sustainable lowland rice production. Rice agriculture provides wetlands and complex habitats supporting biodiversity. We set our sights beyond Sustainable Development Goal (SDG) 2, which focuses on ending hunger and achieving food security via the promotion of sustainable agriculture. Often agricultural scientists are so motivated to achieve food security that they pay insufficient attention to the need for a healthy and dynamic agroecosystem that promotes floral and faunal biodiversity. SDG 15 emphasizes the need to promote sustainable use of terrestrial ecosystems and halt biodiversity loss. Given the high losses in global biodiversity, especially in tropical zones where most of the world's rice is grown, we set our sights on achieving SDGs 2 and 15. We provide case studies on amphibians, bats, birds, and rodents living in and around irrigated rice cropping systems. We report on transdisciplinary studies supported by CORIGAP that included agronomic, sociological, ecological, biochemical, environmental physiological, and genetic studies. Most of these studies identified potential positive ecosystem services provided by wildlife, which can lead to more sustainable and healthier rice production landscapes. Chapter 3 concludes with recommendations for future research and development projects.

Chapter 4 describes innovations, technologies, and management practices for sustainable rice production. One of the major barriers to improving rice value chains in Asian countries is farmers' lack of knowledge and their limited access to good and scale-appropriate technologies and practices. We review the main features, benefits, and potential barriers of technologies and practices that were developed and promoted under the CORIGAP project. These include:

- 'One Must Do, Five Reductions' (1M5R);
- Alternate wetting and drying (AWD);
- Laser land leveling;
- Mechanized crop establishment;
- Nutrient management; ecological engineering; and
- Sustainable postharvest management practices.

1M5R (1 M = certified Seed, 5R = reductions of seed rate, fertilizer, pesticide, water uses, and postharvest losses) was introduced in Vietnam in 2004 but until 2015 was only adopted at a low level. CORIGAP activities ramped up adoption on about 150,000 ha of rice production in the Mekong River Delta of Vietnam. AWD was promoted to optimize water management and reduce the time of standing water in the field. Laser land leveling and mechanized crop establishment were promoted to significantly increase agronomic use efficiency. Furthermore, best-postharvest management plays an important role in upgrading the rice value chain tailored to sustainability. Lessons learned from case studies in Vietnam, Indonesia, and Thailand are also included.

Chapter 5 provides an overview of greenhouse gas-reducing technologies and practices. Rice production significantly contributes to greenhouse gas emissions, especially methane (CH_4) at various cropping stages. A major source of methane emissions is the decomposition of fertilizers and organic residues in flooded fields during the irrigation cycle. CORIGAP technologies and practices are mainly associated with closing yield gaps by increasing productivity and profitability but have been co-designed to address environmental challenges. Therefore, over the last decade, the CORIGAP interventions not only helped to reduce yield gaps substantially but also resulted in a significant reduction of the carbon footprint in rice production. We start with an in-depth synthesis of science-based evidence and knowledge on challenges and constraints to reducing the rice-carbon footprint in CORIGAP countries. Furthermore, life-cycle assessments outline the quantification of the carbon footprint in rice production. Case studies cover specific technologies including AWD, land-laser leveling, and residue management at postharvest stages. We harness the outcomes related to greenhouse gas emission reduction and provide specific recommendations that can be readily implemented in other countries. In order to apply such recommendations, partnerships are essential to successfully engage in outreach activities and to scale best management practices and technologies.

Chapter 6 focuses on partnerships and scaling of outreach. International agricultural research centers such as IRRI have been using multi-stakeholder learning platforms (MSPs), including learning alliances (LAs) and private partnerships, to support research activities that drive scientific innovations. LAs involve various stakeholders who represent different organizations and interests. These stakeholders organize, discuss, and generate learning in order to tackle specific technological, organizational, and institutional challenges and increase the adoption of best management practices. A key assumption is that establishing an LA accelerates communication processes that enable the spread of new knowledge and practices and promote sharing of the learning of varied stakeholders toward faster alignment with others. This would ultimately enable innovations. We consider multi-stakeholder learning platforms, in particular, the roles they portray and their expected contribution to rice-based innovation systems. Of specific interest are LAs and private partnerships. We consider the communication processes that have been documented and what can be expected from a process that enables learning and scaling within a network of stakeholders. We also disentangle existing gaps where more theoretical reflection is needed and the emerging opportunities for MSPs to drive meaningful impacts at scale for agricultural innovation systems. We provide specific examples such as the sociotechnical analysis of an LA for the adoption of flatbed dryers in Myanmar, the development of solar bubble dryers, and the scaling of laser leveling.

Chapter 7 assesses the inclusiveness of sustainable rice value chain upgrading to provide lessons for policymakers. Actors along rice value chains range from their willingness to adopt sustainable practices to their willingness to pay for them. The actual adoption is driven by incentives to reduce costs or increase yields apart from government policies or market demand for sustainably cultivated rice. We discuss how policymakers can overcome the challenges for these mechanisms to succeed and identify areas for future research. We review and evaluate the changes that have occurred in the different CORIGAP countries. A multi-method approach combining qualitative and quantitative evaluation methods is presented in conjunction with country-specific case studies that provide detailed information about the changes that have happened at different levels. We also provide a detailed breakdown of all the materials produced over time, the communication processes, and the lessons learned from implementing the evaluation methods. We finish the chapter by harnessing anecdotal evidence of how CORIGAP has influenced policymaking in different countries and make recommendations for future projects by outlining the lessons learned.

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Chapter 2
Environmental, Social, and Economic Challenges in Lowland Rice Production

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Abstract The CORIGAP project was implemented in six main rice granaries in South and Southeast Asia. The project introduced several country-specific sustainable best management practices, including nutrient management, pest management, water management, and several postharvest technologies, among other specific practices. This chapter introduces each country and its respective challenges to rice production. It outlines cultivation practices, historical developments, and their impacts on opportunities for the development of the rice sector. This is accompanied by specific case studies that highlight the adoption of specific technologies and practices. Case studies encompass the adoption of various best management practices in Myanmar and Thailand, especially postharvest technologies. Furthermore, the chapter highlights the outreach of "One Must Do, Five Reductions" in Vietnam, the development and implementation of the "Three Controls Technology" and alternate wetting and drying (AWD) practices in China, rodent pest management in Indonesia, and weed and water management in Sri Lanka. These case studies identified positive agronomic, social, and economic changes. The chapter concludes by harnessing the agricultural development strategies in each country with a synthesis of outcomes and impacts.

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2.1 Myanmar

2.1.1 Rice Cultivation in Myanmar

In Myanmar, rice has been a staple crop for many centuries. Today, it is one of the most important crops in the country. Rice is cultivated widely across the country, and the total rice cultivation area is 8 million hectares (ha). The Myanmar agricultural sector and, in particular, rice cultivation have been characterized by several changes over the past centuries. British colonizers established agricultural policies to boost rice production in the 1850s, moving to create a monoculture characterized by poor technological innovation. In the 1950s, Myanmar became one of the biggest global rice producers, which was unfortunately followed by a rice export collapse in the 1960s. As a result, Myanmar's rice cultivation stagnated for many decades (Perry 2008). Nonetheless, agricultural production in Myanmar has become more market oriented since 1988 (Soe 2004). In 2010, a political restructuring took place that resulted in the establishment of the Myanmar Rice Industry Association, which aims to reorganize and modernize the domestic rice sector. In 2015, the Myanmar Rice

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Sector Development Strategy was launched, which was jointly conceptualized by the Ministry of Agriculture and Irrigation of Myanmar, IRRI, the FAO Regional Office Asia–Pacific, and the World Bank to boost agricultural productivity to transform rural areas that are highly dependent on rice farming (Kraas et al. 2017).

The aforementioned agricultural reforms enabled an increase in Myanmar's rice production. Between 1995 and 2010, the total rice production increased from 18 Megatons (Mt) to over 32 Mt. However, the total rice production decreased to 25 Mt in 2017 (GRiSP 2013; Kraas et al. 2017; FAOSTAT 2023). During the same period, the average rice yields rose from below 3 t ha^{-1} in the 1990s to around 3.7 t ha^{-1} in the 2010s. In 2020, Myanmar ranked the world's seventh-largest rice-producing country, following Vietnam and Thailand (GRiSP 2013; FAOSTAT 2023). This is also reflected in the 30% contribution rice cultivation makes to the country's gross agricultural output since it also accounts for about 95% of Myanmar's total cereal output and is Myanmar's second most exported agricultural commodity after pulses. Still, a significant number of rural households are not able to have a sufficient intake of nutritious food with high rates of malnutrition due to limited purchasing power (Raitzer et al. 2015). About 30% of the rural households in Myanmar fall below the national poverty line (Michigan State University (MSU), Myanmar Development Resource Institute's Center for Economic and Social Development (MRDI/CESD 2013). It can, therefore, be concluded that national self-sufficiency has not translated into food security for the poor.

Rice farming in Myanmar is characterized by subsistence-oriented agriculture in the lowlands, predominantly in the Ayeyarwady Delta, which contributes to approximately 31% of Myanmar's total rice production, followed by Bago and Sagaing regions, which account for 17% and 11%, respectively (USDA—Foreign Agricultural Service 2020). Most rice cultivation (approximately 60%) takes place under rainfed conditions. An additional 20% of agricultural land is artificially irrigated. The major irrigated zones lie within the Ayeyarwady Delta, near the Bago Yoma dams (GRiSP 2013; Kraas et al. 2017).

Most farmers have access to less than 2 ha of land, with only one-third of the farming population having access to up to 4 ha of land (Kraas et al. 2017). Farmers generally use modern varieties introduced through various development programs (Connor et al. 2021a). However, the application of inputs to support cultivation is low due to limited access to the necessary inputs. As a result, farmers are not achieving the yield potential, and big yield gaps exist, as shown in the Bago Region (Stuart et al. 2016). Furthermore, Myanmar has considerably lower rice yields than other Southeast Asian countries (GRiSP 2013; FAOSTAT 2023). Some authors (e.g., Yuyu and Hye-Jung 2015) describe Myanmar's rice production as being traditional, although mechanization has occurred recently. Farmers have, in general, limited access to formal sources of credit, access to irrigation systems, and postharvest facilities (such as mills and storage), and roads linking farms to markets are lacking and, consequently, rice production is negatively impacted (Connor and San 2021).

Even though development programs have aimed to introduce new and modern agricultural practices and technologies (Wehmeyer et al. 2022), Myanmar is still lagging behind its neighboring countries, especially in applying farm mechanization

(Yuyu and Hye-Jung 2015). Rice is not a highly profitable crop for farmers. Rice production can be described as highly labor intensive with low labor efficiency due to a low degree of mechanization and low agricultural productivity. Yuyu and Hye-Jung (2015) outline that farmers need to use farm mechanization tools more efficiently to improve and modernize the agricultural sector, particularly rice cultivation. Training on the utilization of such mechanization tools and machinery is necessary to advance agricultural productivity and cropping intensity. While efforts have been made on the national policy level, these efforts have not been successful on a large scale due to the lack of skills, education, and training of the farmers as well as insufficient extension activities. Furthermore, the governmental mechanization scheme involving the distribution of farm machinery to farmers has not shown the expected effects (Yuyu and Hye-Jung 2015).

2.1.2 Constraints and Opportunities for Rural Development in Myanmar

As briefly described above, Myanmar lacks sufficient, high-quality infrastructure in rural areas. Therefore, producers and traders are forced to substitute the lack of public infrastructure by paying private companies, e.g., for fuel-based generators, in place of national electricity supplies. These are high-cost expenses that lower profits, hinder exports, and reduce incentives for other investments (World Bank 2014; OECD 2015; Snoxell and Lyne 2019). The lack and the development of an adequate financial system exacerbate this problem even further, leaving many smallholder farmers without access to formal credits or other financial opportunities to reinvest in their farming enterprises (OECD 2015; Snoxell and Lyne 2019). Farmers will often obtain agricultural credit through loans from family members, friends, or expensive moneylenders even though the government has been adapting their credit system and is providing more services to farmers (Snoxell and Lyne 2019). This results in a negative feedback loop due to farmers' problems of low liquidity and lack of credit. It is hence difficult for farmers to accumulate savings and reinvest in their farms (Snoxell and Lyne 2019). Therefore, household income remains low.

Regarding rice production, access to agricultural inputs is a major constraint. For example, a lot of farmers use their own seeds instead of certified seeds because many farmers have either no financial means to buy certified seeds, the seed system is not sufficiently developed to provide enough certified seeds, or they are not easily accessible (World Bank 2014; OECD 2015). Additionally, seeds are often of poor quality due to weak extension support to seed multiplication farms and poor storage conditions of seeds (OECD 2015). From 2015 to 2021, the government focused on quality seed production (MoALI 2018). International Development Partners such as LIFT, United States Agency for International Development (USAID), and Japan International Cooperation Agency (JICA) invested in the quality seed production industry development. The International Seed Sector Development Myanmar program (https://issdmyanmar.org/about/) collaborated with Welthungerhilfe (WHH) in the Central Dry Zone to improve seed sector coordination, seed business development, and increase the availability of improved seeds for farmers. Farmers' awareness of using quality seeds has been improved. However, there are still limited numbers of seed-producing farmers, and the accessibility of quality seed is still challenging for farmers both in the delta area and in the Central Dry Zone.

Along the rice value chain, a plethora of further constraints can be described, e.g., insufficient mechanization in land preparation and crop establishment processes, limited input use such as fertilizer and pesticides, and constraints in postharvest processing. There is a lack of dryers, storage facilities, modern milling equipment, and efficient transportation to markets after harvest contributing to high postharvest losses and poor quality rice, reducing its market value (GRiSP 2013).

Myanmar has great potential to produce green products, given its low use of fertilizers and pesticides in crops, livestock, and fisheries. Eighty-five percent of total chemical fertilizers in the country are imported from China and Thailand (Lwin et al. 2014), and the data from the Myanmar Statistical Information Service stated that Myanmar imported US$132 million in nitrogen-based fertilizers in 2018. Maize and rice farmers use more inorganic fertilizers than pulses farmers (IFPRI 2021), while vegetable farmers use both inorganic fertilizers and pesticides. The substantial increase in international inorganic fertilizer prices and shipping in 2021 resulted in higher border prices for fertilizers in Myanmar (IFPRI 2021). This further resulted in farmers returning to their conventional farming system with fewer inorganic fertilizers.

As described by Yuyu and Hye-Jung (2015), the agricultural extension system in Myanmar is weak, with little interaction between extension staff, researchers, and farmers. In general, agricultural extension programs are underfinanced, and extension workers do not possess adequate knowledge to share with farmers leaving many farmers behind in terms of knowledge acquisition (World Bank 2014).

In addition, the security of land tenure and production rights, especially freedom in crop choice, hinder agricultural development. In Myanmar, the state retains ownership of all land and farmers are granted land use rights (World Bank 2014; OECD 2015). For example, unresolved land tenure issues and mandatory cropping regulations increase farmers' risks of investing in land improvements and farm commercialization, as well as perpetuate the vulnerability of smallholder and landless farmers resulting in many smallholder farmers avoiding changes and choosing to cultivate their land only to the minimum requirements, which impedes agricultural development (Wehmeyer et al. 2022). Therefore, policy changes are required that recognize the importance of secure rights for attracting investment in land development (World Bank 2014).

Like most Southeast Asian countries, Myanmar is also disproportionally affected by climate change due to its long and exposed coastline and the delta region. Farmers' vulnerability to drought, flooding, salinity intrusion, and extreme weather events has significantly increased over the last decade and is expected to negatively impact agricultural production further. Studies have shown that farmers who have an adequate amount of knowledge of climate change and its consequences are more likely to accept new and sustainable technologies and practices (Connor et al. 2021a). Therefore, improving farmers' knowledge about climate change and climate-smart agricultural practices is necessary in order to help them become more resilient and adapt to changes in climatic conditions (Myanmar Ministry of Agriculture and Irrigation 2015).

Despite the aforementioned difficulties, Myanmar remains a country with a large potential to develop economically, socially, and environmentally on the basis of the SDGs (Wehmeyer et al. 2022). Myanmar's rural development initiatives are still in their early stages and, therefore, provide good opportunities to design and establish more robust strategies to achieve increased productivity, greater socioeconomic equality, and stability in social and economic development. Furthermore, there are a lot of learnings which can inform rural development strategies; for example, one aim should be to avoid mistakes that have been made in the past, such as agricultural input overconsumption and soil degradation due to monoculture agriculture which has been seen in Thailand, China, and Vietnam (OECD 2016; Holzhacker and Agussalim 2017). The potential for successful rural development is high in Myanmar. Myanmar benefits from an advantageous geostrategic position bordering India in the west and China in the east as well as being part of ASEAN (Wehmeyer et al. 2022). This opens several trading opportunities to serve the growing Asian markets as well as also becoming a more important global exporter. This requires, however, the development of policies that exclusively focus on domestic agricultural production systems, exports, and pricing regulations, but also on reducing trade barriers (Myanmar Ministry of Agriculture and Irrigation 2015; OECD 2016; Aung 2019). Furthermore, Myanmar also has the necessary natural resources, such as vast amounts of cultivable land, water resources, and generally favorable climatic conditions. Finding avenues to provide farmers with the necessary infrastructure, such as roads, irrigation facilities, adequately trained extension services, and machinery, will considerably improve agricultural production. Different ways can be explored, such as a greater promotion and involvement of the private sector and investments in critical public services (e.g., road and electricity infrastructure, education and research, health services, and social protection) (OECD 2016; Wehmeyer 2021).

2.1.3 CORIGAP Activities in Myanmar

The CORIGAP activities in Myanmar started in 2013 with the objective of introducing sustainable best management practices in rice production to reduce rice yield gaps due to unfavorable environments and high postharvest losses (Wehmeyer 2021). These best management practices include primarily the introduction of balanced nutrient management and postharvest technologies that help farmers increase their rice yields and improve agricultural efficiency (IRRI 2018). Activities in Myanmar focused on promoting learning alliances, developing business models, establishing joint in-country training activities, and supporting gender research (Singleton and

Labios 2019; Connor and San 2021). Therefore, improved rice and pulse varieties were introduced. Adapted inputs for better nutrient use management, ecological rodent management, and specific machinery, such as drum seeder, mechanical transplanter, combine harvester, lightweight thresher, flatbed dryer, and storage bags for rice seed were introduced to farmers in the Ayeyarwady Delta and Bago Region (Singleton and Labios 2019; Connor and San 2021; Wehmeyer et al. 2022).

In order to facilitate knowledge exchange, farmers and other stakeholders associated with rice farming, such as millers, traders, government officials, and NGOs, were invited to participate in learning alliances by the CORIGAP team. Learning alliances were held at the village level to provide information and exchange knowledge between the different stakeholders (Singleton and Labios 2019). Adaptive research combined with the learning alliance approach realized positive outcomes (Flor et al. 2017). In Maubin Township, in the Ayeyarwady Region, a learning alliance introduced farmers to lightweight threshers and new varieties (Quilloy 2014; Wehmeyer et al. 2022). Further activities concentrated on using good-quality seeds, reducing postharvest losses, and developing business models for implementing postharvest technologies to improve farmers' livelihoods. The IRRI postharvest team, together with the national partners, implemented postharvest demonstration trials where principles of grain quality, drying, and hermetic storage were discussed. Furthermore, participants were introduced to postharvest techniques to produce good-quality grains through threshing, drying, and storing (Quilloy 2014; Wehmeyer et al. 2022).

The introduction of high-yielding varieties was another component of the CORIGAP activities in Myanmar. These varieties have been developed using a "bottom-up" approach to varietal selection that was introduced by IRRI under a different project (Rahman et al. 2015). Participatory varietal selection field trials were established together with farmers that also focused on making best management practices more accessible to farmers, including sustainable pre-and postharvest activities, such as direct seeding, proper fertilizer application, and weed and herbicide management (Singleton and Labios 2019). Large field demonstrations to introduce best management practices were conducted in Hlegu Township (Yangon Region; 7 ha), Letpadan Township (Bago Region; 40 ha) from 2015 to 2017, and Pyinmana Township (Nay Pyi Taw Region; 20.3 ha) in 2020–2021. Furthermore, a combination of best management practices for rice production was conducted as a large field trial demonstration in Letpadan Township with six farmers in the 2016 wet season. The technologies were taken up by neighboring farmers quickly (Box 2.1).

Box 2.1: Success Story of the Large-Scale BMP Demonstration Trial in Myanmar

Increasing rice yield by using improved technologies was established in Myanmar in 1986 as a national program financed by the government. The CORIGAP project started as the Irrigated Rice Research Consortium (IRRC) project in Myanmar in 2005, which was aligned with national policy. The IRRC project introduced new technologies to rice farmers in Myanmar, such as Site Specific Nutrient Management (SSNM), Alternate Wetting and Drying (AWD), the use of drum seeders, and the use of hermetic storage bags and flatbed dryers. Adaptive research, involving close linkages and feedback from farmer groups, and learning alliances among farmers, researchers, and extension staff from both the public and private sectors have played a powerful role in this process (Flor et al. 2017). One of the large-scale demonstration trials in the Bago Region supported the evidence of technology adoption in the project.

Background information on the process
A large field trial demonstration in Letpadan Township was conducted with six farmers in the 2016 wet season. A package of best management practices (BMP) was developed based on the challenges identified by farmers. The field experiments were conducted at Kyoet Pin Sa Khan Village (17° 47.45′ N, 95° 48.18′ E), Letpadan Township, Tharrarwaddy District, Bago Region. The major cropping patterns are rice-rice and rice-pulse, and farmers practice wet direct seeding in flooded areas. At the end of the cropping season, a farmers' field day was organized with collaborating farmers to share their findings and experiences with other farmers and local authorities. An Exchange Farm Visit program was organized for the farmers from another region (Nay Pyi Taw) to learn about the experiences of Letpadan farmers.

Technology adoption
Since the start of the trial, the neighboring farmers of the BMP farmers copied the technologies that BMP farmers practiced. All information was recorded through a farmer diary data collection process. Furthermore, yields from the plots of BMP farmers, modified farmer practices (Modified FP), and traditional farmer practices (FP) were harvested and compared. In the 2016 dry season, BMP yield (5.1 t ha^{-1}) was 12% higher than the modified FP yield (4.5 t ha^{-1}) and 26% higher than FP yield (3.8 t ha^{-1}) (Fig. 2.1). However, the cost and benefit ratio of BMP and Modified FP was not significantly different.

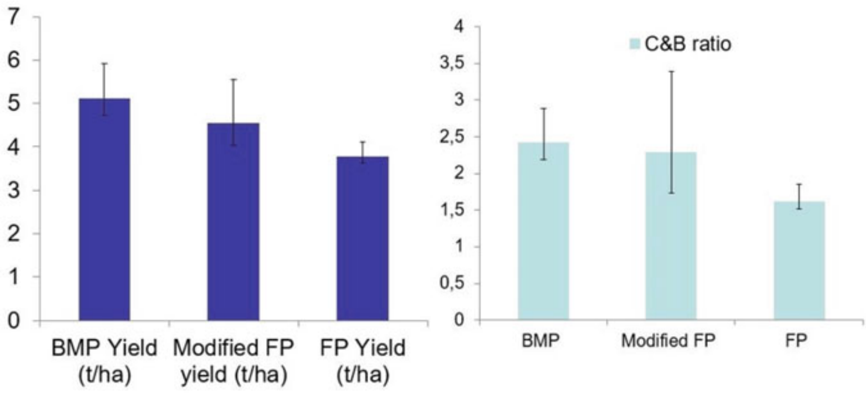

Fig. 2.1 Comparison of yields and cost–benefit ratio between Best Management Practice (BMP), modified farmer practice (modified FP), and farmer practice (FP)

BMP practices, and cost and benefit information, were shared with other farmers by the BMP farmers during the field day. Within a year, the area cultivated under BMP increased to 34.8 ha through the strong collaboration of BMP farmers and the Department of Agricultural Extension at the township level. In the 2017 dry season, BMP farmers' yield was 3.4 t ha^{-1} higher than FP farmers' yield, and the benefit was increased to 284 US$ ha^{-1}. Usually, the adoption and diffusion pathway of a new technology takes five years or above. However, BMPs were adopted by farmers from 13 villages within two years of the project. The two key success factors of this project were:

i. **The introduced technologies were proven research outcome technologies from the regional level, which are simple, affordable, and adaptable and**
ii. **The strong collaboration of local champions, both from the farmer group and from the local department extension staff, facilitated fast adoption**.

Source DoA CORIGAP annual presentation, 2021

2.1.4 Adoption of Best Management Practices and Changes in Rice Production

The CORIGAP project reached more than 25,000 households in Myanmar. The learning alliances facilitated the active participation from both public and private sectors and the subsequent formation of a network between farmers and providers (Wehmeyer et al. 2022). This resulted in the development of a market model for mechanical dryers, in particular, the solar bubble dryer, and supported a local manufacturer in making lightweight threshers (Singleton and Labios 2019; Wehmeyer et al. 2022). These aspects will be further described in Chap. 6.

As part of the monitoring and evaluation activities (described in Sect. 7.2), the CORIGAP project collected data on various aspects that indicate change for farmers. The aim was to capture social, economic, and environmental changes. In collaboration with the national partners, the CORIGAP team collected data on 129 farmers from the Bago Region in the Ayeyarwady Delta. These farmers were project farmers and had attended CORIGAP training events. There were two groups of farmers: one group followed a rice-rice cropping pattern, and the second group followed a rice-pulse cropping pattern. The objectives also included investigating the adoption of the practices and technologies that were introduced in the area. We were particularly interested in the reasons for adoption but even more so in the non-adoption or even disadoption, where farmers decided not to continue with a practice or technology. We found that farmers adopt new practices and technologies when they gain higher yields, have reduced costs, and can save labor (Connor et al. 2021a). Reasons for non-adoption and disadoption were unsuitable practices and high costs associated with new practices and technologies. Most of the farmers in the two regions adopted the high-yielding varieties; some farmers even changed varieties more than once. In addition, combine harvesters, nutrient management practices, and post-emergence herbicides were adopted widely (a detailed description can be found in Connor et al. [2021a]).

Comparing the two groups of farmers (rice-rice and rice-pulse) showed that rice-pulse farmers had higher yields during the monsoon season (the season when farmers produce rice) than rice-rice farmers. Apart from that, no other differences were found between the two groups. Input costs, gross revenue, and net profit were very similar between the two groups (Wehmeyer et al. 2022). We conducted further analyses based on the farmers' net change in income, and two groups were created; one containing farmers that had a positive change in net income and the second group was comprised of farmers that did not have a change in net income. There were no farmers that had negative changes in net income. In other words, none of the farmers in the sample experienced a decrease in their income. The analysis showed that farmers with a positive change in income had a higher yield than farmers who did not have a change in income. These farmers also adopted more of the introduced technologies and practices. On average, these farmers were able to increase their income by 113 US$ ha^{-1}, mostly due to an increase in yield and reduced production costs (Connor et al. 2021a).

Farmers were not only asked what type of technologies and practices they had adopted but also why they did not adopt or decided not to continue using the practices and technologies. They were also asked for the reasons for such a decision to provide us with a better understanding of technology adoption or non-/disadoption. Multiple reasons were mentioned for adoption, e.g., higher prices in the market for new varieties, fewer yield losses when using drought-resistant varieties, or the reduction of costs when using machinery such as a combine harvester or lightweight thresher. Similarly, farmers described difficulties when not adopting or disadopting a practice. In some cases, farmers were not able to source new varieties or inputs (e.g., herbicides). In other instances, farmers expressed that, e.g., nutrient management was too expensive or there was a labor shortage, so new practices could not be implemented. Some farmers experienced difficulties using certain technologies and also felt that others may not be suitable for their specific cropping pattern. This highlights the importance of an adaptive participatory approach when introducing new technologies and practices. It is essential to let farmers experience the new practices and technologies and to keep discussing their experiences to advise them appropriately and to refine practices and technologies that are identified as less suitable (Connor et al. 2021a).

2.1.5 The Changes Farming Families Perceived Since Adopting New Technologies and Practices

Knowing that farmers adopt and benefit financially from new technologies and practices is one way to assess possible changes in farming communities. Traditionally, this was the main avenue also to determine impact. However, it is not always easy, nor advisable, to quantify changes or impact, especially in complex environments where several interventions take place at the same time, as described for Myanmar.

Therefore, we conducted qualitative interviews with rice farmers to better understand their perception of change due to technology adoption (Connor et al. 2021a). We conducted 32 interviews with the farmers that have shown a net increase in income and asked them about the changes they have perceived. The interviews started very freely but were guided by a semi-structured interview guide. Farmers foremost explained the changes they had seen in yields through the adoption of the new varieties. Some farmers also explained how they changed their cropping system from rice-rice to rice-pulse due to an increase in prices for pulses. Furthermore, farmers explained how cost-saving technologies such as using a drum seeder allowed them to use the extra money for other inputs that they previously could not afford to boost their rice production. Especially, cost- and labor-saving technologies were adopted widely, which changed farmers' everyday activities considerably. Hence, the workload farmers faced was reduced, and they could account for the labor shortages experienced in the region. Furthermore, farmers experienced significant changes in living conditions, they explained how they have more time and money to repair their houses, and they are able to purchase different types of food and pay for education services for their children. One aspect that was frequently mentioned was how farmers use their extra time and money to serve their community. Donations to the pagoda are part of most people's personal duties in Myanmar (Connor et al. 2021a; Connor and San 2021). Village activities and social events are centered on these religious institutions, and the rural population comes together to build roads and/or canals. Such activities have increased over the past years, and a contributing factor was the adoption of labor-saving technologies.

As part of the aforementioned data collection, we also collected quantitative data on how the farmers spend their additional income. The findings are very much in line with the qualitative interview results in that they show that farmers first chose religious activities followed by food, health care, and education. These findings show that the introduction and adoption of new technologies and practices can trigger quite far-reaching changes at the individual and community levels. What became evident during our research was that we mostly spoke to male farmers. They also dominated our quantitative data collection sample. Roles in Myanmar are gender related, where men and women have particular roles in society, community, and household. With regard to rice farming, women participate in seed-saving, weeding, and transplanting, while men practice plowing and operating other equipment (Faxon 2017). We were also interested in knowing how other family members perceive the introduction of new technologies and practices and how the adoption thereof influences families as a whole. Therefore, we interviewed the wives of the farmers that had adopted new technologies and practices. The interviews were unstructured, and the women were encouraged to tell us about their lives and the changes they had experienced over the past few years (Connor and San 2021). During the interviews, women would explain how the new technologies and practices were brought into the region. They were excited to tell us all about the good things but less so about the not-so-good ones. According to some women, the only bad thing was that the training activities were held at times when they couldn't come to participate because they were busy with the children or housework. This seems to be a common factor hindering women from participating in training events. When women have small children, it often is difficult to find someone to look after them during training sessions. Furthermore, when training sessions include the introduction of machinery, it can be dangerous for young children to be brought to the training. Future projects need to take those constraints into account and find avenues to include women's participation.

Depending on families' economic status, the changes families experienced differed. All women talked about positive changes and how their families reinvest in their farming business. Some used the extra income to lease more land. Another family could buy machinery and become a service provider for agricultural machinery, such as tractors and combine harvesters. This family was economically more secure than others in the sample. A young woman with small children explained how she is happy that she can now serve three meals a day and that her children do not need to be hungry. Interestingly, for some women, the change in income meant that they were able to pursue their own career aspirations. One woman, who worked as an input provider, dreamt of becoming an extension officer. Another woman explained how the extra income enabled her to open her own little shop where she sells household goods. Most of the interviews were conducted in participants' houses, and we were shown around to see all the new things that families acquired over the past years. They were able to improve their housing conditions, repair roofs, getting electricity installed, and one family even purchased a small solar panel to generate their own electricity. Similarly to male interviewees, women also explained how the extra income supported their children's education, both school and university education. One woman talked about how she could afford health care for her elderly parents, and another one how she established a big kitchen garden that produces enough vegetables for her to sell at the local market. This only provides a small insight into the multitude of changes families can experience due to an increase in income from rice farming. Changes obviously differ depending on the economic status of the families (Connor and San 2021). Smallholder farmers are not a homogeneous group, and the introduction of new technologies and practices will affect each farmer and their respective family differently.

2.2 Thailand

2.2.1 Rice Cultivation in Thailand

Thailand is the 6th top rice producer as of 2022 (FAOSTAT 2023) and is one of the top three global rice exporters, together with India and Vietnam, situated in the world's rice bowls in Southeast Asia (ASEAN Vietnam 2022). Rice is Thailand's primary agricultural export product (USDA 2022), with exports reaching US$ 1.7 billion in the first half of 2022 (Rice Today 2022). A study by Kealhofer (2002) found that rice cultivation in north and central Thailand started in the "middle Holocene" period about 7,000–5,000 years ago. Since then, rice has been a staple food in Thailand and fundamental to the country's culture (Roaf 2022); it is used in religious ceremonies such as weddings and offering to Thai Buddhist monks (Roaf Thai Ginger 2023).

Thailand is in the middle of mainland Southeast Asia with a total size of 513,120 km^2 and has a fertile floodplain. The country has 32.9% of arable land (The World Bank 2020). Over half of the arable land in Thailand is cultivated for rice, which is grown by 4 million out of 8 million farm households (Bangkok Post 2020). The area cultivated with rice increased by 2.65%, and production increased by 3.63% from 2016 to 2021 (FAOSTAT 2023). The major rice-growing regions are located in the central, north, and northeast, with a respective share of 24, 20, and 50% of the country's total rice area (GRISP 2013; USDA 2015).

Thailand is characterized by a favorable climate and fertile soil, which makes it suitable for rice production (The World Bank 2022). The main four ecosystems in Thailand are (a) rainfed lowland (72% of the total paddy field and mainly located in the northeastern region), (b) irrigated lowland (20% of the total, located in the Central plain, (c) deep water (5%), and (d) upland rainfed land (3%) (Pongsrihadulchai 2018).

Thailand's rice policy has undergone several changes over the last decades. In 1955, a rice premium export tax was introduced with the following objectives: to secure government revenue, to stabilize the domestic rice price resulting from fluctuating world prices and domestic supply, and to control the exporters' excess profits (Tsujii 1977). Moreover, the rice premium export tax was abolished in 1986 since it consequently resulted in heavy taxation on farmers, higher domestic demand, lower exports, and lower foreign currency receipts.

After the democratic movement in 1973, Thailand shifted from an urban-biased development approach by which urban development is favored to a producer-biased approach (Poapongsakorn 2019). The government introduced paddy pledging schemes for farmers in 1980–1982 and in 2000–2001, providing subsidized non-recourse loans to farmers who did not want to sell paddy in the early harvesting season. In the 1980s and 1990s, most agricultural policies provided incentives to encourage farmers to grow crops other than those with diminishing prices, such as rice and cassava. Following the economic crisis and the constitutional reform in 1997, agricultural policy shifted toward providing subsidies to farmers. The succeeding policies from 2000 to 2018 started on price support and market intervention for almost three years and reverted to a minimum income subsidy for farmers with minimal market intervention.

The rice policy review by Forssell (2008) emphasized that the rice policy by the end of the twentieth century would become neutral for producers and consumers. The beginning of the twenty-first century favored the producers when the mortgage program was introduced. However, the reintroduction of high pledging prices on the first and second crops in 2008 caused huge harm to the domestic rice industry. The main ultimate goal of the scheme was to increase rice prices to protect farmers from middlemen. The government gave farmers higher crop prices than what they would have received from middlemen. The immediate results of the high pledging process policy included a slowdown in exports since supply decreased, high domestic prices, and large government expenditure.

To avoid causing more damage to the Thai rice industry, the government eliminated the paddy pledging scheme from 2014 to 2018. Recently, Thailand's rice policy and management committee agreed to allow another year to resolve the controversial rice-pledging scheme since the pledging scheme resulted in unsold rice of 218,000 tons. Most of this rice deteriorated considerably in quality and was often sold as inedible rice to be converted into bio-fuel (Thai PBS World 2022). In a new attempt, Thailand's Rice Policy Management Committee has approved a budget of about 150 billion baht to guarantee the income of more than 4.6 million farming households for their 2022–2023 rice crops (Thai PBS World 2022; Bangkok Post 2022). The state will set the minimum rice market price to be updated within seven days and will pay the price difference to farmers who are unable to sell their crops at the set prices. Moreover, to encourage farmers not to sell their produce at a time when the prices drop, each farming household will get a subsidy of 1,000 baht per 0.16 ha but will not exceed 3.2 ha or 20,000 baht in total (Thai PBS World 2022).

2.2.2 Constraints and Opportunities in Rice Production

Thailand has a favorable climate and vast land for rice cultivation. Moreover, the combination of the use of technology, advanced knowledge of rice strains and fertilizers, helpful government policies, and massive investment in infrastructure improvements, agricultural research, and road networks in the 1970s all led to a per unit of land increase of 50% in rice production (Poapongsakorn 2011; Wailes 2012; Laiprakobsup 2019). Thus, the synthesis of all these factors paved the way for Thailand to be one of the largest rice producers and top exporters of rice globally.

Thailand consistently ranked as the first rice exporter globally in the past 30 years. The country lost its position to India and Vietnam in 2012 (Pongsrihadulchai 2018; Kishimoto 2021). The move down in the ranking resulted from several reasons:

i. Decreasing rice production caused by droughts and unpredictable wet weather.
ii. Higher export prices and freight charges (Kishimoto 2021; Promchertchoo 2022).
iii. The paddy pledging scheme in 2011 contributed to the weakening of the export competitiveness of Thai rice relative to its competitors in terms of export price and quality.

   The export price of Thai rice was higher than the export prices of its competing countries, such as Vietnam and India, with the belief that Thailand has the market power to raise the export price in the global rice market by stockpiling and decreasing its exports (Mahathanaseth and Pensupar 2014). However, the study on the rice-pledging scheme by Mahathanaseth and Pensupar (2014) indicated that Thailand does not have the market power to influence export prices in its four major export markets, including China, Indonesia, the USA, and South Africa. Moreover, Thailand faces extreme competition from Vietnam and India, whose rice appears to be a very good substitute for Thai Rice (Mahathanaseth and Pensupar 2014; Promchertchoo 2022).

iv. Thai farmers rely heavily on chemical pesticides and fertilizers to improve rice production.

Farmers, in general, are risk-averse, resulting in excessive use of chemical inputs which can negatively affect the environment and the net income of rice farmers. Consequently, increasing the production and selling costs of rice and raising the export price of Thai rice.

The number of pesticide products applied increased from 2 to 7 kg ha^{-1} from 1997 to 2009 and further increased to 8 kg ha^{-1} in 2012 (Praneetvatakul et al. 2013). Pesticide poisoning remains a common work-related illness in Thailand (Ministry of Public Health 2020), which means certain measures are needed to prevent more cases of poisoning.

Approximately 47% of the fertilizer consumed in agriculture was used in rice production (Wannarut et al. 2014). Fertilizer consumption increased from 0.2 to 2.6 million Mt from 1970 to 2010 (Wannarut et al. 2014).

v. High labor costs lead to higher production costs, which is reflected in Thai rice production and price.

All the above-mentioned constraints, if resolved, can greatly help Thailand gain back its position as the world's top exporter. The government is keen to expedite its way back to the top. Among the avenues are the following:

i. Lowering export surcharges to improve the export price competitiveness of Thai rice.
ii. Increasing rice production with emphasis on environmentally safe management practices for sustainable rice production, which includes efficient use of inputs such as (a) water, (b) pesticides and fertilizers, and switching to organic options, and (c) proper management of straw and other rice crop residues that is using rice straw for other purposes like mushroom production rather than burning it.
iii. Cost Reduction Operating Principles (CROP) was promoted by the Thai Rice Department, which is complementary to (ii). Efficient use of available natural and chemical inputs ultimately reduces the production costs (while simultaneously reducing the negative impact of rice production on the environment), consequently increasing farmers' income and competitiveness of Thai rice.
iv. Investment in (a) high-quality rice breeds for exports that can compete with the existing rice varieties in the global market and (b) infrastructure for the ease of transporting rice within the country.

2.2.3 CORIGAP Activities in Thailand

CORIGAP introduced Best Management Practices (BMPs) in the Central Plains of Thailand in collaboration with the Rice Department Ministry of Agriculture and Cooperatives. The five significant activities implemented in 2013 were focused group discussions, a baseline household survey, an environmental indicator workshop and discussions, and capacity-building activities. The focused group discussions were conducted in Ban Nong Jik Ree and Ban Sapan Song in May 2013 to assess the needs and behavior of farmers. Farmers from Nong Jik Ree grow rice for seed production, while those from Sapan Song grow for grain production.

The baseline household survey conducted in November 2013 (more information in Sect. 7.2) intended to obtain necessary information on farmers' practices before introducing any intervention. Eighty-four farmers were interviewed from four villages of Nakhon Sawan: Nongjikree, Sapansong, Packluk, and Sakaeggo.

The Rice Department arranged workshops to facilitate identifying environmental indicators in measuring the ecological footprint from farming practices and technologies adopted in rice production in November 2013, attended by about 50 participants. Follow-up meetings were conducted until 2015 to discuss protocols for ecological indicator monitoring. Three staff from the Rice Department were trained at IRRI headquarters: one attended the rice post-production training course in October 2013, and two attended the ecologically-based pest management training course in November 2013.

The BMPs on cost reduction operating principles (CROP), AWD, drum seeding, fertilizer, pest, and postharvest management (hermetic storage) were established at CORIGAP sites in 2014. The activities were promoted through farmer participatory demonstration trials and field days. The CROP approach fostered fertilizer rates based on soil analysis, the use of certified seeds, reduced seed rates, and reduced chemical application. Protocols for monitoring water and soil quality were developed and executed in the wet season of 2014. Trials on using the Superbag were conducted in Ban Nong Jikree to compare the rice seed quality between Grainpro-Superbags and traditional storage systems. A Participatory Impact Pathway Analysis (PIPA) workshop was held in 2014 to discuss and better understand how various actors gather and use data on ecological indicators.

The plant growth-promoting rhizobacteria (PGPR II) and bio-fertilizer (LDD#12) are bio-fertilizers promoted by the Department of Agriculture and Land Development Department mainly to reduce the application of chemical fertilizers. Both bio-fertilizers can fix atmospheric nitrogen (N) to lower the amount of chemical fertilizer applied to the soil (Pame 2016; Pame et al. 2023). Moreover, PGPR II is mixed with seeds before broadcasting, while the bio-fertilizer LDD#12 is mixed with the soil during land preparation.

Laser leveling was also promoted in collaboration with Thai Rice NAMA, the Rice Department, and Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) to replace high-methane emitting approaches.

A joint workshop on *Adaptive Research for Target Groups and Best Practices* from the CORIGAP project was held from November 28 to 30, 2022, in Chainat Province, Thailand (IRRI 2022). It was a collaborative activity between experts from the Chainat Rice Research Center (CRRC) and the IRRI-CORIGAP project aimed to share the best practices and technologies of the project with broader groups under the Thai Rice Department to capture their perceptions on the effectiveness and relevance of the presented interventions, and ultimately help them replicate and integrate these into their division's agenda even after the termination of CORIGAP (IRRI 2022).

2.2.4 Adoption of CORIGAP Technologies and Changes

Under the CORIGAP project, field trials were established to investigate different BMPs, such as CROP recommendation, Alternate Wetting and Drying (AWD), and the use of drum seeders. Stuart et al. (2018) compared the three best management practices (CROP recommendation, CROP+AWD, CROP+drum seeder (DS)) with farmers' practice (FP) in eight field trial sites in the Chao Phraya River Basin in terms of input use (fertilizer, seeds, water) and income. CROP recommendations had lower fertilizer inputs of 64% and higher net income of 24% per season versus FP without yield penalty. The CROP+DS treatments had lower seed rates by 67% and higher income than FP. Forced AWD was followed when the study was conducted due to water shortage, yet high yields were still achieved with AWD practices. In summary, the study showed that an increase in income paired with reducing inputs that would otherwise cause adverse environmental impacts could help enhance the sustainability of rice production.

Replicated production scale trials of CROP in combination with land laser leveling (LLL), the use of mechanical drum seeders, and the application of the bio-fertilizers PPGR and LLD#12, which contains *Azotobacter tropicalis*, *Burkholderia unamae,* and *Bacillus subtilis,* were investigated by Pame et al. (2023). The study's objective was to see how the different combinations can help improve the sustainability of rice cultivation in Central Thailand. The study found that CROP+PGPR had significantly higher net income (79%) and nitrogen-use efficiency (57%) compared with farmer practice. All CROP treatments had lower pesticide use (28%), seed rate (60%), inorganic fertilizer nitrogen (41%), and lower total production costs (19%) compared with FP. These results provide evidence-based findings that the practice of CROP, LLL, mechanical drum seeders, and bio-fertilizers can vastly enhance rice production's economic and environmental sustainability in the Central Plains of Thailand.

A cross-sectional survey with 170 farmers, of which 108 were female, investigated the different changes farmers have perceived over the last years since CORIGAP interventions were introduced. Farmers were recruited from ten different villages, four from Nakhon Sawan and six from Chainat. Farmers had a choice of adopting multiple technologies and practices and, on average, adopted 2 (SD = 1.3) technologies and practices in the dry season and 2.5 (SD = 1.1) technologies and practices in the wet season. There were no statistically significant differences between male and female farmers in the average number of technologies and practices they adopted. Almost all farmers ($n = 168$) indicated that they were using a combine harvester, 71% ($n = 121$) adopted new varieties, 33.5% (57) of the farmers adopted improved fertilizer management, and another 20.6% ($n = 35$) adopted AWD. There were no differences between the number of male and female farmers adopting the different technologies and practices. Our analysis further found that farmers reported an increase in yield of 1.5 tons ha^{-1} (SD = 1.4) in the dry season and 1.9 tons ha^{-1} (SD = 1.7) in the wet season, which is associated with adopting best management practices. This, in turn, accounts for an approximately 26% increase in yield per season. Up to 25% of the farmers reported that input costs have decreased, while the rest reported that costs had stayed the same, indicating minimal general savings on production. Nonetheless, the yield increments directly translate to an added revenue of US$ 359 ha^{-1} (SD = 332) to US$ 458 ha^{-1} (SD = 397) in the dry and wet seasons, respectively, with an estimated increase in earnings from rice of 25 to 32% per season. Half of the farmers surveyed, 51% ($n = 86$), perceived that their income increased since adopting the best management practices. We disaggregated the data by gender and conducted the same type of analysis, and found that there were no statistically significant differences between male and female farmers. Farmers who perceived an increase in income were asked if they could remember how they used the additional income. Only half of the farmers could actually remember. Most farmers indicated that they put the additional income into savings or invested in their rice farming activities to buy either machinery or inputs.

We also asked farmers if they have perceived other changes in the same way as reported by Connor et al. (2021b, c) using different dimensions of change. These dimensions included financial capital, employment opportunities, physical capital, poverty reduction, land tenure, health, food security, social capital, human capital, and natural capital. Farmers perceived great changes in social, cultural, and natural capital. In other words, farmers reported that they now feel able to provide advice to their fellow farmers on how to improve their farming practices. They feel that they can devote more time and resources to community and cultural or religious activities. A lot of farmers also indicated that they see a lot more wildlife in their fields. In general, male farmers perceived more changes in these three areas than female farmers.

2.2.5 Conclusions

The adoption of best management practices under the CORIGAP project led to significant improvement in the economic and environmental sustainability of rice production in Thailand. Field trials have demonstrated that BMPs such as CROP recommendations, AWD, the use of drum seeders, land laser leveling, and bio-fertilizers can help increase yields, reduce input costs, lower pesticide use and inorganic fertilizer nitrogen, and enhance nitrogen-use efficiency.

Moreover, a cross-sectional survey of 170 farmers showed that the adoption of BMPs has led to an approximately 26% increase in yield per season, resulting in an estimated increase in earnings from rice of 25 to 32% per season. Farmers also reported an increase in their ability to provide advice to fellow farmers on improving farming practices, as well as an increase in their ability to devote time and resources to community and cultural or religious activities.

The benefits of BMP adoption go beyond just economic and environmental sustainability. By promoting the adoption of BMPs, not only can farmers increase their yields, lower their input costs, and reduce their environmental impact, but they can also enhance the social and cultural fabric of their communities and support the natural ecosystems that surround them. As farmers adopt BMPs and see improvements in their yields and income, they may be better able to invest in their families and communities. They may have more time and resources to participate in cultural and religious activities, strengthening social ties and building community cohesion. Additionally, the use of bio-fertilizers and reduced pesticide use can help support the natural ecosystems that surround rice farms, leading to benefits such as improved water quality and increased biodiversity.

BMP adoption is a multifaceted solution to improving rice production sustainability and highlights the importance of promoting BMP adoption both in Central Thailand and in other regions where rice farming is a critical part of the economy and the environment. The adoption of BMPs does not only enhance the sustainability of rice production but can also have positive impacts on social, cultural, and natural capital.

2.3 Indonesia

2.3.1 Rice Cultivation in Indonesia

The need for rice as the main food of the Indonesian population continues to increase from year to year. In 2045 when Indonesia will celebrate their 100th year of independence, the population is estimated to be around 325 million people, and domestic rice needs will reach 47.9 million tons (Sulaiman et al. 2018). The government set a production target of 92.3 million tons of dry-milled grain or an equivalent to 57.9 million tons of rice, and a surplus of 10.0 million tons of rice to be exported (Sulaiman et al. 2018). Meanwhile, the area of paddy fields as the backbone of national rice production to date is around 8.2 million ha, of which 4.75 million ha (58%) has irrigation infrastructure, including 2.2 million ha of technical irrigation (Wahyunto 2009).

The current rice cultivation area is too small to meet food sufficiency in the future if it is not offset by increased productivity, an increase in the area of technically irrigated rice fields or the creation of new rice fields. Agricultural land conversion poses a serious threat to achieving and maintaining food independence (Mulyani et al. 2016). In addition, there are various challenges in maintaining rice self-sufficiency, including increasing land degradation, limited water resources, limited availability of suitable land for area expansion (Mulyani et al. 2016), and increasing pest and disease populations (Hendarsih and Sembiring 2007). Climate change characterized by shifts in rainfall patterns, extreme climate events, and rising sea levels also threatens rice production (Sembiring et al. 2008).

The Integrated Crop Management (PTT) approach has been the mainstay of the Ministry of Agriculture in an effort to increase rice productivity and production in Indonesia. PTT's approach is based on land, water, plant management and plant pest control, highlighting the synergy between technological components and soil, water, and environmental resources. The main objectives are increased productivity to break through leveling off of yields, increased efficiency of production factors for increased income, and improved soil fertility and environmental quality (Badan et al. 2014).

The supporting technology components of PTT are dynamic, following the development of science and technology and information technology. The leverage point in the reorientation and transformation of PTT as the basis of precision farming systems is the refocusing of technological components and the support of information technology in its dissemination systems.

Indonesia has a goal to be food independent and sovereign. The government, from era to era, continues to strive to increase rice production to provide national rice reserves. Through the Special Efforts Program (UPSUS), in the current government era, Indonesia managed to achieve rice self-sufficiency in 2016. Rice PTT based on soil and water resource conservation characterized by a precision agriculture system is believed to be able to answer the challenges of maintaining national food independence and sovereignty in a sustainable manner and making Indonesia a World Food Barn.

2.3.2 Challenges in Indonesia

2.3.2.1 Rice Situation and Challenges in Yogyakarta

Yogyakarta is one of Indonesia's rice-producing areas, with an average harvested area of 110,000 ha for the last decade. The rice cropping index is about 2–2.5 in a year (5 rice harvests within two years), and production occurs predominately in irrigated agroecosystems. Yogyakarta's rice production reached 319,200 tons of milled rice in 2021, with an average yield of 5.21 t ha^{-1}. However, there are some significant challenges to maintaining this high level of rice production in this area. The rate of annual rice consumption is high (81.4 kg per capita and year), and combined with the high rate of population growth (5.53% per year, Yogyakarta population is 3.71 million), results in growing pressures to produce sufficient rice to fulfill the increased demand (BPS-Statistics 2022a). Other challenges are the land conversion from rice farming to other purposes resulting in limited growth in rice harvested area, combined with problems of smallholder farm size, limited water availability, pest and diseases, and labor shortage. Yogyakarta had not established new rice fields since 1996. In contrast, over twenty years, the rice fields were reduced by 7,968 ha or about 257.5 ha per year. This reduction relates to the conversion of land from rice farming to other purposes (Herdiansyah et al. 2020; Central Bureau of Statistics (BPS 2018).

Most Yogyakarta farmers own small land holdings with cultivated areas for rice on about 1,400 m^2. Input costs in rice farming include seeds, fertilizers, pesticides, irrigation fees, hired labor, and cover for machinery rental costs (Connor et al. 2021b). With their small land size, farmers face challenges in applying fertilizer and using seeds at the recommended rate, combined with their knowledge regarding healthy and vigorous plants which bear a resemblance to dark green leaf color. This condition causes excessive application of nitrogen. According to Devkota et al. (2019), more than 80% of farmers planted certified seeds, but most used more seeds than required by 40–45 kg ha^{-1}. With regard to fertilizer usage, more than 74% of farmers applied N, and more than 67% of farmers applied P and K. In Yogyakarta, the local recommended rate for N is about 250 kg ha^{-1}, where most farmers applied N by 200 kg ha^{-1}. Meanwhile, the topmost farmers exceeded the recommended rates without an overall increase in yield (Stuart et al. 2016). The rate of N, P, and K application was, on average, 200 kg, 22 kg, and 45 kg ha^{-1}, respectively (Devkota et al. 2019).

Water shortage which occurs in particular areas during the second crop season also becomes a constraint. According to Devkota et al. (2019), the total number of irrigations per cropping season in Yogyakarta is quite low, but it increased to 45% during the dry season. However, the water productivity is high, which means that fields in Yogyakarta exploited 2100 l of irrigation water and rainfall to produce 1 kg of grain.

The main pests and diseases in Yogyakarta during the last decade were rodents, stem borer, brown plant hopper, blast, and bacterial leaf blight with a damaged area of 2,365 ha, 3,066 ha, 891 ha, 363 ha, and 1,842 ha every year, respectively (Yogyakarta Institute of Agricultural Plant Protection 2020). However, farmers in Yogyakarta were categorized into the gold category in the utilization of overall pesticides during their farming practices regarding sustainable rice platform (SRP) performance indicators. Using the Field Calculator scoring method based on the number and timing of insecticides, fungicides, herbicides, molluscicide, and rodenticide applications, the scoring of Yogyakarta farmers was, on average, 70% (Devkota et al. 2019). Rice establishment and harvest activities affected labor use, which was high, but labor productivity was low. Roughly 80% of farmers applied puddled transplanted rice and manually harvested it (Devkota et al. 2019). Currently, Yogyakarta is struggling with labor shortages due to increased farmer age and a lack of young people commencing in rice farming.

All of these challenges resulted in variations in rice yield among farmers and created yield gaps. Based on studies conducted by Devkota et al. (2019) and Stuart et al. (2016), farmers' yield in Yogyakarta was 5.8 t ha^{-1}, with a 42.4% yield gap. The obtainable farm yield (average yield of the topmost farmers) was 9.1 t ha^{-1}. Research and demonstration plots were conducted in Yogyakarta to encourage farmers to improve their farming practices to increase rice yield (Connor et al. 2021b).

2.3.2.2 Rice Situation and Challenges in South Sumatra

The "Musi River Basin" refers to the distribution of tidal land on the east coast of Sumatra Island. In this downstream region, the rivers of South Sumatra flow into the Delta Channel. As a wet ecosystem positioned among an area with a terrestrial system and an aquatic system, characterized by its shallow or flooded groundwater level, this location is a center for rice food production, similar to some other Mega Deltas in South and East Asia (Fig. 2.2).

There are 362,749 ha of reclaimed tidal land in South Sumatra. The area covered by tidal rice fields is 273,919 ha (BPS-Statistics of Sumatera Selatan Province 2016) or 35.36% of the overall scope of rice fields. This reclamation is a strategic move to enhance the utilization of natural resources to encourage increased food production and rice availability.

Farmers in South Sumatra's tidal land cultivate rice annually over 131,936 ha, although agronomic cultivation can potentially be conducted twice a year. Some 95,408 ha of tidal lands have been cultivated with paddy twice, 19,226 ha have been grown with other crops, and 27,349 ha remain unplanted (BPS-Statistics of Sumatera Selatan Province 2016). South Sumatra's harvested paddy area totaled 551,321 ha in 2020, yielding paddy production of 2,743,060 tons, or 1,575,216 tons of milled rice (BPS-Statistics Indonesia 2022c). South Sumatra had a rice surplus of 883,935 tons in 2020 due to its population of 8,467,432 people, with a rice consumption rate of 81.64 kg per person per year.

Fig. 2.2 Map tidal land in South Sumatra (provided by the Directorate of Irrigation and Swamp, Directorate General of Natural Resources)

Utilizing a combined harvester with a leasing system is a viable solution to the labor scarcity that frequently causes harvesting delays. It is more efficient than paying harvest workers, whose consumption costs are substantial. Similarly, land preparation in certain areas, especially on land with overflow, already uses four-wheel tractors, therefore, making land preparation more efficient. Although direct seeding equipment, including tractor-drawn machinery, has been introduced, farmers still prefer the spreading method because it's cheaper and quicker. A major restraint to a second rice crop has been high rodent and weed infestations. This issue is discussed further in Chap. 4.

The rise in the rice cropping index is expected to enhance possibilities for processing by postharvest organizations; nevertheless, the rice milling unit activity is declining. In addition to the farmers' time being used in promptly cultivating and replanting the land, the low selling price of grain and rice, particularly during the harvest season, and the lack of drying facilities contribute to the problem of the standard or declining working capacity of rice mills. This problem increases farmers' interest in selling their products as dry grain. Transport vehicles from outside the province of South Sumatra visit the harvest location or wait at the pier for the paddy to be unloaded from the boat. This situation renders by-products, such as husks and bran, the property of prominent entrepreneurs or factory owners.

Wetlands have the potential to be transformed into agricultural land, but their development faces several challenges. As a result of the marginal and fragile nature of swamp land, large-scale development must be undertaken with caution. The diversity of physicochemical features of the land, such as low soil fertility and pH, poisonous chemicals (aluminum, iron, hydrogen sulfide, and sodium), peat layers, drought/waterlogging, and even seawater intrusion during the dry season, indicates biophysical limitations (Ananto and Pasandaran 2011).

Most tidal land is peat or peat land; in addition to being understood as an ecosystem that must be preserved, it is also considered a resource that may be developed and exploited following the concept of sustainability. Improving the water system in tidal areas for drainage purposes alone will trigger the groundwater level to decline and over-drain. This condition is highly hazardous in wetlands with thin pyrite layers. The raised layer of pyrite that undergoes oxidation will induce an acidification reaction and poison, so restoring it will be difficult or impossible. The paradigm of water management should transform to irrigation-drainage adapted to agricultural purposes. The design of water systems enhances the leaching of hazardous chemicals produced by pyrite oxidation (Ananto and Pasandaran 2010).

2.3.2.3 Rice Situation and Challenges in North Sumatra

North Sumatra is the seventh biggest rice-producing area in Indonesia, with an average productivity of 5.26 t ha^{-1}, which is the same as the national rice productivity in 2021 (BPS-Statistics 2022b). Rice consumption per capita in the year 2020 was 98.28 kg, with a decrease of 1.67% over the last four years (BPS-Statistics 2022a). Based on the trend of the increasing population of North Sumatra over the last 12 years, by 12.70%, it is not comparable with the trend of production, which has decreased by 23.81%. The decline in production for the last 11 years was accompanied by a 34.42% decrease in harvested area. According to the GYGA (2020), the potential for rice production in North Sumatra can reach 9–10 t ha^{-1}, while the average production in North Sumatra is only 5.26 t ha $^{-1}$, meaning that there is a yield gap of 4–5 t ha^{-1}.

Several programs that have been implemented by the central and regional governments in reducing the yield gap were in the form of seed-independent village programs, special efforts for rice, corn, and soybeans, rice field planting, subsidy for production and agricultural machinery, and other government programs (Girsang et al. 2021). The seed program through seed-independent villages is an easy way to increase rice production. This activity began in 2015 in 25 regencies/cities in order to meet the needs of the region (Department of Food Crops and Horticulture of the Provincial Government 2016). In fact, this activity has not shown significant evidence of increasing production, and the reason is that often the types and quantities of seeds needed during the growing season are not available. This is due to the non-uniform level of knowledge, inappropriate locations, motivation of farmer seed producers, and the low support from the Provincial/District Agriculture Service (Darwis 2018; Directorate of Rice Seeds 2014).

Furthermore, farmers prefer certain varieties, such as Mekongga and Ciherang, although several other varieties have high-yield potential (Mustikawati 2021). The tendency of farmers to use the same variety continuously may trigger changes in the biotype of a pest which will then lead to resistance (Dianawati and Sujitno 2015) and decreased production (Samrin 2018). Likewise, the subsidy of agricultural machinery, such as transplanters, was not able to function properly because of the unskilled human resources of farmers and non-uniform agricultural land. The rapid development of tools in the field, such as the combined harvester used by farmers to date, results in cleaner and cheaper quality rice. It has also accounted for the shortage of manpower for harvesting.

For site-specific nutrient management, farmers use various methods such as soil test kits, integrated katam, and rice consulting services. These tools have helped farmers on a small scale, but the lack of skilled human resources and extension workers and many questions from farmers has led to low use of the tools. The solution that can be offered is increasing the human resources of farmers and extension workers through training, simplification of tools, and more aggressive seed dissemination. Land intensification through the provision of technology that is easily adopted by farmers is a way to answer the challenge of decreasing agricultural land in North Sumatra.

2.3.3 CORIGAP Activities

2.3.3.1 CORIGAP Indonesia

In Indonesia, CORIGAP was a collaborative project between the Indonesian Agency for Agricultural Research and Development (IAARD) and IRRI, and began in 2013, initially involving the Indonesian Center for Food Crops Research and Development (ICFORD), the Assessment Institute for Agricultural Technology (AIAT) South Sumatra, and the AIAT Yogyakarta. It was only in 2017 that AIAT North Sumatra joined CORIGAP.

CORIGAP Indonesia focuses on efforts to close the gap in rice productivity by optimizing the application of existing agricultural research and development innovations. Phase I of CORIGAP was carried out during the period 2013–2016, and starting in 2017, the project entered Phase II (CORIGAP-PRO), which emphasized more on the up-scaling aspect of the application of the best practices recommended from the previous phase. In 2021, CORIGAP Phase 3 was launched to document the lessons learned from implementing best management practices as well as reaching policymakers to ensure sustainable adoption of the BMPs (e.g., Integrated Crop Management in Indonesia) aligned with the country's national rice program.

Within ten years of CORIGAP implementation in Indonesia, we have conducted many introductory studies and improvements in agricultural technology innovations. Some innovations were implemented in all locations, but some innovations were only suitable for certain agroecological systems. Many agricultural innovations in the form of high-yielding varieties, Integrated Crop Management (ICM), AWD, solar bubble dryers, direct seeding, rodent control with trap barrier systems, hermetic storage bags, semi-automatic downdraft rice husk furnaces, rice husk box dryer, stripper harvester, land laser leveling, combine harvester, and Rice Crop Manager (RCM) were intensely studied by the CORIGAP Indonesia team and applied by cooperating farmers.

In order to increase the benefits of the studies we conducted in the CORIGAP, we formulated the activities of the CORIGAP project in synergy with the national rice programs implemented by the Ministry of Agriculture (MoA). The innovations that are our flagships are included as the subcomponents of national programs implemented by local governments in the three provinces where the CORIGAP project was carried out. Within ten years of CORIGAP's journey in Indonesia, there are at least three national programs that we have utilized to be the vehicle to deliver CORIGAP interventions.

The first program was GP-PTT or Gerakan Penerapan Pengelolaan Tanaman Terpadu, an integrated crop management implementation program rolled out by the government in 2013–2015. In the program, the main mission was the dissemination and adoption of ICM with an emphasis on the use of high-yielding varieties (HYV) and the arrangement of planting systems using two methods, transplanting in irrigated fields and direct seeding in tidal swamp areas.

The second national program was Upaya Khusus (UPSUS) Padi, a special program to increase rice production that was implemented in 2015–2019, which was the first term of President Joko Widodo's cabinet. This program was similar to GP-PTT, which carried out the mission of implementing ICM with a focus on utilizing HYV, some decision support system tools such as RCM or Layanan Konsultasi Padi, and improving postharvest handling and optimizing the use of agricultural machinery were also implemented.

The third national approach included two programs: Rawa Intensif, Super dan Aktual (RAISA) and the Selamatkan Rawa, Sejahterakan Petani (SERASI). These programs were specially executed for the development of tidal swamp land. RAISA emphasizes focusing more on mentoring farmers to carry out intensive, super, and actual swamp rice cultivation. Meanwhile, SERASI was more about integrated swamp land optimization for farmer welfare. These two programs for swamplands were implemented in 2018–2020 and are similar to UPSUS. The two programs also promoted ICM as a package of recommended technologies with an emphasis on the use of high-yielding swamp adaptive varieties, dissemination of RCM/LKP use, postharvest handling, and utilization of agricultural mechanization. Layanan Konsultasi Padi (LKP) is an accumulation of rice nutrient management science from IRRI and the innovations developed by the IAARD.

2.3.3.2 CORIGAP Activities in Yogyakarta

The activities of research and demonstration plots were conducted in Yogyakarta to encourage farmers to improve farming practices to increase rice yield and close the yield gaps. Rice technology had a substantial improvement, whereas high-yielding rice varieties, machinery, optimized fertilizer usage, and pest and disease management effectively contributed to the rice farming system. The aim was to reduce the gap between the potential yield attained on experimental activities and the actual yield achieved at farmers' fields. According to Silva et al. (2022), inefficient fertilizer use and high-rate inputs result in low profitability, which is an aspect that should be of concern in reducing yield gaps. By reducing N fertilizer application to the recommended rate, the increase in rice yield and, therefore, yield gap closure is possibly gained.

Through CORIGAP, Yogyakarta farmers were encouraged to implement ICM to reduce input and improve yields which will improve poverty, preserve the environment, and increase food security. Some elements of ICM, such as HYV, direct planting using drum seeders, transplanter machinery, AWD, RCM, ecologically-based rodent management named PHTT (*Pengendalian Hama Tikus Terpadu*), and combine harvesters, were introduced to farmers over two years of research in two villages in the Sleman district, and over four years of adaptive participatory activities supported with massive dissemination process in four districts (Sleman, Bantul, Gunungkidul, and Kulon Progo), which reached many farmers. Adaptive participatory activities enriched with an intensive dissemination process were conducted through field schools, field and class training, technical assistants, demonstration plots, field days, farmers cross visits, flyers, television, social media, and online (virtual) training during two years in the COVID-19 period.

Farmers who planted Ciherang as the dominant variety before the CORIGAP project were introduced to alternative varieties like Inpari 10 to Inpari 43 during the CORIGAP project activities. Regarding the labor shortage in Yogyakarta, the drum seeder was introduced. Using a drum seeder, farmers distribute pre-germinated rice seed directly in neat rows with less labor and less time consumption compared to manual transplanting, which requires five women (laborers) with more than 50% higher costs. Mechanical transplanting machines and combine harvesters were also introduced to overcome labor shortages during the peak of planting season and harvest season, as well as to increase labor productivity. A study conducted in East Java by Durroh (2020) showed that the effectiveness of a combine harvester was 58%. Moreover, this machinery gave a 36% impact on the community income with R/C criteria > 1; this means that the revenue was greater than the expenditure. Water management has an important role in increasing rice production and was implemented through AWD. With AWD, the field is permitted to dry out for one or quite a few days and is not continuously flooded (Lampayan et al. 2015). The rice crop manager, an SSNM tool, was introduced to provide better knowledge to farmers about the importance of the appropriate fertilizer rate. According to Stuart et al. (2016), increasing rice yields in Yogyakarta could be achieved by the application of fertilizer using the local recommended rate, for example, a nitrogen rate of 250 kg ha^{-1}, while exceeding this rate would not relate to higher yields obtained. Ecologically-based rodent management was implemented by farmers, in particular in areas which had large damage and were endemic to rodent attack. Increasing farmers' awareness about yield loss caused by rodents, breaking traditional mindsets (mystic story) about rodents, and encouraging synchronous planting were conducted with great support from Yogyakarta Agriculture Office (*Dinas Pertanian Yogyakarta*). Promising better yield (50–75% increase in yield) was obtained by farmer groups who implemented ecologically-based rodent management.

2.3.3.3 CORIGAP Activities in South Sumatra

From 2004 until 2022, IRRC activities, followed by CORIGAP, were implemented in the tidal paddy-producing center of Banyuasin Regency in South Sumatra. The aim was to accelerate ICM, support the government's Rice Special Effort Program (known as UPSUS), and reach 4,500 adopter farmers. As mentioned, tidal swamps covering 273,919 hectares are the second most extensive rice cultivation in South Sumatra. However, the limited availability of human resources requires that farmers adopt various strategies, especially in planting technologies, such as direct seeding. This method causes multiple problems, including slowed rice growth and a rise in pest infestation. Therefore, improvements in planting technology were needed. CORIGAP activities were carried out with the assistance of South Sumatra AIAT by disseminating several superior technologies developed by IRRI and IAARD.

Utilization of new HYV, land leveling with laser leveling techniques (LLL), jajar legowo planting system, rat control with trap barrier system, utilization of AMATOR planting equipment, postharvest technology support in the form of adaptation of dryers powered by rice husk and diesel, and the utilization of a hermetic system for seed storage are examples of the technological innovations applied. The study was implemented in two Banyuasin sub-districts encompassing four villages: Sumber Mulyo, Telang Rejo, Mekarsari (Muara Telang sub-district), and Sidoharjo (Air Saleh sub-district). The rice cultivars include Inpari 22, 33, and 43, which are adapted to tidal marshes. The modification-dragged drum seeder by a hand tractor, AMATOR, is a planting tool developed by Usaha Pelaganan Jasa Alisintan (UPJA), PPL, and South Sumatra AIAT researchers in collaboration. AMATOR is derived from the IRRI drum seeder and a tractor. The results indicated that rice growth and planting time on the AMATOR or drum seeder are faster than on a mechanical transplanter, but their performance is subpar. The mechanical transplanter has the lowest percentage of unfilled grains (10.7%) and the maximum output (6.9 t ha^{-1}) compared to the broadcast seed system, which produces just 4.4 t ha^{-1} or even less at the farm level. Due to the spacing that gives efficacy and efficiency in plant maintenance, planting tools can even suppress the population of several types of weeds. Optimum plant spacing is essential to maximize the use of sunlight for photosynthesis. The plant acquired a well-balanced growing space due to the appropriate spacing.

Implementing the rodent trap system to control rats proved to be highly efficient in minimizing the possibility of paddy damage by reducing the rat population. Farmers who wish to cultivate rice on tidal land are required to perform rodent management. Initially implemented with a small plot area of traps and early-planted rice, the technique has evolved into a barrier that encompasses the whole expanse of the farmers' rice fields. Thus, rats are no longer the predominant problem in tidal land (see Chap. 4 for more details).

Although land-leveling technology with LLL causes changes in specific soil physical properties, such as water content, it was demonstrated to increase the total pore space of the soil by 38–50% and decrease the soil density. Bulk density and the entire pore space of soil are crucial in evaluating soil density because soils with high bulk density and low porosity make it hard for plant roots to penetrate. In contrast, soils with low density stimulate root development.

Currently, Banyuasin Regency produces 887,256 tons of rice, making it the regency with the most significant rice production in Sumatra and the fourth most in the country. This accomplishment is remarkable in comparison with other regions dominated by irrigated land.

2.3.3.4 CORIGAP Activities in North Sumatra

Farmers in North Sumatra are still using conventional techniques such as transplanting, habit-based fertilization, using certain varieties continuously, and controlling pests and diseases based on farmer habits. The CORIGAP project was launched in North Sumatra at the end of 2017 in conjunction with the Jarwo Super program.

The combination of these two programs disseminated new HYVs and SSNM in the form of rice consultancy services. A total of 108 farmers were involved in this activity consisting of six groups of farmers in three sub-districts which focused on Deli Serdang Regency as a place for Jarwo Super implementation. The reach of best management practice was 120 farmers, consisting of farmers implementing demonstration plots with assistance from extension workers from the Deli Serdang Regency Agriculture Service and AIAT. The training was conducted twice with materials on Jarwo Super technology and rice consulting services. Field meetings with 120 participants were conducted four times during nursery, planting, fertilizer application during active tillering, and after harvesting. In 2018, there were 880 farmers reached by BMP, consisting of 15 farmer groups in ten sub-districts covering three districts: Deli Serdang, Langkat, and Simalungun. There were 126 farmers who conducted demonstration plots consisting of seven groups of farmers in four sub-districts who implemented demonstration plots of Jarwo Super and LKP. The training was conducted four times consisting of land processing and bio-decomposer application, the potential use of new superior varieties in increasing production, LKP, and Jarwo Super technology. Field visits were implemented four times during planting, active tillering, panicle initiation, and harvesting, which were attended by farmers and agricultural extension workers.

In 2017–2018, the focus was on Deli Serdang Regency (Sunggal, Beringin, Lubuk Pakam, Pagar Merbau, Pantai labu, Percut Sei Tuan, dan Tanjung Morawa). In 2019–2020, the focus was on 2000 farmers spread across the Regencies of Batubara, Langkat, Serdang Bedagei, Deli Serdang, Simalungun, Karo, North Tapanuli, and Humbang Hasundutan. Due to the COVID-19 outbreak, a virtual meeting was held by AIAT North Sumatra with the topic of nutrient integration and rice pest control to boost rice productivity in various ecosystems. Participants attending the meeting consisted of researchers, extension workers, farmers, and private companies. The training materials provided to farmers focused on new superior varieties and rice consulting services. The total number of farmers who were reached by BMPs was 1260 in 2019 and 2345 in 2020. In total, 4605 farmers were reached, spread throughout North Sumatra both online and offline. The results achieved from the activity were the use of new HYVs such as Inpari 32, the use of fertilizer recommendations with rice consulting services at rice centers in North Sumatra, fertilization efficiency, and increased production.

2.3.4 Adoption of BMPs in Indonesia

The adoption of drum seeders was seen in 50% of farmers in Yogyakarta during the first phase of the project. However, in 2018, drum seeder was abandoned due to technical difficulties during the wet seasons. High intensity of rainfall made sowing seeds untidy, which affected higher time consumption and labor to replant the growing seedlings. High intensity of rain also meant that seeds pulled apart and were easily visible to birds. This resulted in more seeds being required for re-direct seeding.

Farmers' seed costs increased dramatically due to higher rainfalls and the losses that occurred. Another reason for not using a drum seeder was weed problems. In Yogyakarta, as reported by Devkota et al. (2019), the application of herbicides was not common for rice farmers. As a consequence, the problem of weeds in direct seeding resulted in higher time allocation and laborious activities regarding manual weeding. Farmers described that time limitations and labor scarcities were the foremost motives for ceasing their use of drum seeders. The decision to adopt or not adopt or then re-adopt, even adapt an innovation, is not only determined by farmers' ability to change but also needs support from the environment (Hellin and Ridaura 2016; Sumberg 2005).

The adoption of new varieties occurred, based on survey results (Connor et al. 2021b), with more than 90% of farmers continuing to plant the improved rice varieties because it was proven that they could increase the yield and close the yield gap (Parhusip et al. 2020). Through demonstration plots, field days and cross-site visits, farmers, as part of the CORIGAP activities, increased their knowledge of several alternative varieties that are suitable for their specific location and showed significant enforcement in the adoption process of new improved varieties. Farmers explained that improved varieties are one of the innovations that are easiest to be applied as long as the seed is available in the market. Moreover, the implementation of improved varieties was relatively cheaper and less time-consuming compared to the implementation of other innovations. This finding is in line with other studies where practices and innovations are adopted by farmers because they are easily applied (Connor et al. 2021c; Wehmeyer et al. 2020).

The adoption of AWD was reported by 50% of surveyed farmers (Connor et al. 2021b). Those who did not adopt the innovation mentioned technical difficulties regarding AWD implementation. Community support was required for the implementation of AWD because it has strong linkages with the Water-using Farmers' Association (named P3A, *Perkumpulan Petani Pemakai Air*) and the policy of water usage by the local government and the eligible institution. Field trials and demonstration plots accommodated the adoption process of multifaceted innovations like AWD regarding farmers' knowledge improvement, which influenced changes (Lampayan et al. 2015; Connor et al. 2021b).

Another innovation which was largely adopted by farmers was ecologically-based rodent management, particularly in the intensive lowland rice fields in Sleman. Farmers recognized the importance of synchronous planting, mass campaigns, habitat manipulation, and a Trap Barrier System (TBS) at their village community level within a 50–100 ha area. In line with a study conducted by Jacob et al. (2010), rodent management suppressed rat abundance at the late cropping phase, which led to a 75% reduction in rat feeding activity and increased yields by 6%.

2.3.5 Development of Mechanization Technologies in South Sumatra's Tidal Lowlands

South Sumatra uses three technologies: (1) a tub-type Rice Dryer powered with husk energy, (2) a modified drum seeder-type direct seeding machine pulled by a tractor, known as "AMATOR," and (3) laser-guided land leveling (LLL). The implementation and adoption status of each of these technologies ranged from rapid uptake for husk-powered rice dryers to moderate uptake for the "AMATOR" planting tool to the currently emerging uptake of LLL technology.

To solve the issue of paddy drying in tidal areas, the South Sumatra Forest Fire Management Project (SSFFMP)-European Union supported the design and construction of the ABC model husk furnace with a 3-ton capacity in 2003. Farmers who operated the rice milling unit (RMU) were introduced to the prototype of a drying machine with an "ABC" furnace in 2004 in Upang Village, Makarti Jaya District, Banyuasin Regency (BPTP Sumsel 2007). The semi-automatic husk furnace (d-HRF) type dryer was also introduced in 2013 with a more effective and labor-saving direct heating system, mainly when providing husk material and removing charcoal from burning (Raharjo et al. 2013).

Following the BBS dryer pilot project in Upang Village, 70 units of the BBS dryer box were independently developed in a relatively short period from the 2004 release of the BBS box dryer to the end of 2008. At the end of 2018, more than 500 units had been constructed by farmers/owners of RMU, some of which were supported by the governments of Banyuasin Regency and South Sumatra Province. The Santoso (private sector) workshop in Plaju, Palembang, has expanded the distribution of dryer machines to other provinces and islands, including South Nias and Nias Regencies of North Sumatra Province, Tanjung Jabung Timur Regency of Jambi Province, and Merauke Regency of Papua Province. The rapid spread/adoption of the dryer technology in tidal areas of South Sumatra is due to the following: (1) the technology for drying grain with the BBS box dryer is perceived as a solution to the problems in the field, as it utilizes the husks that have previously been wasted and the resulting husk charcoal can be used as an ameliorant; (2) simple device models can be made locally, and modifications can be made as needed, and (3) researchers facilitate socialization and technical assistance. The findings of a study conducted by Bhandari (2007) in the tidal area of Banyuasin Regency comparing the operation of box dryers with sun drying revealed that if a farmer had 1 t of grains that were processed into gabah kering giling (GKG) (dry unhusked rice) and then sold, it would be more profitable for the farmer to dry it. However, a box dryer is more profitable for the farmer if the grain is processed into rice. It is because when using a box dryer, the proportion of whole rice and head rice is more significant than when field drying and there is an increase in selling price due to the difference in rice quality (Fig. 2.3).

The direct spread (tabela) cropping method used among farmers in South Sumatra's tidal lowlands can reduce the amount of work needed for planting. However, the conventional "tabella" system of manually spreading ("sonor") rice has many weaknesses, such as: (1) seeds do not grow when they drop on the ground

Fig. 2.3 First pilot project flatbed dryer using husk energy at Upang Village, Banyuasin

of a water-logged rice field (wet sown), (2) high seed rates of more over 60 kg ha^{-1}, (3) irregular spacing, (4) the seeds that are spread are vulnerable to being consumed by bird pests, (5) requires resources for replanting and thinning plants, and (6) susceptible to pests and diseases.

In 2008, the “IRRI drum seeder” type direct seed planting tool (Fig. 2.4) was used in several tidal areas of Banyuasin Regency, South Sumatra, to overcome these limitations. This planting tool was initially created to distribute seeds evenly throughout the field’s surface. The operation is relatively straightforward; seeds are placed into tubes that can hold 2 kg of seeds. When the device is pulled, the seeds flow through the existing holes and form a row of plants. The BPTP Bali built a modified version of the IRRI Drum Seeder that consisted of wood and PVC tubes. The modified drum seeder releases seeds in an array with a gap of 20–25 cm between rows and in a “legowo” row.

The use of direct seed planting machinery (Atabela) can solve the limitations of the “sonor system,” including reduced seed rates to 35–40 kg^{-1} ha, regular plant spacing that does not collapse easily, enhanced plant growth, and reduced risk of pests and plant diseases (Raharjo et al. 2013; Maryana et al. 2022). This performance does not necessarily encourage farmers to use “Atabela” widely; additional labor costs

Fig. 2.4 Atabela “IRRI Drum Seeder” (on the left) and Atabela “Legowo” (on the right) (Raharjo et al. 2013)

Fig. 2.5 AMATOR operations using 2-wheel (left) and 4-wheel tractors (right)

(tool operators) and duration of work are the primary reasons, in addition to the expense of tool manufacturing. To improve the effectiveness of the "Atabela" planting tool, they were modified to be dragged by a tractor by incorporating "AMATOR" iron tubes of appropriate diameter. Agricultural Equipment and Machinery Service Business (UPJA) "Agro Assalam" developed the planting devices in collaboration with technicians and field extension officers, which were then manufactured by a local workshop. The redesigned planting tool "AMATOR" was first demonstrated during the 2015 rainy season and is currently widely used in tidal locations, primarily in the Air Saleh Delta and many areas in Banyuasin Regency and in several tidal regions of the provinces of South Sumatra and Jambi. Moreover, AMATOR use has extended to West Java, South Kalimantan, Riau Islands, and North Maluku. The performance measurement shows that AMATOR's theoretical working capacity is 0.7135 ha h^{-1} (1,402 h ha^{-1}), and its actual capacity is 0.5244 ha h^{-1} (1.6012 h ha^{-1}) (Suprihatin et al. 2022) (Fig. 2.5).

Flatness and topography in tidal swamp influence rice management and yield. Undulating tidal land contour inhibits the production and growth of plants. Farmers use a hand tractor and a four-wheel tractor with a scraper to level the field during plowing. Since 2016, laser-light-guided land-leveling technology (LLL) has been implemented. On May 3–5, 2022, training for service personnel, farmers, extension workers, and researchers, owners of agricultural tools and machinery workshops, and agricultural machinery operators kicked off the project. This exercise is part of a process of continuous learning in the Tanjung Lago District of Banyuasin Regency (Fig. 2.6).

2.3.6 The Adoption of Decision Support System "Layanan Konsultasi Padi" in North Sumatra

The technologies that stand out in North Sumatra are the rice consulting service called Layanan Konsultasi Padi (LKP) and the dissemination of HYVs such as Inpari

Fig. 2.6 Pumping times are longer with the unequal tide (CORIGAP Photo 2017)

28, 32, 42. The results of the 2017–2020 period are that LKP and HYVs were introduced through training, demonstration plots, and field meetings. The increase in the production of irrigated lowlands is about 9.9%, and upland rice fields about 52%. The average rice production in North Sumatra is 5.26 t ha^{-1}, which can increase by about 520 kg on average in the demonstration area. The research plots were able to reach 9.46 t ha^{-1} with the addition of 30 kg of nitrogen after panicle initiation. The use of LKP in North Sumatra has spread among farmers in determining fertilizer recommendations.

Furthermore, the variety Inpari 32 was able to replace Ciherang and Mekongga in almost 70% of rice centers in North Sumatra. This means that the Inpari 32 variety was adopted widely in low to medium-topography rice fields (Parhusip et al. 2020), while for highland rice Inpari 28 was adopted and replaced local varieties with an average production of only 4.23 kg ha^{-1} (Santoso et al. 2021). The success of this activity is due to the support of the Ministry of Agriculture, local governments, farmer groups, and the private sector. The sustainability of this activity is through the empowerment of village funds for food security in terms of the use of high-yielding varieties that have been introduced and the use of fertilizer recommendations through LKP. Suggestions for improvement for rice consulting services so that farmers can easily adopt them are to add local varieties to the list of varieties as an alternative if there are no suitable varieties for upland irrigated rice fields.

2.3.7 Policy Implication

Indonesia is targeting to become the world's food granary by 2045 (Sulaiman et al. 2017) and also wants to build independent, advanced and modern agriculture by adopting precision and digital agriculture. The extensibility of agricultural land is one of the determining factors for success in maintaining food self-sufficiency and making Indonesia a world food barn (Mulyani and Agus 2017). In addition, various innovations and technologies that are efficient, environmentally friendly, and easy to implement are urgently needed.

Agriculture 4.0 is an effort to utilize modern Information and Communication Technology to manage agricultural businesses efficiently so that it can support agricultural development as a way to improve the quality and quantity of agricultural production so that it can manage agriculture more precisely. The Ministry of Agriculture has formulated policies related to the rice production system in an effort to realize food security and independence in a sustainable manner, including (a) technological innovations designed and produced are directed to support the improvement of business efficiency and product competitiveness to support the development of agribusiness, (b) research and development activities are in line with efforts to improve the mastery and development of agricultural science and technology, including the use of information technology, as well as other techniques and methods to improve the effectiveness, efficiency, and quality of research results, (c) in order to improve the usefulness and impact of the resulting technological innovations they must be supported by the acceleration of the process and the expansion of the dissemination network as well as innovation feedback to the key actors.

In the nearly ten years of involvement in the CORIGAP project, we identified significant achievements in closing rice yield gaps through the utilization of agricultural innovations tailored to the needs of each participating province (Yogyakarta, South Sumatra, North Sumatra). One of the prominent innovations is the Rice Advisory Service through a website-based application called Layanan Konsultasi Padi (LKP). LKP technology is an accumulation of rice nutrient management science from IRRI and the innovations developed by the Indonesian Agency for Agricultural Research and Development, such as new high-yielding varieties, location-specific planting systems, and pest and disease control, which are formulated into a web-based application. LKP was launched at the end of 2015 and has been evaluated mainly in irrigated agroecosystems. The Ministry of Agriculture follows up on the results of the use of LKP that have been achieved from the CORIGAP project by allocating funds to expand the application of LKP in seven provinces in 2021 and targeting the implementation of LKP as one of the national agricultural programs starting in 2023. The expansion of LKP implementation covers not only irrigated agroecosystems but also rainfed and tidal swamp areas. The potential for expansion to other agroecosystems covers rainfed rice fields of 2 million ha, swamp land of around 35 million ha, and dry land of 7 million ha.

The results of LKP validation activities in seven provinces divided into three agroecosystems: irrigated rice fields, rainfed rice fields, and tidal swamp rice fields show a similar trend where the implementation of LKP recommendations results in higher rice productivity than controls without the implementation of LKP recommendations. Increased rice productivity occurred in each of the three agroecosystems, reaching 31% in irrigated paddy fields, 23% in rainfed paddy fields, and 62% in tidal swamp paddy fields. Based on these positive outcomes, it is highly recommended to encourage the wider use of LKP in areas with sub-optimal land conditions, leading to a great opportunity to leverage higher rice productivity. A significant increase in productivity coupled with the use of more efficient fertilizer inputs will have a great opportunity to increase farmers' profits.

At the end of 2019, the Ministry of Agriculture established the Agricultural Development Strategic Command (Kostratani) in every sub-district. In its technical implementation, Kostratani involves various technologies based on the Internet of Things, artificial intelligence, and information technology, as well as being connected to the Agriculture War Room. Kostratani is one of the dissemination channels of LKP, especially in supporting the development of advanced, independent, and modern Indonesian agriculture.

The increasing price of fertilizers and the reduction of subdivisions allocated by the government encourage farmers to consider the use of agricultural inputs, especially fertilizers, with the level of yield to be obtained. In this condition, the massive use of equipment/software such as LKP for agricultural extension workers and farmers will be more effective and efficient in the process of diffusion of technological innovations and increasing national rice production. The effectiveness of LKP and the opinions of farmer extension workers and their validation need to be evaluated to continue to improve the use of LKP in the future.

At the end of 2022, the Ministry of Agriculture through the Indonesian Agency for Agricultural Instruments Standardization, IAAIS (previously Indonesian Agency for Agricultural Research and Development, IAARD), held a Rice Crop Manager (RCM) Indonesia Project Inception Workshop with IRRI, the Ministry of Agriculture of the Republic of Korea, the Korean Rural Economic Institute, and the National Development Planning Agency. The workshop was held to consolidate further collaboration between the Indonesian government, IRRI, and South Korea to support LKP implementation in 2023–2025 where the expansion of LKP implementation will be carried out in eight provinces, namely West Java, Central Java, East Java, North Sumatra, South Sumatra, South Kalimantan, Central Kalimantan, and South Sulawesi.

2.4 Vietnam

2.4.1 Rice Production in Vietnam

Vietnam is one of the world's largest producers and exporters of rice. The country's favorable climate and topography provide a diverse rice production ecosystem. Moreover, its vast network of waterways, particularly the Mekong Delta, provides ample water resources for irrigation, making it an ideal location for rice production. Vietnam also has a large and growing domestic market for rice consumption, providing a stable source of demand for its rice farmers. Finally, its strategic location in Southeast Asia offers opportunities for export to neighboring countries and regions with high demand for rice, such as China and the Middle East. Vietnam's agricultural area covers approximately 40% (12.39 million hectares) of the country's total land area (FAO 2019). Rice accounted for around 11% of the agricultural GDP (World Bank

2022). Most rice is grown in the low-lying areas of the Mekong and Red River deltas (Yuen et al. 2021; Yen et al. 2019).

The Mekong River Delta, which comprises 40,000 km^2, has around 26,000 km^2 area for agriculture and aquaculture and is the primary rice-producing region in Vietnam, accounting for over 50% of the total rice production in the country and 90% of the rice exported (Nguyen 2007; Connor et al. 2021c; USDA Foreign Agricultural Service 2018; Ricepedia 2021). Farmers in the delta Mekong Delta Region can cultivate rice up to three times per year, making it particularly suitable for intensive rice cultivation due to its favorable natural conditions (FAO 2002; GRiSP 2013; Ricepedia 2021).

Vietnam's rice production increased by 1.48% from 2007 to 2021, reaching 43.85 million metric tons in 2021 (FAOSTAT 2023). During the same period, the total land cultivated for rice production in Vietnam increased slightly by 0.03%, while the yield increased by 1.48%, reaching 6 t ha^{-1} in 2021 (FAOSTAT 2023). Vietnam has consistently been one of the top five rice producers in the world from 2017 to 2021. It is the second-largest producer in Southeast Asia (FAOSTAT 2023). Consequently, Vietnam was the third-largest exporter of rice in the world in 2021 and 2022, with US$ 2.96 to US$ 3 billion worth of rice exports (USDA 2022). According to the Vietnam Food Association, the country had a 41% year-on-year increase in its rice shipments in the first two weeks of 2023 and earned US$ 115 million (Xinhua 2023).

Aside from the essential role of rice in the economy, it holds a significant cultural value in Vietnam. People have high regard for rice and perceive it as a symbol of prosperity and life. Vietnamese ceremonies, rituals, and festivals often involve rice-based dishes. Rice is a staple food and a sacred crop in Vietnam, closely linked to traditional beliefs and practices (Farnworth 2014). Rice is more than just a crop since it is an integral part of the country's culture, beliefs, and traditions (Farnworth 2014; Nguyen et al. 2004).

Various factors contribute to Vietnam's success in rice production, including the country's diverse ecosystem for rice cultivation, the use of different cropping systems and management practices, and advancements in agricultural technology (World Bank 2022). Additionally, the government of Vietnam has implemented policies and programs to support the rice sector and improve the livelihoods of rice farmers (World Bank 2022).

2.4.2 Transformation of the Rice Industry

In the early years of Vietnam's history, rice cultivation was primarily carried out by small-holder farmers using traditional methods. However, in the mid-twentieth century, the Vietnamese government began to prioritize agriculture and initiated several policies aimed at increasing rice production. One of the most significant government interventions was the establishment of Agricultural Production Cooperatives (APCs) in the 1950s. These cooperatives were designed to bring together small-scale farmers and provide them with access to resources such as land, equipment, and credit. The APCs were also responsible for redistributing inputs such as seeds and fertilizers and providing technical assistance to farmers (Glewwe et al. 2000).

Collective farming in Vietnam persisted until about the 1990s. It has benefitted both farmers and landless laborers by ensuring subsistence rice cultivation and encouraged the rural population to exchange all other kinds of labor such as repairing thatched roofs, helping each other with the supervision of children and other non-farm activities. The collective mode of farming in Vietnam survived major socioeconomic and political changes, such as the country's reunification in 1975, despite facing poverty, stagnant economic growth, and decreasing rice output. However, the collective farming system began to decline in the 1990s due to drastic changes in the rice farming industry, including land reforms and the implementation of new farming technologies and practices. The increase in production and productivity of paddy in Vietnam during the mid-1990s and early 2000s can be attributed to government reforms in land use rights, production decision-making, tariffs, and quotas, as well as the increasing use of fertilizers, pesticides, and high-yielding varieties (Purcell 2011). A momentous transformation took place as farmers' status transitioned from being tenants or landless to becoming smallholders who owned land (Tuan et al. 2014). This shift in land ownership, coupled with the adoption of innovative technologies, enabled farmers to fulfill their subsistence requirements and ensure food security, consequently expanding their cultivation exponentially. Vietnam's successful shift in rice farming practices has been reflected in its emergence as one of the top three rice-exporting countries in Asia by 2019.

2.4.3 Constraints and Opportunities in Rice Production

Vietnam's rapid agricultural development since the mid-1980s has significantly transformed the country, but it has also had considerable ecological, social, and economic impacts that could lead to long-term issues in the twenty-first century, particularly in the context of climate change (ADB 2013). As Vietnam is considered one of the countries to be hit more severely by climate change, it will experience serious implications for economic development, especially in the agricultural sector.

According to a comparative analysis by the World Bank Development Research Group, Vietnam would be the most seriously impacted country in East and Southeast Asia by sea level rise, with almost 40% of the population affected (Dasgupta et al. 2007). Most of the impact is expected in high population density areas, such as the Mekong River Delta (Nguyen 2007). Saltwater intrusion, the irregular intensity of rainfall, and frequent flood occurrences can affect the available period of cultivation, and shortening the crops' growth period, and reduce yield growth. Furthermore, high levels of salinity in irrigation water coupled with reduced surface water flow could lead to a significant reduction in the total rice cultivation area. Without effective adaptation strategies, the agricultural sector in this region could experience significant losses, which would, in turn, lead to a decline in Vietnam's overall GDP by 0.7–2.4% by 2050 (Smyle and Cooke 2010). Moreover, intensive cropping patterns such as cultivating rice two to three times per year are likely to decrease in the future, and the performance of high-yielding rice varieties may decline as well (Khang et al. 2010; Rutten et al. 2014; Deb et al. 2016).

Intensive cropping coupled with excessive use of chemical inputs such as fertilizers and pesticides is also a major concern in Vietnam. Several studies have shown excessive use of pesticides, fertilizers, and seeds in the Mekong River Delta (Cassou et al. 2017; Soong 2006; Nguyen et al. 2022). Such practices have a great impact on soil fertility and quality, microbial diversity, rice yield, water quality, the development of pesticide-resistant pests and weeds, and human health (Berg 2001; Nguyen 2016).

Labor shortage is among the constraints in the country's rice production, which arises from the migration of young people from rural to urban areas in search of better employment opportunities. As a result, the cost of labor has increased, potentially causing a decrease in rice production unless farmers can adapt to these rising costs.

Vietnam's cost-competitiveness in the rice export sector is unsustainable and may face significant challenges in the future (Eckardt et al. 2016; Lam 2019). While the country's economic growth model has been centered on boosting agricultural exports for rural development and job creation, this approach has limitations and is no longer sustainable due to rising input costs (Eckardt et al. 2016; Lam 2019). As a result, agriculture's role in driving rural development and economic growth has diminished.

Overall, it is clear that Vietnam's agricultural sector faces significant challenges due to climate change, intensive rice production practices, and labor shortage. The government is taking proactive measures to mitigate the risks and impacts associated with the aforementioned constraints. Research and investment in breeding varieties that can compete with the existing rice varieties in the world market were given priority by the government.

2.4.4 CORIGAP Activities in Vietnam

Several studies have shown excessive use of pesticides, fertilizers, and seeds in the Mekong River Delta (Cassou et al. 2017; Soong 2006; Nguyen et al. 2022). It led to the promotion of "Three eductions, Three Gains (3R3G), and subsequently to the promotion of 1 Must Do, 5 Reductions" (1M5R) developed during the 4th phase of the IRRC-IRRI and which was rolled out by the Agricultural Competitiveness Project (ACP) and implemented by the Ministry of Agriculture and Rural Development (MARD) with financing from the World Bank to the Mekong Delta in 2013. 1M5R was certified by MARD as nationally approved best management approaches in the same year. CORIGAP worked with national partners on the "Small Farmers, Large Field" (SFLF) initiative to minimize yield gaps, improve rice production efficiency, and align smallholder farmers more closely with traders and millers. Several fields of individual farmers were consolidated to make larger fields. The boundaries of ownership are maintained with bunds. Each farmer manages their area and strictly follows the 1M5R guidelines to be part of the SFLF (see also Chap. 3). They are also required to buy or use seeds as prescribed by the program, and their paddy is bought right after harvest by participating food companies in the SFLF scheme. Farmers receive 4–5% above market value from the participating companies, while the provincial Department of Agriculture and Rural Development (DARD) provided extension services and monitored which varieties are planted by the farmers. A total of 208 farmers participated in the SFLF cooperatives organized by the Sub-Departments of Plant Protection Services and Crop Production under provincial DARD. Mushroom production at the village level was a new initiative in Can Tho and Long An in 2013. The said initiative was aligned with the national directive not to burn rice straw and to provide jobs to displaced women through the rapid adoption of mechanical thresher-harvesters.

Field trials were set up in the second half of 2014. The adaptive research and field calculator were combined to compare the sustainability performance of good agricultural practice (GAP), SFLF, and regular farm practice. The development of business models for better straw management and strengthening of extension on market integration of mushroom production were accomplished in 2014.

Farmer participatory field trials were established in Can Tho to identify and demonstrate the best practices for different crop establishment practices, including drum seeding, manual broadcasting, blower seeding (using a seed broadcasting machine), and mechanical transplanter. Mechanical fertilizer spreaders and combine harvesters, as well as paddy dryers, were also demonstrated. All best agricultural practices, including VnSAT standards for 1M5R, such as AWD and activities to reduce postharvest losses, were also demonstrated through field trials. Rice straw management using a baler and mushroom production were promoted.

2.4.5 Adoption of CORIGAP Technologies and Documentation of Changes

In the mid-2000s, the Three Reductions, Three Gains (3R3G) (see Chap. 4), and later 1M5R integrated practice and technology packages were introduced in various provinces of the Mekong River Delta, reaching over 130,000 farmers to date. The promotion of 1M5R recommendations has been the focus of the CORIGAP project in Vietnam, with a particular emphasis on the provinces of An Giang and Can Tho. The spread of 1M5R to other provinces in the MRD has been facilitated via a World Bank-funded project, “Vietnam – Sustainable Agricultural Transformation (VnSAT).”

Several studies have focused on the adoption of 1M5R. In the study by Wehmeyer (2021) on the adoption and diffusion of agricultural best management practices through the CORIGAP project in Vietnam, the most commonly adopted technologies in rice production were AWD, combine harvesters, drum seeders, and improved rice varieties. With these technologies, most farmers were able to reduce their input usage and achieve higher rice yields. However, during the CORIGAP project, farmers using 1M5R recommendations used significantly fewer inputs than control farmers, resulting in lower productivity levels. Despite this, the project showed that farmers were able to maintain profitability by reducing input costs, achieving yield consistency, and ensuring livelihood stability by producing rice more sustainably.

A study by Connor et al. (2021c) examined the factors affecting the adoption of sustainable rice farming practices in the 1M5R program and identified adoption constraints among 465 farmers in An Giang and Can Tho Province. While most farmers followed pesticide and postharvest loss reduction requirements and the use of certified seeds, they faced difficulties reducing fertilizer use, water use, and seed rate due to implementation challenges and weather conditions. Ease of implementation, education, satisfaction, and non-rice income were the main drivers for adopting the whole package, while the ease of implementation and non-rice income drove the adoption of individual requirements with lower rates. Adoption monitoring and continued extension services are needed to overcome physical barriers and ensure successful implementation.

Similarly, Tuan et al. (2022) investigated 1M5R adoption barriers with 155 farmers qualitatively conducting 17 focus group discussions. The study has shown that external factors such as the geographical location of farms and access to water seem to be the main barriers. Furthermore, knowledge provision, demonstration fields, and access to extension services were most important in increasing the adoption of sustainable rice farming practices.

2.4.6 Conclusions

The CORIGAP project in Vietnam has significantly promoted sustainable rice farming practices through the 1M5R integrated practice and technology package. The project has successfully reached over 130,000 farmers in various provinces of the Mekong River Delta, with a particular emphasis on the provinces of An Giang and Can Tho. Studies have shown that farmers who adopted 1M5R recommendations could reduce their input use by using technologies such as AWD, combine harvesters, drum seeders, and improved rice varieties, as shown in Wehmeyer et al.'s (2022) study. These practices led to higher rice yields, improved profitability, and ensured livelihood stability.

However, the studies have also highlighted the challenges farmers face in reducing fertilizer use, water use, and the reduction of seed rate, as well as external factors such as geographic location and access to water, which can hinder the adoption of sustainable rice farming practices (Connor et al. 2021c). Despite these challenges, the project has identified several drivers for adopting the whole package, including ease of implementation, education, satisfaction, and non-rice income. Tuan et al. (2022) found that knowledge provision, demonstration fields, and access to extension services were most important in increasing the adoption of sustainable rice farming practices.

The project has also emphasized the need for continued adoption monitoring and extension services to ensure the successful implementation of sustainable rice farming practices since they help to overcome physical barriers and ensure successful implementation.

The CORIGAP project has demonstrated the importance of promoting sustainable rice farming practices and providing farmers with the necessary resources and knowledge to adopt these practices effectively. The project's success in reaching many farmers and improving their productivity and profitability underscores the importance of continued efforts to promote sustainable agricultural practices in Vietnam and beyond.

2.5 China

2.5.1 Rice Production in China

With about 9% of the world's arable land, China has been able to feed nearly 20% of the world's population or 1.4 billion people (Xu et al. 2021). Rice plays a very important role in maintaining China's food security. China is the largest rice producer and consumer in the world, with average annual rice production and consumption accounting for about 30% of the world. The annual rice planting area is 30 million hectares. More than 60% of China's population depends on rice as their staple food. Guangdong, with a population of 127 million, is one of the major rice-producing provinces in China (Xu et al. 2021). Rice is the most important food crop in Guangdong, with 1.8 million hectares of planting area, accounting for 80% of food crop area and production. However, due to limited farming land, the food self-sufficiency of Guangdong is less than 30%. Guangdong Province was the focus of CORIGAP activities in China.

2.5.2 Challenges Facing Rice Production in China

Guangdong is a relatively highly developed province in China. In the 1990s, rice production in Guangdong as well as in China, was facing a number of challenges. Fertilizer nitrogen (fertilizer N) input was quite high, while nitrogen-use efficiency (NUE) was very low. On average, the total fertilizer N input was 194 kg N ha^{-1} in Guangdong, but the recovery efficiency of N was only 24%. A huge amount of N fertilizer was lost to the environment resulting in serious non-point source pollution. Moreover, the overuse of N fertilizer, in combination with the warm and humid climate, made the rice crop more susceptible to diseases and insect pests, and farmers had to spray more pesticides to avoid yield loss. Furthermore, lodging prevails and causes heavy yield loss, especially in the coastal regions with frequent typhoons. The grain yield of rice was only 5.8 t ha^{-1} and 16% lower than the national average. The profit of rice production was quite poor as a result of low grain yield and high input costs. More recently, water shortage, labor shortage, environmental pollution, and greenhouse gas emissions became new challenges for rice production with the development of social economy and urbanization.

2.5.3 CORIGAP Activities in Guangdong China

A series of studies and extension activities were conducted to solve the problems facing rice production. From 2001 to 2012, the Guangdong Rice Research Institute (GDRRI) developed the “3 controls” technology (3CT) in cooperation with IRRI. Compared with farmers’ practice, 3CT can reduce N fertilizer input by about 20% while, at the same time, increasing grain yield by about 10%. The recovery efficiency of fertilizer N is increased by 10%. Occurrence of sheath blight, plant hopper, leaf roller, and other diseases and pests is significantly reduced, and hence, pesticide application can be reduced by one to three times per season. Lodging resistance is substantially improved (Zhong et al. 2010). The 3CT technology has been recommended to rice farmers by the Ministry of Agriculture and Rural Affairs of China and the Department of Agriculture and Rural Affairs of Guangdong, Jiangxi, and Hainan provinces. The 3CT technology has been widely used in major projects such as the high-yield creation, demonstration of super rice, agricultural non-point source pollution control, and reduction of fertilizer and pesticide use. Since 2013, with the support of the CORIGAP project and other projects in China, GDRRI carried out two aspects of work. The first was the research and development of low-carbon and high-yield cultivation technology (LC), and the second was the demonstration and large-scale dissemination of the 3CT and the LC technologies.

For the development of LC technology, GDDRI first introduced safe alternate wetting and drying (safe AWD) technology from IRRI. Secondly, the safe AWD was integrated with the 3CT technology to establish the LC technology. Compared with farmer’s practice (FP), the 3CT technology can save nitrogen fertilizer by 20% and increase grain yield by about 10%. Compared with 3CT, the LC technology can save water by 20%, reduce methane emissions by 20–30%, and reduce N and P loss to the environment by 50%. In 2017, the LC technology was recommended to rice farmers as one of the key technologies for low-carbon development by the National Development and Reform Commission of China.

The 3CT and the LC technologies were then promoted to large-scale use in Guangdong and other parts of South China. Field trials, demonstrations, and training courses were carried out. The performances of the new technologies were reported by newspapers, TV programs, websites, WeChat, and other media. The implementation of the CORIGAP project was combined with various national and provincial projects or actions, including the agricultural non-point source pollution control project jointly supported by the World Bank and Guangdong provincial government.

2.5.4 Case Study of Development and Implementation of 3CT and Low-Carbon Technologies

2.5.4.1 Case 1: On-Station Comparison of Grain Yield, Greenhouse Gas Emission, and Nitrogen Losses Under Different Crop Management in Guangzhou

In the early and late seasons of 2016–2017, field comparison trials were conducted at the Dafeng Experimental Station of the Guangdong Academy of Agricultural Sciences in Guangzhou. The experimental field is located in the Tianhe District of Guangzhou and is characterized by the humid subtropical monsoon climate. The main physical and chemical properties of the soil are pH 6.0, total N 1.62 g kg^{-1}, available N 82.6 mg kg^{-1}, available P 40.4 mg kg^{-1}, available K (Potassium) 58.7 mg kg^{-1}, and organic matter 41.4 g kg^{-1}. A hybrid rice variety, Tianyou 3618, was transplanted at a plant spacing of 20 cm × 20 cm with two seedlings per hill. There were three crop management treatments arranged in a randomized complete block design with three replications. The three treatments were as follows:

1. **FP**. Fertilizer N in the form of urea was applied at a rate of N 180 kg ha^{-1} for the early season and N 200 kg ha^{-1} for the late season. In total, 40% of fertilizer N was applied as basal one day before transplanting, 20% was top-dressed at 3–5 days after transplanting (DAT), 30% at 8–10 DAT, and 10% at 18–20 DAT. Fertilizer P was applied in the form of calcium superphosphate as basal at 45 kg P_2O_5 ha^{-1}. Fertilizer K was applied in the form of potassium chloride at 135 kg K_2O ha^{-1}, with 50% applied as basal and 50% at panicle initiation. After transplanting, a 2–5 cm water layer was kept for tillering until the tiller number (including main stem and tillers) reached 80% of the targeted panicle number, followed by midseason drainage for about 20 days to suppress excessive tillers, and then, a 2–5 cm water layer was maintained during the whole heading stage. A shallow water layer was maintained during grain filling until seven days before harvest when final drainage was implemented.
2. **3CT**. The technical procedure of "three controls" technology was employed (Zhong et al. 2010). Fertilizer N was applied in the form of urea at 150 kg ha^{-1} for the early season and 180 kg N ha^{-1} for the late season, with 40% as basal, 20% at mid-tillering (15 DAT), 30% at panicle initiation (35 DAT for early season and 30 DAT for late season), and 10% at heading. The application of P and K fertilizers and water management was the same as FP.
3. **LC**. The application of N, P, and K fertilizers was consistent with 3CT. AWD was used for water management. Field water depth was kept at 2–5 cm during the first 10 DAT to allow the seedlings to recover and suppress weeds. Perforated field water tubes were installed to monitor the water level below the soil surface. The timing of irrigation was based on the water depth in the field water tube installed in the field to a depth of 15 cm. When the water disappeared in the tubes, the plot was irrigated to a depth of 3–5 cm above the soil surface. At the beginning of the heading date (when 1% of the panicles had emerged from the leaf sheath of the

flag leaf), the field was re-flooded for seven days, and hereafter, the AWD cycles were repeated until terminal drainage, which was imposed seven days before harvest.

The 3CT and LC technologies had higher grain yield, less irrigation water input, lower greenhouse gas emission and N loss, and greater water productivity than FP for both early and later seasons (Table 2.1). Compared with FP, 3CT increased grain yield, reduced greenhouse gas emissions and N loss to the environment, and increased water productivity. Irrigation water input was comparable for 3CT and FP. Compared with 3CT, the LC technology significantly reduced water input, greenhouse gas emission, and N loss and increased water productivity. The grain yield of 3CT and LC technologies was comparable. On average, the grain yield of 3CT was 13.1 and 14.7% greater than FP for the early and late seasons, respectively. The LC technology had a slightly higher grain yield than 3CT. Irrigation water input was comparable for FP and 3CT. However, the LC saved 82.5 and 36.0% of irrigation water for early and late seasons, respectively, compared to FP. Greenhouse gas emission (including CH_4 and N_2O) under 3CT was 6.9 and 5.0% lower than that under FP in the early and late seasons, respectively. The LC technology further reduced greenhouse gas emissions by 24.6 and 33.3% for early and late seasons, respectively, in comparison with 3CT. Compared to FP, the 3CT reduced N loss by 32.2% for the early season and by 31.6% for the late season. The LC further reduced N loss by 16.9% in the early season and 12.4% in the late season based on 3CT (Liang et al. 2017, 2019).

Table 2.1 Grain yield, irrigation water input, greenhouse gas emission, N loss, and water productivity under different crop management in the field experiment at Guangzhou during the 2016–2017 early and late seasons

Year	Season	Treatment	Grain yield	Irrigation water	Total GWP	N loss	Water productivity
			(kg ha^{-1})	(m^3 ha^{-1})	(kg CO_2 ha^{-1})	(kg N ha^{-1})	(kg m^{-3})
2016	Early season	FP	6491	1281	4181	89.4	0.63
		3CT	7388	1373	3929	59.0	0.72
		LC	7476	146	3263	51.9	0.82
	Late season	FP	7400	2757	5853	80.9	1.11
		3CT	8363	2828	5211	55.7	1.25
		LC	8682	1964	3473	47.0	1.48
2017	Early season	FP	6768	1053	5984	73.8	0.71
		3CT	7602	956	5532	51.8	0.81
		LC	7658	263	3872	40.1	0.88
	Late season	FP	5808	2189	6047	74.6	0.81
		3CT	6780	2327	6098	50.7	0.93
		LC	6875	1203	4068	46.2	1.11

Note FP, 3CT, and LC denote farmer's practice, 3 controls, and low-carbon technology, respectively

In South China, the climate is hot and humid with abundant rainfall, and the nutrient N and P runoff and N volatilization loss of paddy fields are serious. The large amount and improper timing of water and fertilizer input in FP have caused non-point source pollution. Compared with FP, the 3CT and LC technologies can reduce N fertilizer input and hence reduce N loss from ammonia volatilization, runoff, and leaching. The LC technology reduced irrigation water input and improved the water storage capacity of the rice field, and therefore, the runoff loss of N was further reduced compared to 3CT.

2.5.4.2 Case 2: On-Farm Demonstration of 3CT and Low-Carbon Technologies for Transplanted Rice at Gaoyao County, Guangdong Province

From 2016 to 2019, demonstrations of 3CT and LC technologies were carried out in Gaoyao County of Guangdong Province. The demonstration plot was located in Baitudong Village, Lubu Township, with an area of 167 ha. The demonstration site belongs to the subtropical monsoon humid climate zone, with an annual mean temperature of 22 °C, an annual accumulated effective temperature of 7,905 °C, and annual rainfall of 1,700 mm. The paddy soil contained 26.8 g kg^{-1} of organic matter, 1.98 g kg^{-1} total N, 116.0 mg kg $^{-1}$ available N, 25.3 mg kg^{-1} available P, and 51.6 mg kg^{-1} of available K.

In the demonstration area, comparison trials with three treatments and three replications were set up. The three treatments were:

1. **FP**. Total fertilizer input was 202 kg N ha^{-1} (in the form of urea), 45 kg P_2O_5 ha^{-1} (in the form of calcium superphosphate), and 113 kg K_2O ha^{-1} (in the form of potassium chloride). Nitrogen fertilizer was applied with 40% as basal, 20% at the rooting stage, 30% at early tillering, and 10% at the late tillering stage. All phosphorus was applied as basal. Potassium was applied at the proportion of 50% as basal and 50% at the late tillering stage. Conventional water management was adopted, with a 2–5 cm water layer maintained in the field during the whole growth season except for the midseason drainage to suppress unproductive tillers.
2. **3CT**. Total fertilizer input was 135 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, and 113 kg K_2O ha^{-1}. In the early seasons, nitrogen fertilizer was applied with 50% as basal, 20% at mid-tillering (MT), and 30% at panicle initiation (PI). In the late seasons, fertilizer N was applied with 40% as basal, 20% at MT, 30% at PI, and 10% at heading. All phosphorus and 50% of potassium were applied as basal. Another 50% of potassium was applied at PI. Water management was the same as FP.
3. **LC**. Fertilizer management was the same as 3CT. The alternate wetting and drying technology (AWD) was adopted for water management. Field water depth was kept at 2–5 cm during the first 10 DAT. Irrigation was done whenever the water disappeared in the water tubes installed 15 cm below the soil surface, and a

3–5 cm water layer was resumed. Terminal drainage was imposed seven days before harvest.

As shown in Fig. 2.7, both 3CT and LC technologies improved grain yield and profit compared to FP. In the early season, the number of irrigations was lowest in LC. Compared to the FP, grain yield of 3CT and LC was significantly increased by 11.5 and 11.4%, while production costs for 3CT and LC were significantly decreased by 11.1% and 11.7%, respectively ($p < 0.05$). The number of irrigations was reduced by 0.4 and 0.8 (9.3 and 18.6%) for 3CT and LC. Profit was significantly increased by 429 US\$ ha^{-1} (35.8%) and 441 US\$ ha^{-1} (36.8%), respectively ($p < 0.05$). In the late season, the number of irrigations in LC was significantly decreased by 41.6% and 46.6% ($p < 0.05$), respectively, in comparison with FP and 3CT. The advantages in the late season were similar to that in the early season regarding grain yield, cost saving, and profit. The water saving in the late season was much greater than that in the early season (Zhong et al. 2022). As the water storage capacity of the field is improved in LC, the number of runoff during rainfall is significantly reduced, which lays a foundation for reducing non-point source pollution. In addition, the occurrence of sheath blight, leaf roller, plant hopper, and other diseases and pests in 3CT and LC was also significantly lower than in FP. The main reason is the reduced unproductive tillers which help to improve the microenvironment of the canopy. Water saving also reduced the humidity between rice plants, which favored inhibiting the propagation and transmission of pathogenic bacteria.

The new technologies 3CT and LC have been warmly welcomed by rice farmers. The main incentive for farmers to adopt the new technologies is the higher and more stable grain yield, lower costs of fertilizer and pesticides, and, most importantly, improved profit. Furthermore, farmers can save labor and cost for irrigation, which is very important in the western part of Guangdong, where water shortage prevails, especially for late season rice. The new technologies have also been welcomed by officials of different levels who pay more attention to environmental protection and public welfare because the new technologies can effectively reduce greenhouse gas emissions and non-point source pollution and improve food safety, biodiversity, and sustainability of rice production. As more and more farmers adopt and keep adopting new technologies, the above-mentioned benefits will become increasingly noticeable.

2.5.4.3 Case 3: On-Farm Demonstration of 3CT and Low-Carbon Technology for Direct-Seeded Rice at Lianjiang County, Guangdong Province

Lianjiang County is a traditional direct-seeded rice production area located in the coastal area of western Guangdong. Grain yield is quite low (about 20% lower than the national average) and unstable in that area due to frequent typhoons and improper crop management, for example, high seeding rates and the overuse of N-fertilizers. On-farm demonstrations of 3CT and LC technologies were conducted during 2018–2020 at Yunxia Village, Yingzai Township, Lianjiang County. Soil properties at the

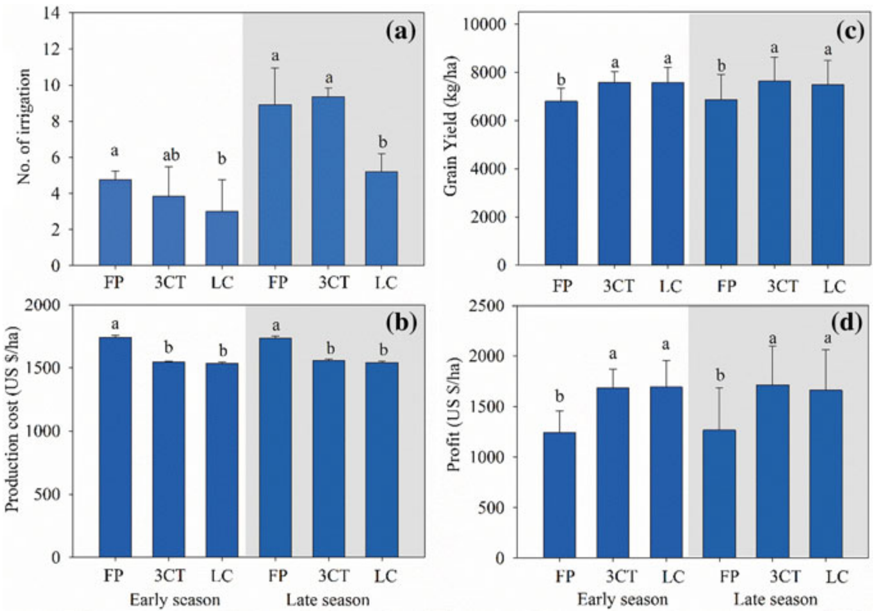

Fig. 2.7 Number of irrigations (**a**), production cost (**b**), grain yield (**c**), and profit (**d**) of early and late season rice under farmer's practice (FP), three controls technology (3CT), and low-carbon and high-yield technology (LC) in the on-farm demonstration conducted at Gaoyao County of Guangdong Province during 2016–2019. Data in the figure are means of the four years of 2016–2019. The different lowercase letters indicate significant differences for treatment at $p < 0.05$ by one-way ANOVA (LSD test)

demonstration site are as follows: pH 5.28, organic matter 14.65 g kg^{-1}, total N 0.69 g kg^{-1}, total P 0.41 g kg^{-1}, total K 10.33 g kg^{-1}, available N 72.49 mg kg^{-1}, available P 35.30 mg kg^{-1}, and available K 89.36 mg kg^{-1}. A high-quality inbred rice variety Baixiang 139 was used. There were three treatments:

1. **FP**. The total amount of fertilizer applied was 240 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, and 240 kg K_2O ha^{-1}. Before sowing, 25% of N and 50% of P were applied as basal. At 15 days after sowing (DAS), 45% of N, 25% of P, and 25% of K were applied. At 25 DAS, 30% of N, 25% of P, and 75% of K were applied.
2. **3CT**. Total fertilizer input was 165 kg N ha^{-1}, 50 kg P_2O_5 ha^{-1}, and 135 kg K_2O ha^{-1}. A compound fertilizer with 24% of N, 7% of P_2O_5, and 19% of K_2O was applied with 50% as basal, 20% at mid-tillering, and 30% at PI.
3. **LC**. Total fertilizer input was 150 kg N ha^{-1}, 45 kg P_2O_5 ha^{-1}, and 120 kg K_2O ha^{-1}. The compound fertilizer with 24% of N, 7% of P_2O_5, and 19% of K_2O was applied with 40% as basal and 60% at PI, respectively.

The plot size for each treatment was about 1300 m^2 with three replications. The seeding rate for each treatment was 75 kg ha^{-1}. For FP and 3CT, seeds were allowed to emerge in moist soil, and a 2–5 cm water layer was added and maintained when the seedlings grew to the 3-leaf stage. When the number of tillers (including main stems) reached about 300 m^{-2}, the field was drained until the top second leaf was exposed, and then, a 2–5 cm water layer was restored and maintained until heading. The field was kept moist during grain filling until seven days before harvest when the final drainage was done. For LC, AWD irrigation technology was adopted.

The demonstration showed that the 3CT and LC technologies significantly increased rice grain yield and net income and reduced fertilizer costs and the number of irrigations. Compared with FP, 3CT saved 31.3 and 43.8% of N and K fertilizers while increasing 11.0% of P fertilizer. The LC technology reduced N, P, and K fertilizers by 9.1%, 10.0%, and 11.1%, respectively, in comparison with 3CT. The 3CT and LC technologies had 1.7 and 4.0 fewer irrigations than FP, respectively. Production costs were 10.1 and 17.1% lower for 3CT and LC than FP, respectively. Grain yield was 22.9% greater for 3CT and LC than that for FP. With higher grain yield and lower production cost, the 3CT and LC technologies increased net income dramatically in comparison with FP. The net income of 3CT was 747 US\$ ha^{-1} or 168.64% greater than FP. The LC technology further increased net income by 135 US\$ ha^{-1} or 11.3% based on 3CT. In addition, the reduction of irrigation water input in the LC technology should have benefited the environment and farmers' livelihood due to its reduced methane emission and N loss to the environment (Zhong et al. 2022).

The demonstration results showed that 3CT and LC technologies performed well not only in transplanted rice systems but also in direct-seeded rice systems. Labor shortage and low profit are major challenges facing rice production in Guangdong as well as in China (Table 2.2). As labor costs increase, more and more rice farmers shift from transplanting to direct seeding. However, lodging is a major problem for direct-seeded rice. The 3CT and LC technologies are advantageous in lodging resistance and have been proven to be very helpful for farmers to achieve high and stable yields and hence profit in direct-seeded rice production. Therefore, the increase in direct-seeded rice will further stimulate the adoption of 3CT and LC technologies in the future.

2.5.5 Farmers' Adoption and Perceptions of 3CT

In 2019, we conducted a study on farmers' adoption and perception of 3CT in Guangdong Province. We implemented a cross-sectional survey questionnaire with 142 farmers (see Chap. 7 for more information) from six villages that were randomly selected by the local partners (Wehmeyer et al. 2020). The study was conceptualized focusing on three different impact factors: economic, social, and environmental. The findings show that all interviewed farmers adopted the 3CT. However, it needs to be noted that all farmers were part of a World Bank project that also promoted the 3CT. Farmers perceived benefits and changes in all three impact areas of sustainable development. Farmers reported having higher yields and reduced input costs. They felt that their health had improved and perceived to have gained better social and

Table 2.2 Grain yield, production cost, net income, and number of irrigations of direct-seeded rice under different crop managements at Lianjiang County, Guangdong Province, during 2018–2020

Year and season	Treatment	Grain yield (kg ha^{-1})	Production cost (US\$ ha^{-1})	Net income (US\$ ha^{-1})	No. of irrigations
2018 Late season	FP	5350	1938.9	504.6	7
	3CT	6810	1751.1	1361.7	5
	LC	6820	1616.6	1502.0	3
2019 Early season	FP	4920	1938.9	98.6	8
	3CT	5870	1723.7	708.4	6
	LC	5880	1585.7	848.7	3
2020 Late season	FP	5490	1938.9	725.7	5
	3CT	6690	1751.1	1499.8	4
	LC	6670	1616.6	1624.7	2
Mean	FP	5253	1938.9	443.0	6.7
	3CT	6457	1742.0	1190.0	5.0
	LC	6457	1606.3	1325.1	2.7

human capital. It became apparent that the longer farmers had been using 3CT, the more benefits they perceived, indicating that monitoring and evaluation of project outcomes need to be conducted in appropriate time frames. The Chinese farmers did not yet perceive changes in biodiversity since the timeframe was probably not long enough to see real effects on faunal population growth. However, the study showed that 3CT is highly appreciated by farmers due to its effectiveness, ease of use, and compatibility with their farming needs. The study highlighted that 3CT not only works in closely monitored field trials but also performs well in farmer fields (Wehmeyer et al. 2020).

2.6 Sri Lanka

2.6.1 Rice Production in Sri Lanka

Sri Lanka is a small island (65,610 km^2) in South Asia surrounded by the Indian Ocean. The geography of the country includes coastal plains and hills and mountains in the interior. Sri Lanka has a population of around 22 million and is a multinational country with diverse cultures, languages, and ethnicities. It has a documented history of over 3000 years, and rice cultivation has been evident since then. Being the staple food of Sri Lankans, rice plays a vital role in the country's agricultural sector. The paddy production and productivity have increased during the past 50 years up to the level of self-sufficiency since 2010 due to the introduction of high-yielding, improved varieties, advanced technologies, increased fertilizer usage, and land expansion. The average annual per capita consumption of rice is about 108 kg, while the demand for rice is increasing gradually due to an increase in population, shifting of food habits from wheat flour to rice, and increasing demand for other rice-based products.

2.6.2 Challenges Faced in Rice Production

A wide yield gap exists between the potential yield of varieties and farmers' actual yield in Sri Lanka. About 24% of the yield gap (1.3 t ha^{-1}) is prominent in the major rice-growing districts such as Polonnaruwa district, while the yield gap reported in the dry zone was around 50% (Devkota et al. 2019). Poor productivity is recorded in the rainfed areas and in some of the minor irrigation systems due to poor crop management practices such as improper pest, disease, and especially poor weed and nutrient management. Furthermore, frequently occurring unfavorable weather conditions, such as severe droughts that Sri Lanka experienced in years 2014 and 2017, are another cause of the wide yield gap.

Current rice yields across the world's main rice-growing areas are approaching the highest crop yield that a farmer can attain using conventional technologies. Sri Lanka is no exception, and yield stagnation can be observed in several regions. In Sri Lanka, the rice productivity is about 4.3 t ha^{-1}, which remained at a plateau during the last ten years (except for 4.8 t ha^{-1} recorded in the year 2019). Despite the limited genetic and agronomic improvement possible for rice, increasing the production and maintaining the level of self-sufficiency could be a big challenge with limited or diminishing land and water availability and with unfavorable weather conditions.

Deficiencies of soil nutrients due to the long-term cultivation of rice without soil rehabilitation remedies are evident in many parts of the country. In addition, the government policy banning the use of chemical fertilizers in 2021 drastically reduced rice productivity by about 40% and severely threatened the country's self-sufficiency. Though the policy was revised in 2022, the effect is continued even at present due to the limited availability of chemical fertilizers to rice farmers. Inappropriate land preparation techniques, such as primary land preparation using the rotary plow, poor attention to water management, continued use of chemical fertilizers, lack of organic matter incorporation, and changes in weather patterns, enhance the depletion of soil nutrients further.

Weeds are the most disastrous biotic stress in rice cultivation in Sri Lanka, causing an average of 30–40% of the yield loss if not controlled. Since 95% of the rice cultivated in Sri Lanka is direct-seeded, weed infestation is a menace and difficult to control without having intensive integrated approaches. Weed infestation raises production costs and diminishes crop quality. The diverse weed flora in rice systems contributes to increased yield gaps and hence reduces the national rice production considerably. Among the weed species, weedy rice, *Ischaemum rugosum*, *Echinochloa crus-galli,* and *Cyperus species* contribute to a significant yield loss. Weed density of 50 weeds m^{-2} accounts for the 38% yield loss in rice (Herath et al.

2018). Further, the presence of *Ischaemum rugosum* biomass significantly contributes to yield losses ($r = 0.84$***) which is higher compared to other weed species.

Weedy rice types are also spreading at an alarming rate in most rice-growing agroecological zones of the country (Rathnasekara 2015). Weedy rice contributes to significant yield loss depending on its density in the field. Some farmers with weedy rice-infested areas experienced that 300–350 weedy rice m^{-2} contribute to 100% yield loss. A high density of weedy rice causes more competitiveness to rice; further tallness of weedy rice causes lodging incidences and combined, these factors can be responsible for total yield loss in rice. Weedy rice control has become an immense challenge for rice farmers in Sri Lanka due to its similarity to cultivated rice, long-lasting seed dormancy, its seed-shattering nature, and massive soil seed bank enrichment. The lack of a selective herbicide for the control of weedy rice or other effective measures has made its control a subject of national significance.

Drought, high temperatures, floods, and salinity are the major abiotic stresses causing yield losses in rice in Sri Lanka. Due to the severe drought reported in 2017, approximately 2.4 million tons (46.1%) of production was lost, recording the lowest paddy production over the last decade (CBSL 2017). Soil problems such as bog and half bog soils, iron toxicity, and acidity in the wet zone also reduce the productivity of rice considerably.

Recently, rice production in Sri Lanka was considerably decreased due to the shortage of synthetic fertilizers and other inputs such as herbicides and fuel. Though fertilizer became available in 2022, the shortage in the first half of the 2022 season and unaffordable prices were detrimentally affecting the yield. For example, the price for 50 kg of urea increased from Rs. 500.00 (US$ 1.55) to Rs. 25,000–40,000.00 (US$ 77–US$ 124).

The use of machinery and chemicals, including herbicides and pesticides, is increasing with the expansion of paddy cultivation, creating high production costs. Meanwhile, labor charges are very high due to the shortage of labor during the peak cultivation period. In each season, the cultivation period starts in parallel in all paddy tracks, and therefore, there are only a limited number of laborers available. Due to land fragmentation over generations, most of the paddy plots in Sri Lanka are small and irregular in shape. This increases the cost of management, inefficiency in machinery use, and the reduction of the net area.

2.6.3 Introduction of CORIGAP Activities

The CORIGAP activities in Sri Lanka aimed to promote the delivery of best management practices on a large scale that reduce yield gaps and improve the profit of smallholder farmers in irrigated lowland rice systems. The project activities were initially implemented in two major rice-growing districts, i.e., Polonnaruwa (North-Central part of Sri Lanka) and Kilinochchi (Northern part). After 2015, the activities were also expanded to Kurunegala, Hambantota, Anuradhapura, Vauniya, Mulathive, and Ampara districts, which are also major rice-growing districts in Sri Lanka. These activities benefited more than 20,000 farmers by the end of the year 2021.

Initially, a baseline survey in Polonnaruwa and Kilinochchi districts was conducted to identify the socioeconomic background and the existing yield gap in 2014. In Polonnaruwa, the average land size per farmer was 0.81 ha. Wet direct seeding into puddled soil was practiced at a rate of 80–100 kg seeds/ha. The use of herbicides, both pre- and post-emergence, to control weeds was common. The average yield of a farmer was 5–6 t ha^{-1}, and the profit was around Rs. 50,000 ha^{-1} (approximately US$ 155). The average yield of the top 10% of farmers was 6.3 t ha^{-1}, while the average yield of the average farmer was 4.9 t ha^{-1}. The size of farm holding in Kilinochchi varied between 2 and 15 ha, and all farmers practiced dry seeding. Based on the survey results and to resolve the challenges with national importance, the following activities have been initiated since 2014.

Dry row seeding: Dry row seeding was demonstrated in Polonnaruwa and Kilinochchi districts to test an alternative method to overcome the disadvantages of random seeding. In Polonnaruwa, seeding depth could not be maintained at optimum level as there were large soil clots. As plots were irregular, rows were not straight, and some areas were left without seeding. A small strip along the bund was also left out without seeding. Thus, the establishment was poor and irregular in all plots. Farmers did not want to keep the crops and started to puddle the plots under wet conditions about two weeks after seeding, which coincided with the time they started land preparation. In Kilinochchi, a yield advantage of 0.7 t ha^{-1} was recorded in line sowing by using a multi-crop seeder compared to farmers' practice of manual broadcasting. In addition, there was a saving in seed costs due to savings in seed rate (50 kg ha^{-1} was used in line sowing compared to 100 kg ha^{-1} recommended in direct-wet seeding). Hence, the introduction of row seeding with a row seeder into the existing farming system in Polonnaruwa as an alternative crop establishment method is not possible due to poor yield and non-acceptance by farmers, but it has a potential to use in the Kilinochchi district due to comparatively higher yield than that of conventional wet direct seeding.

Adaptability testing of new rice varieties and establishment methods for rice cultivation: Demonstrations were conducted in Polonnaruwa, Kurunegala, and Kilinochchi districts to popularize Bg 370, a newly released high-yielding variety and Zhonghua, a promising high-yielding variety with better characteristics. Several demonstrations were conducted, presenting seedling broadcasting and mechanical transplanting to show the advantages of these methods. Demonstrations showed that both seedling broadcasting and mechanical transplanting reduced pest and disease incidences while increasing the yields by 10–20% compared to direct seeding. However, farmer adoption of these methods is still lacking due to some technical barriers.

Plot combining and land laser leveling: Paddy plot combining involved the amalgamation of small irregularly shaped plots into large regular-shaped plots to increase machinery use efficiencies and profitability in rice farming while minimizing labor costs for bund preparation. A lot of activities and demonstrations were conducted related to paddy plot combining and land laser leveling in most of the rice-growing districts in Sri Lanka. In the Polonnaruwa district, this was initially practiced to evaluate the feasibility of the practices and to estimate their impact on the net area, crop establishment, and efficiencies of field operations. Plot combining could recover 4% of paddy lands and reduce the labor requirement for bund preparation from 12 man-days ha^{-1} to seven man-days ha^{-1} (saved five labor requirement ha^{-1}) (Illangakoon et al. 2020). It also increased input-use efficiencies (e.g., fuel, time in land preparation and harvesting). In the Kurunegala district, the consolidation of plots resulted in a 3 to 5% increase in land area by reducing the number of bunds. It also saved labor associated with bund management by 3.3 man-days ha^{-1}. Identifying the importance of this activity, the Department of Agriculture has initiated a mega program of plot combining to reach 600 farmers covering all rice-growing districts of the country. A survey on plot combining revealed that it increased yield and farmers' income by 10.4% and 15.1%, respectively, and reduced costs of cultivation by 11.5%. A study to identify farmers' perceptions of benefits revealed that almost all farmers gained several benefits from participating in the activity and having positive perceptions of land consolidation of their paddy lands (Rambodagedera et al. 2022). The major benefits were the improvement of paddy lands productivity, improvement of the time due to minimizing bund maintenance, machinery and labor efficiency, the addition of a few more hours to farmers' spare time in a busy day, comfort during harsh farming operations, and easiness in weed management. Land laser leveling was also demonstrated in Kurunegala and Trincomalee districts, and the farmers were satisfied because of easy water management, uniform plant growth, and high yield on their paddy plots. In addition, making field canals to convert water from one field to another was simple and more cost-effective. The loss of harvest in the rice field has also been reduced in larger plots when harvesting was done using combined harvesters.

Development of an agronomic package for mechanically transplanted rice: Suitable rice varieties, suitable planting distances, seedlings per hill, and planting depth were evaluated for the self-propelled walk-behind type of mechanical transplanter. All medium-duration varieties (110–135 days) and most of the short-duration rice varieties (100–109 days), such as Bg 406, Bg 379-2, Bg 403, Bw 367, Bg 366, Bg 357, and At 362, were identified as suitable for mechanical transplanting (Illangakoon et al. 2017). The possibility of using 12–16 cm spacing levels, 4–6 seedlings/hill, and 1.5–2.5 cm depths in mechanical transplanting depending on the age of varieties and existing soil type was highlighted. Nursery management practices in mechanical transplanting were also optimized. A nursery mixture comprised of topsoil and compost at a 1:1 ratio, 0.5 kg of seed paddy m^{-2} of nursery bed, and 12 days old seedlings for transplanting were identified as the optimum for mechanical transplanting. There was no yield reduction in mechanical transplanting compared to other crop establishment methods, while it yielded comparable to seedling broadcasting (Illangakoon et al. 2018). In addition, mechanical transplanting had the potential to produce 6–7 t ha^{-1} under best management practices. Therefore, mechanical transplanting was identified as a feasible option in rice cultivation and a suitable agronomic package for mechanical transplanting was developed.

Adaptability testing of establishment methods: Farmer participatory research was conducted in the Mullaitivu district to compare row sowing by seeders, mechanical transplanting, and parachute and direct seeding methods (Sivaneson and Ponnegipprenthiraraja 2018). Mechanical transplanting and the parachute method produced a higher number of effective tillers, higher spikelet number per panicle, and higher filled grain percentage and grain yield compared to direct seeding. The demonstration highlighted the possibility of using mechanical transplanting and the parachute method for rice cultivation in the Northern region of the country.

Integrated weed management (IWM) solutions: IWM practices were demonstrated to achieve efficient weed management. It included the use of weed-competitive rice varieties and the use of pre-emergent herbicides. Furthermore, information was identified and generated for integrated weed management programs in rice-based cropping systems. A survey was conducted with 300 farmers in Hambantota district. The study revealed that 95% of farmers in the Hambantota district depend on herbicides to control weeds. Significant knowledge gaps in relation to the selection of correct herbicides, dosage, time of application, and application methods existed.

Weedy rice management package: Proper land preparation practices, application of pretilachlor herbicides, weedy rice seed bank management, and different establishment methods (transplanting, parachute, and broadcasting) were used to manage weedy rice in infested areas of Hambantota and Ampara districts. Proper land preparation practices and reduction of weedy rice seed bank, application of pretilachlor herbicides before crop establishment, and row transplanting resulted in a 90% reduction of weedy rice and a 23% yield increase in rice. A weedy rice seed bank is the number of weedy rice seeds available in the different depths of soil after seed shattering. The continuous seed shattering of weedy rice increases the number of seeds available in the soil in a particular area. For example, topsoil up to 20 cm depth comprised of weedy rice seeds, which led to difficulties in controlling weedy rice. The application of pretilachlor herbicides before field establishment provided excellent control of weedy rice. Transplanting and the parachute establishment managed the occurrence of weedy rice by more than 75%. Proper land preparation, including five times plowing, has been shown to reduce the weedy rice seed bank level and resulted in a reduction of more than 50% soil of the weedy rice seed bank.

Herbicide usage and Herbicide resistance studies: Herbicide use increased tremendously during the last decades, and thus, malpractices of herbicide application also increased. Herbicide mixing practice was more popular among the farmers in the Hambantota district, where most farmers (87%) mix two to three herbicides before the application, while 13% use a single application of herbicides. The study identified the most popular unspecified fifteen-tank mixing of herbicides. Bispyribac sodium 40 g/1 + metamifop 100 g/1 SE + carfentrazone-ethyl 240 g 1EC^{-1} was the most popular unspecified tank mixture among the majority of farmers (20.3%). Furthermore, the majority of farmers used hand sprayers (66%), while 34% used power sprayers for herbicide application (Herath et al. 2017). Due to the increase in the misuse of herbicides among farmers, the study highlighted the need for awareness and multiple approaches to weed management in rice (Herath et al. 2017).

Herbicide resistance in weed development is a common phenomenon in herbicide dominance systems. A study reported that the three main modes of action herbicide group popular among the farmers in Sri Lanka with protoporphyrinogen oxidase-inhibitors (PPO), ALS-inhibiting herbicides, and acetyl CoA carboxylase (ACCase) inhibitors (Herath et al. 2017). It also revealed the poor efficacy of herbicides on *Cyperus diformis* and *Ischamum rugosum. Cyperus difformis* developed resistance to 2-methyl-4-chlorophenoxyacetic acid (MCPA) and bispyribac sodium 40 g/l + metamifop100g/lSC. The ED_{50} values from the dose–response experiments indicated that the R biotype of *Cyperus difformis* was 1.95 times more resistant to MCPA than susceptible ones. The R biotype was 2.4 times more resistant to bispyribac sodium 40 g/l + metamifop100g/l SC than the S biotype (Herath et al. 2017). Furthermore, some populations of *I. rugosum* showed a moderate level of resistance against bispyribac sodium 40 g/1 + metamifop 100 g/1 SC (Herath et al. 2019).

Water management: Alternative Wetting and Drying (AWD) is a water-saving technology in rice cultivation. In AWD practice, irrigation is started after 2–3 weeks of crop establishment, and then, the field is allowed to drain off until the water level goes down to 15 cm below the soil surface. This procedure is repeated until the flower initiation. After flower initiation, the water level is maintained continuously around 0–5 cm until two weeks before the expected date of harvesting. Demonstrations on AWD were conducted in Polonnaruwa and Kilinochchi districts to monitor water levels in rice fields and also to convey the importance of water saving in rice cultivation for farmers. Farmers were able to save four irrigations during the cropping season, and farmer awareness on water saving in rice cultivation was initiated. However, the partnership with the irrigation department was identified as important to control water release as per AWD criteria. AWD was also demonstrated in Hambantota district in 2018 and Anuradhapura district in 2019 at a large scale, and it was found that 20–30% irrigation water could be saved using this practice.

Characterization of water quality and effects of pesticide use: Detailed field studies on water quality with a strong focus on monitoring pesticide presence were completed in the Deduru Oya River Basin. The study was an SDC-funded PhD project under CORIGAP. This, at a landscape level, was the first study of its type in Sri Lanka. The occurrence of twenty commonly used pesticides was monitored. The findings indicated that many pesticides were used between 1.2 and 11 times the recommended use. Of major concern was the detection of high levels of 2-methyl-4-chlorophenoxyacetic and diazinon in irrigation water. Refer to Jayasiri et al. (2022a, b) for details of the design and findings of this impressive research.

Awareness programs on best management practices (BMP): Several awareness programs were conducted to make farmers aware of the BMPs. They included training programs, field days and field visits, demonstrations, TV and radio programs, newspaper articles, videos, news bulletins, and web pages. Programs included proper land preparation techniques and crop establishment methods, plot combining and laser leveling, nutrient management, weed and weedy rice management, pest and disease management, and water management. More than 20,000 farmers were reached with these awareness programs to adopt BMPs in rice cultivation.

2.6.4 Conclusions

Plot combining to enhance agricultural efficiency had a very high impact on reducing yield gaps. The elimination of micro-parceling and curved boundaries of rice fields and the readjustment of plots with correct configuration made farm operations easier and more profitable. It also increased machinery use, harvesting efficiencies, and farmers' income by more than 10% and profit by more than 15% in lowland irrigated rice cultivation. Studies on weeds, weedy rice, and herbicide resistance and training programs created great farmer awareness of correct practices in weed management. The adoption of integrated weed and weedy rice management packages minimized the yield loss due to weeds and weedy rice significantly.

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Chapter 3
Faunal Biodiversity in Rice-Dominated Wetlands—An Essential Component of Sustainable Rice Production

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Abstract Rice agriculture provides wetlands and complex habitats supporting biodiversity. Wetlands associated with rice agriculture since the 1960s have increased by 32% and now form nearly 12% of wetlands globally at a time when vast areas of natural wetlands are being lost. In this chapter, we set our sights beyond Sustainable Development Goal (SDG) 2 that focuses on ending hunger and achieving food security via the promotion of sustainable agriculture. Often, agricultural scientists are so motivated to achieve food security that they pay insufficient attention to the need to have a healthy and dynamic agroecosystem that promotes floral and faunal biodiversity, which may also provide ecosystem services including support for food security of smallholder families. Because of their aquatic, semi-aquatic, and terrestrial ecological phases, rice fields represent a changing mosaic of ecological niches and have the potential to sustain a broad diversity of wildlife. In addition, a multitude of studies have investigated how modifications to rice cultivation have the potential

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to support a greater diversity of species across biological scales while often maintaining or increasing yield. SDG 15 emphasizes the need to promote sustainable use of terrestrial ecosystems and halt biodiversity loss. Given the high losses in global biodiversity, especially in tropical zones where most of the world's rice is grown, we set our sights on achieving both SDGs 2 and 15. We provide case studies on amphibians, bats, birds, and rodents living in and around irrigated rice-cropping systems. We report on transdisciplinary studies supported by CORIGAP that include agronomic, sociological, ecological, biochemical, environmental physiological, and genomic studies. Most of these studies identify potential positive ecosystem services provided by wildlife, which can lead to more sustainable and healthier rice production landscapes. We conclude that our current management of rice landscapes contributes to the biodiversity crisis. Rice production often overuses pesticides and fertilizers and applies unsustainable intensification practices and land modifications, which result in biodiversity loss. Finding a balance, where human population requirements for food

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are met without degrading the natural environment, is critical to the health of smallholder agricultural communities. We propose that future research and development projects need to: build capacity of countries to scale-up use of proven practices that reduce rice farming's ecological footprint and conserve biodiversity, increase investment in biodiversity research in rice production landscapes, promote Green "Rice Value Chains" and "Agri-input Markets," and monitor and evaluate the ecological benefits to biodiversity of broadscale promotion of sustainable rice production.

Keywords Faunal biodiversity · Sustainable Development Goal (SDG) · Ecological footprint · Sustainable rice production

3.1 Setting the Scene

Rice agriculture is a staple for over half of the world's population (Muthayya et al. 2014) and provides wetlands and complex habitats supporting biodiversity. The report from the RAMSAR Convention on Wetlands (RAMSAR 2018) highlighted that 35% of wetlands have been lost since 1970. However, since the 1960s, wetlands associated with rice agriculture have increased by 32% and now form nearly 12% of wetlands globally, indicating the increased urgency for research on existing agricultural wetland systems. Finding a balance, where human population requirements for food, shelter, and health are met without degrading the natural environment, is critical to the health of smallholder agricultural communities (Duru et al. 2015; Tilman et al. 2011).

The current UN Sustainable Development Goals (SDGs)[1] highlight the need to ensure sustainable food production systems that enable the maintenance of functional ecosystems (Goal 2) (United Nations 2015). Our approach has been to set our sights beyond SDG 2 that focuses on ending hunger and achieving food security via the promotion of sustainable agriculture. Often agricultural scientists are so motivated to achieve food security that they pay insufficient attention to the need to have a living, healthy, and dynamic agroecosystem that promotes floral and faunal biodiversity. Given the documented loss in global biodiversity, especially in tropical zones where most of the world's rice is grown, we set our sights on achieving both SDGs 2 and 15. Goal 15 emphasizes the need to promote sustainable use of terrestrial ecosystems and halt biodiversity loss (see Barlow et al. 2018). The tropics cover 40% of the world's landmass and are home to 91% of terrestrial birds and more than 75% of amphibians and terrestrial mammals. Conversely, ecologists, who address SDG 15 in terrestrial agricultural systems, need also to balance their efforts so that delivery of SDG 2 is not compromised.

1 https://sdgs.un.org/goals.

In this chapter, we review interdisciplinary research over the past decade supported by CORIGAP that focused on assessing the biodiversity of wildlife living in and around irrigated rice lands. We report on research on amphibians, bats, birds, and rodents. Human-wildlife research in agricultural systems has often focused on conflicts between the human and natural world and less is understood regarding the ecosystem services that wildlife provide within the context of agroecology. For example, Tancoigne et al. (2014) found few socio-agroecosystem studies that integrate these linkages with wildlife. Several studies have identified the need for such human-wildlife integration, especially in agricultural systems outside of the developed world (Luo et al. 2014; Stafford et al. 2010). Most of the studies in this chapter identify potential positive ecosystem services provided by wildlife to rice-cropping systems that lead to more sustainable and healthier rice production. In general, this research was conducted in parallel with field trials that applied best management practices for lowland-rice production (see Stuart et al. 2018a, b, Chapters 2.3 and 2.5). The unifying theme of this chapter is to present research supported by CORIGAP that addresses SDG 15 in combination with SDG 2 and to outline a future strategy for mainstreaming biodiversity into rice-based production landscapes.

3.2 Amphibians

3.2.1 Introduction

Amphibians provide several regulatory services including reducing human-insect vector populations and consuming agricultural crop pests (Hocking and Babbitt 2014; Shuman-Goodier et al. 2019; Khatiwada et al. 2016). Because their early life stage is aquatic, they also function as bio-monitors for developmental problems associated with chemical contamination. Recently, studies have determined that the addition of frogs to rice fields can increase yields (Teng et al. 2016; Fang et al. 2021) and may even reduce greenhouse gas emissions (Fang et al. 2019). Over the course of 5 years, we conducted a series of studies on amphibians at the International Rice Research Institute (IRRI) farm near Los Baños, Philippines. Our research involved transdisciplinary investigations that included agronomic, sociological, ecological, biochemical, environmental physiological, and genomic studies. Our results demonstrate that wetlands created as part of rice agricultural systems form a powerful model for understanding how humans interact with modified environments and how sustainable agricultural practices can integrate both human and wildlife needs.

3.2.2 Case Study 1: Differences in Diversity and Abundance of Amphibians Between Conventionally Farmed (Higher Pesticide Use) and Improved-Management (Lower Pesticide Use) Rice Fields

Seven species of amphibians (Fig. 3.1) were observed to inhabit irrigated rice fields at the IRRI experimental farm. These included three native species: Luzon wart frog (*Fejervarya vittigera*), common tree frog (*Polypedates leucomystax*), and puddle frog (*Occidozyga laevis*); and four non-native species: cane toad (*Rhinella marina*), banded bullfrog (*Kaloula pulchra*), Chinese bullfrog (*Hoplobatrachus rugulosus*), and paddy frog (*Hylarana erythraea*). We undertook surveys to evaluate whether there were differences in diversity and abundance of these species between conventionally farmed (higher pesticide use) and improved-management (lower or no pesticide use) fields at IRRI. The number of adult individuals across all species was higher in the improved-management fields than in the conventional ones with *R. marina* representing 70% of the observations in the improved-management vs. 30% in the conventional fields (Table 3.1). Surprisingly, diversity was higher in the conventional compared to the improved-management fields (Simpson Index: $p = 0.02$), However, this outcome may have been a result of us noting that neighboring farmers were hunting frogs for food, including *F. vittigera* and *H. rugulosus*, species in the improved-management fields at night.

Fig. 3.1 Compilation of amphibian species, to scale in reference to each other, observed in rice fields at IRRI's experimental farm in Laguna, Philippines (photos by Phoebe Shuman-Goodier)

Table 3.1 Number of adult individuals observed for each anuran species in improved-management (low-pesticide use) and conventional (high-pesticide use) fields at the Zeigler Experimental Farm of the International Rice Reserarch Institute farm, Philippines, in June and July, 2014

Species	Low			Total	High			Total
	Plot A35	Plot 516	Plot 709		Plot 835	Plot B4	Plot A37	
F. sp.	41	0	9	**50**	23	36	22	**81**
R. marina	33	9	93	**135**	10	13	17	**40**
P. leucomystax	1	0	2	**3**	0	0	2	**2**
K. pulchra	0	1	0	**1**	0	0	0	**0**
H. ruguloses	1	1	1	**3**	5	3	3	**11**
O. laevis	0	0	0	**0**	0	1	0	**1**
				192				**135**

Once we identified the frogs in the rice fields, we determined whether two species, *F. vittgera* and *R. marina,* have species-dependent diets with the potential to impact overall pest-control ecosystem services (Shuman-Goodier et al. 2019). The native frog, *F. vittigera,* ate a high proportion of rice pests, demonstrating that this species has the potential to provide regulatory ecosystem services. However, the diet of the invasive cane toad (*R. marina*) was replete with the predators of rice pests. These results suggest that *F. vittigera* may provide pest-control services, while the larger numbers of *R. marina* individuals in rice fields, throughout many of the islands of the Philippines, may lead to increased numbers of rice pests resulting from lower predator availability. While this outcome was surprising, it suggests that working with farmers to integrate conservation practices in parallel with their economic and food-resource needs may simultaneously provide benefits to both the farmers and the rice agroecosystem.

3.2.3 Case Study 2: Tadpoles as Bio-Indicators for Effects of Current-Use Pesticides on Vertebrate Physiology, Behavior, and Species Interactions

Environmental contaminants, including pesticides, have been identified as a contributing factor in global amphibian declines (Blaustein et al. 2003, 2011; Hayes et al. 2010). Several studies have identified effects relevant to rice ecosystems (Nataraj and Krishnamurthy 2020; Thammachoti et al. 2013; Shojaei et al. 2021). Because amphibians that live in rice ecosystems are exposed to herbicides and insecticides during sensitive life stages, such as development and reproduction (Fig. 3.2), they can be studied to identify chemicals that cause adverse physiological effects. In addition, because vertebrate endocrine systems and the physiological mechanisms that

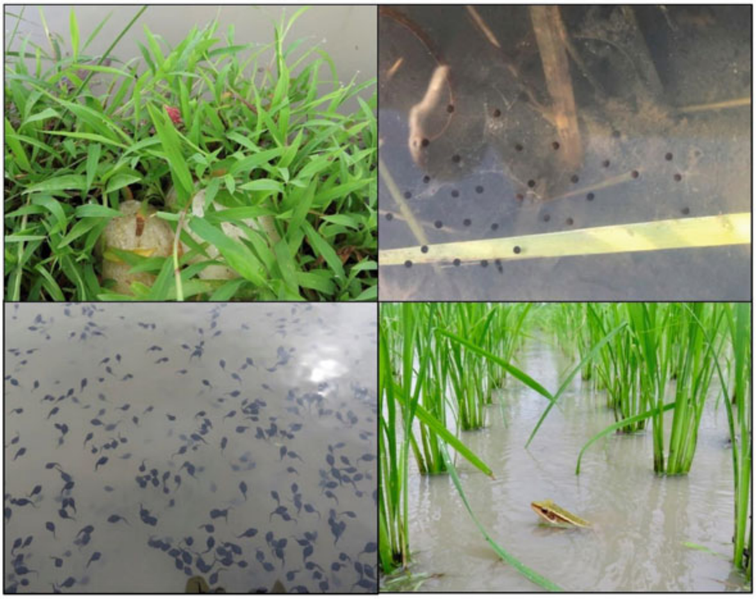

Fig. 3.2 Examples of the amphibian life stages observed in irrigated rice fields, which include eggs, larvae, metamorphs, subadults, and adults. Top left: two foam nests on a rice field bund that contain eggs produced by *Polypedates leucomystax*. Top right: *Fejervarya* sp. egg mass attached to a submerged rice plant leaf. Bottom left: *Rhinella marina* tadpoles swimming in a flooded rice field. Bottom right: an adult *Hylarana erythraea* documented the morning after a night-time breeding chorus (photos by Molly Shuman-Goodier)

underlie development are highly conserved, these effects may translate to potential harbingers for human health.

Through a series of experiments and surveys conducted at the IRRI farm in the Philippines, we demonstrated that wild amphibian tadpoles can be used to screen for effects of current-use pesticides on vertebrate physiology, behavior, and species interactions (Shuman-Goodier et al. 2017, 2021). Specifically, we found that a commercial herbicide formulation of Butachlor, Machete EC, can cause endocrine disruption at an environmentally relevant concentration (0.002 mg/L) and alter competitive interactions between invasive (cane toad, *R. marina*) and native (Luzon wart frog, *F. vittigera*) species. We also propose that the cane toad is an ideal candidate for monitoring pesticide exposure in rice in rice-growing countries where it has been previously introduced. The species is abundant, sensitive to chemical exposure, and has extensive reference resources (e.g., annotated genome).

3.2.4 Case Study 3: Knowledge, Attitudes, and Practices of Farmers with Regard to Amphibians That They Find in Their Fields

Throughout the centuries, amphibians have provided human populations with important ecosystem services relating to food, economic, and even cultural resources (Crump 2015). In 2014, we surveyed and interviewed 22 farmer owners, managers, laborers, and tenants regarding their knowledge, attitudes, and practices of the amphibians that they found in their fields (Propper et al. 2020). We found that nearly half of the surveyed farmers thought there was a decline in amphibian populations and two-thirds believed that pesticides have a negative effect on individual animals. Farmers mentioned seeing dead and fewer frogs in the fields after spraying and some lamented that, in recent years, there are fewer frogs in the fields to use as a food resource. One farmer worried that neighbors may be catching animals contaminated with pesticides and selling them at local markets. These results suggest that farmers are aware of the impact of pesticide exposure on the frogs in their fields while simultaneously demonstrating that frogs are both an economic and provisioning resource.

Farmers also expressed other perceptions of the potential ecosystem services the frogs in their fields provide. Many of the farmers agreed that the frogs eat the insects in their fields and that these animals provide pest-control services. Some farmers also mentioned that there has been a reduction of frogs calling in their fields and that they miss the "singing," indicating that there are some cultural services provided by the animals. Another potential service the farmers noted was the belief that the tadpoles deliver nutrients to the soil.

3.2.5 Integration of Key Findings on Amphibians

Rice agroecosystems around the globe may play a key role in maintaining local amphibian populations that provide ecosystem services to the environment and to the farmers managing their fields. Our research at IRRI supports the hypothesis that frogs in this tropical-farming system provide regulatory, provisioning, and cultural resources to farmers. Recent other studies in China demonstrate the potential for complex-scaled interactions between frogs and the rice ecosystem. Fang et al. (2021) found that higher frog abundances in rice fields indirectly reduce methane gases emanating from rice fields by increasing both rice root porosity and oxygen secretion. Together, our studies and others demonstrate that amphibian conservation practices combined with optimizing farmers' needs for economic, food, and health security may lead to the development of a shared-goals approach for more sustainable rice production.

3.3 Bats in Rice Ecosystems

3.3.1 Introduction

Rice-growing landscapes offer foraging opportunities to bats and ecosystem services to people; however, unsustainable practices within and outside rice-growing areas, such as cave disturbance and limestone quarrying, habitat loss, pesticide and herbicide use, and hunting, threaten this mutualistic relationship and contribute to the decline of bat populations (Kingston 2010; Voigt and Kingston 2015; Furey et al. 2016; Toffoli and Rughetti 2017; Costantini et al. 2019). If we are to maintain this mutually beneficial relationship with bats, we must learn to identify the precise role of our key bat collaborators and adopt management practices that allow them to thrive.

3.3.2 Case Study 1: Bat and Insect Activity at IRRI

Despite the potential benefits of and threats to bats, information on the species utilizing rice-dominated landscapes as a foraging habitat in Southeast Asia is sparse. To begin filling this gap, between 2014 and 2016, we sampled bat activity acoustically and through mist-netting and roost searches within, and in the vicinity of, the IRRI farm (Sedlock et al. 2019). The Makiling Forest Reserve lies adjacent to the farm and is one of the most studied bat assemblages in the country (Sedlock 2001; Ingle 1992) that provides baseline information on species present in the area and an echolocation call library for identifying passively recorded calls (Sedlock 2001). We assessed the extent to which bats were tracking aerial-insect abundance on the farm by simultaneously sampling bats and insects. Insects were sampled using large hoop nets mounted on a truck that was driven along transects (Fig. 3.3A). We acoustically monitored bat activity simultaneously over early and late tillering growth stages to reveal whether bats were tracking early colonizers, such as aquatic-emergents (e.g., midges, mosquitoes) or herbivores (e.g., planthoppers, stemborers) that arrive at later crop stages. Finally, we acoustically monitored bats from 50-m radio towers on the farm to compare the diversity and activity levels of bats immediately above the rice to that at higher altitudes (Sedlock et al. 2019).

3.3.2.1 Key Findings

We documented 11 bat species on the farm; the most abundant species living and foraging within the farm were the Asian house bat (*Scotophilus kuhlii*) (Fig. 3.3E), the Javan pipistrelle (*Pipistrellus javanicus*), and the black-bearded tomb bat (*Taphozous melanopogan*) (Fig. 3.3D). Conspicuously absent was the wrinkled-lipped bat (*Chaerophon plicatus*), an ecologically and economically important consumer of

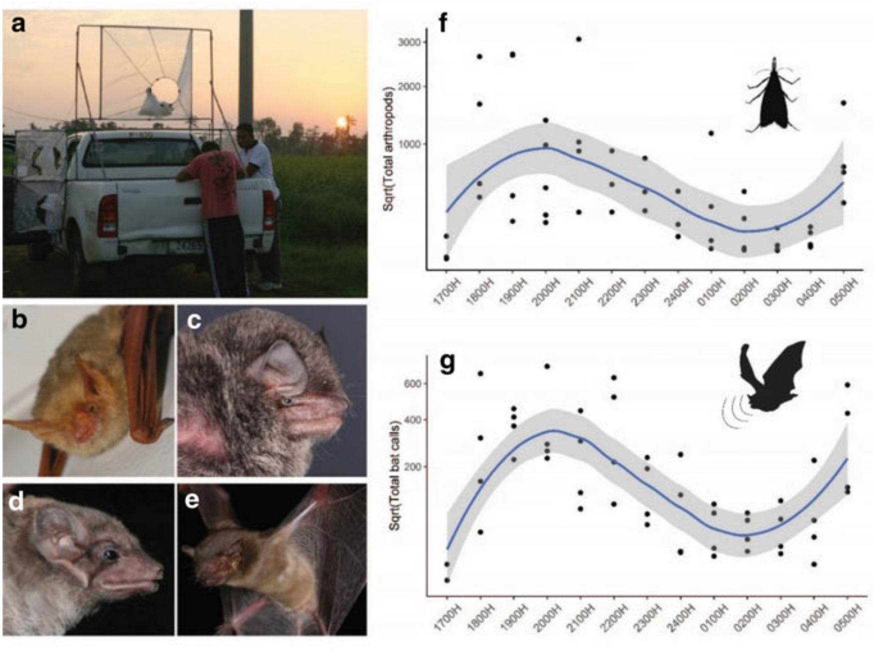

Fig. 3.3 Bat and arthropod sampling on the Zeigler Experimental Farm of the International Rice Research Institute, Philippines. Nets mounted on a pickup truck passively sampled aerial arthropods along a driven transect (A). Representative bats captured within the farm and acoustically sampled, include *Myotis rufopictus* (B), *Miniopterus australis* (C), *Taphozous melanopogon* (D), and *Scotophilus kuhlii* (E). Relative abundance of insects captured (F) and bat calls recorded (G) during each of four driving transects across the night (Photos by Jodi Sedlock)

brown planthoppers in Thailand (Srilopan et al. 2018). Nevertheless, our data provide evidence of a rich bat community supported by the rice ecosystem and the surrounding landscape and potentially serving as natural enemies to rice-associated pests.

Our simultaneous bat and insect sampling, while not definitive, provides strong evidence of prey tracking by bats on the farm (Fig. 3.3) and echoes the pattern of bat and insect activity documented with Lidar technology over a Chinese rice paddy (Malmqvist et al. 2018). Moreover, most of the insect species we captured were decomposers (70%) during part of their life cycle, over 90% of these were flies (including biting midges, mosquitoes, etc.); 22% of captures were herbivores (including important rice pests such as planthoppers and leafhoppers (nearly 10% of captured herbivores); and the remaining 8% of captures included parasitoid and predatory insects and spiders. Additionally, over two rainy seasons of acoustically sampling bats simultaneously in early and late tillering fields, we found that the most recorded species, the Asian house bat and the Javan pipistrelle, foraged more over early tillering than late tillering fields when rice herbivores are most abundant (Fig. 3.4) (Sedlock et al. 2019). Therefore, the most conspicuous and abundant bats foraging immediately over irrigated paddies at IRRI are potentially critical in their

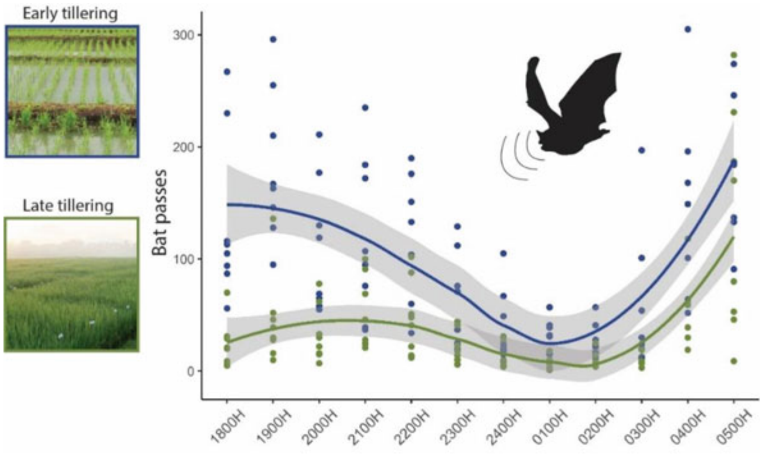

Fig. 3.4 Acoustic activity of aerial-hawking bats over paired early and late tillering plots at the Zeigler Experimental Farm of the International Rice Research Institute, Philippines. Each data point represents total bat passes during a 1-h sampling period in August 2016

consumption of disease vectors (mosquitoes). Molecular analysis of bat diets in a rice-growing region of Spain confirmed the consumption of dipterans (Puig-Montserrat et al. 2020), which underscores bats' role as natural enemies in rice agroecosystems worldwide.

Bat species whose flight morphology and echolocation call design allow them to forage closer to vegetation, such as *Myotis rufopictus* (Fig. 3.3B) and *Rhinolophus macrotis*, were active throughout the night and over all sampled rice-growth stages. Lacking a dusk and dawn peak in activity that is apparent for the Asian house bats that track the nightly activity pattern of aerial insects—these bats may be more important as consumers of moth pests, such as stem borers and armyworm moths that alight on vegetation. Adept at flying and detecting prey near and on vegetation, these species may exploit eared noctuid (armyworm), pyrallid (stem borer), and arctiid moth pests that evade most bats by flying close to vegetation and that respond to rapidly approaching bats with evasive maneuvers and, in some cases, ultrasonic clicks of their own (Hofstede and Ratcliffe 2016). In Thailand, *Myotis horsefieldii*, a species that is present in the IRRI area and similar to *M. rufopictus*, was the most commonly recorded bat at ground level in a rice-dominated area of central Thailand (Nguyen et al. 2019).

3.3.3 Case Study II: Free-Range Bat Guano Farming in Cambodia

Insectivorous bats produce nutrient-rich guano that is highly valued as a plant fertilizer by farmers in Southeast Asia (Thi et al. 2014; Furey et al. 2016). The guano is typically sun-dried in places where it accumulates beneath the roost sites, then collected and sold. Monthly incomes for farmers employing traditional roost structures (Fig. 3.5) in the Kandal and Takeo provinces of Cambodia range between US$6–22 per roost with numbers of roost per farm ranging from 1 to 20 (Chhay 2012), whereas farmers employing stilt-house roost structures in Soc Trang province in Vietnam (Fig. 3.5C) earn between US$130–215 per roost (Neil Furey, unpubl. data). This farming practice provides a valuable source of income for smallholders in both countries. In addition to the environmentally friendly and nutrient-rich fertilizer provided by the bats (Thi et al. 2014), they undoubtedly help to protect rice crops in the surrounding landscapes by suppressing insect pests (Wanger et al. 2014; Kemp et al. 2019; Puig-Montserrat et al. 2020). It is also possible that this service may contribute to reducing the need for pesticides, although this has yet to be studied in Southeast Asia. To investigate the role that free-range bat guano farms in Cambodia play toward biological pest control in rice agroecosystems, a study was conducted by researchers from the Royal University of Phnom Penh that aimed to quantify bat activity over rice fields surrounding bat farms and evaluate threats to bat populations in this area (Pisey 2017).

3.3.3.1 Key Findings

Results from interviews with bat and rice farmers in the study landscape suggest that bat populations had declined within the study area over the previous 10 years, with loss of palm tree roosts, hunting of bats for consumption, and high-pesticide use identified as possible causes. However, initial results from acoustic analysis revealed that free-range farming of lesser Asian house bats enhanced bat activity over nearby rice fields compared to those further away (Pisey 2017). These findings suggest that, in addition to supporting local bat populations through increased roost availability, the bat farms likely benefit nearby rice farmers. Efforts to address anthropogenic threats to bats, such as high-pesticide use, are clearly needed (Stechert et al. 2014) to ensure the sustainability of bat farms and avoid further declines in Cambodian bat populations and the ecosystem services they provide.

Fig. 3.5 Roost structures employed by free-range bat guano farms in Cambodia and southern Vietnam. (A) traditional roost structure, Kandal province, Cambodia (photo by Neil Furey), (B) composite structure, Kampong Cham province, Cambodia (photo by Julia Guillebaud), and (C) stilt-house structure, Soc Trang province, Vietnam (Photo by Neil Furey)

3.4 Birds

3.4.1 Introduction

Birds provide a great opportunity to study the interaction between biodiversity and agriculture. They are relatively easy to survey, identify, and record, and are wide-ranging and can respond rapidly to changing ecological factors. Recent attention has been given to studying the occurrence of bird species within rice fields, but these are often disproportionately represented by studies from Europe or the USA (Elphick et al. 2010a). Asia produces the largest quantity of rice in the world, but studies on birds in rice landscapes within Asia are within their infancy (e.g., Bourdin et al. 2015) and generally concentrate either on single species ecology or in the pursuit of reduced food damage during production (Lane et al. 1998; Borad et al. 2001; Takahashi and Ohkawara 2007; Smedley 2017).

There is a clear need to expand current knowledge about the avian biodiversity that uses rice fields (e.g., Bourdin et al. 2015). Long-term assessments of bird populations within lowland irrigated rice fields can provide an important foundation to identify general trends and establish a baseline that can be used to measure changes over time. The case study presented below covers two seasons and provides an indication of how changes in cropping systems in lowland irrigated rice systems can influence avian biodiversity in one of the dominant agroecological landscapes in the Philippines.

3.4.2 Case Study: Four Versus Five Crops Over 2 Years

Consisting of over 7,000 islands, the Philippines is one of the most avian-diverse countries in the world and has been identified as a biodiversity hotspot of conservation importance (Balmford and Long 1994; Myers et al. 2000). In 2020, the Philippines produced 19 million t of rice (FAOSTAT 2022), but currently relies on imports to supply the demand for its population. To avoid further loss of natural wetlands to agriculture, methods of producing more rice per unit area of existing agricultural land might be one solution to supply the increase in food demand, while maintaining uncultivated land to support local biodiversity.

In the Philippines, lowland irrigated rice fields typically produce two rice crops annually although this is dependent upon location and available water supply (GRiSP 2013). In 2012, the Philippines government encouraged farmers to intensify their production of lowland irrigated rice. Large-scale trials of crop intensification were conducted using selectively bred rice varieties that have a shorter maturation period, enabling smallholder farmers to grow five rather than four crops every 2 years.

Studies from countries that adopt a single annual-cropping practice, such as Europe and the USA, have shown that, with careful management of the fallow period (time between cropping seasons), rice fields can support an impressive range of bird species (Elphick et al. 2010b; Stafford et al. 2010). In the Philippines, this fallow time is already reduced but with further intensification, what would be the impact on bird species that are currently found within this agricultural landscape? As part of a broader research program on avian diversity of rice fields within the Philippines (Smedley 2017), avian biodiversity was monitored in rice fields, trialing the intensified system of five rice crops over a 2-year period (5-in-2) and compared to the traditional four crop model (4-in-2). Surveys commenced once the crop stage became unsynchronized, as the intensified "5-in-2" sites were harvested but the traditional "4-in-2" were still at the maturity stage. The study was conducted in Isabela province, northern Luzon, where this intensified method of farming had been adopted for the first time. Monthly bird surveys to record the diversity and abundance of species seen and heard were conducted at all sites to provide direct comparisons between the two cropping practices (Table 3.2). Two rice fields, each approximately 10 × 50 m in size, were surveyed at each site with results pooled during analysis, further details of which can be found in Smedley (2017).

3.4.2.1 Key Findings

Over the whole survey period, more individual birds were observed within the 5-in-2 fields ($n = 5{,}419$) than in the 4-in-2 fields ($n = 4{,}263$). This was mainly due to the larger number of Eurasian tree sparrows recorded (5-in-2: $n = 1{,}594$, 4-in-2: $n = 839$), which is likely due to the increase in the amount of time that the rice fields have available grain (i.e., food for Eurasian tree sparrows), both while the crop is maturing and via grain spilled during harvest. In contrast, the total number of water

Table 3.2 Diversity of bird species and mean number of individuals recorded per site per species during the 15 months of data collection between an intensified cropping system (5-in-2) and a traditional cropping (4-in-2) one. Surveys were conducted at two replicate sites per cropping method. Cumulative number of individuals recorded over the 15 months is given in parentheses. Sixty surveys were conducted per site. Common names which end with "(sp.)" represent records that were identified to the family level only. Species are from the Checklist of the Birds of the Philippines (Jensen et al. 2019)

Common name	Species	5-to-2 mean (Range)	4-to-2 mean (Range)
Wandering Whistling Duck	*Dendrocygna arcuata*	15.5 (3–28)	3.5 (1–6)
Duck (sp.)		0.5 (0–1)	
Yellow Bittern	*Ixobrychus sinensis*	14.5 (14–15)	36.5 (34–39)
Cinnamon Bittern	*Ixobrychus cinnamomeus*	15.5 (11–20)	20 (11–29)
Bittern (sp.)		0.5 (0–1)	0.5 (0–1)
Eastern Cattle Egret	*Bubulcus coromandus*	46.5 (45–48)	165 (164–166)
Grey Heron	*Ardea cinerea*	0.5 (0–1)	
Purple Heron	*Ardea purpurea*	1.5 (1–2)	3.5 (3–4)
Great Egret	*Ardea alba*		0.5 (0–1)
Intermediate Egret	*Ardea intermedia*		1 (1–1)
Little Egret	*Egretta garzetta*		3 (3–3)
Egret (sp.)		0.5 (0–1)	1 (0–2)
Pied Harrier	*Circus melanoleucos*	2 (2–2)	8.5 (0–17)
Brahminy Kite	*Haliastur indus*	1.5 (1–2)	1.5 (0–3)
Barred Rail	*Gallirallus torquatus*	1 (1–1)	0.5 (0–1)
Buff-banded Rail	*Gallirallus philippensis*	1.5 (0–3)	2.5 (1–4)
White-breasted Waterhen	*Amaurornis phoenicurus*	1.5 (1–2)	2 (0–4)
Ruddy-breasted Crake	*Porzana fusca*		0.5 (0–1)
White-browed Crake	*Porzana cinerea*	30 (14–46)	5.5 (5–6)
Watercock	*Gallicrex cinerea*		0.5 (0–1)
Common Moorhen	*Gallinula chloropus*	80 (41–119)	31 (0–62)
Pacific Golden Plover	*Pluvialis fulva*	6.5 (4–9)	

(continued)

Table 3.2 (continued)

Common name	Species	5-to-2 mean (Range)	4-to-2 mean (Range)
Little Ringed Plover	*Charadrius dubius*	6.5 (0–13)	4.5 (0–9)
Greater Painted Snipe	*Rostratula benghalensis*	3.5 (0–7)	1 (0–2)
Snipe (sp.)		3.5 (2–5)	3.5 (3–4)
Common Sandpiper	*Actitis hypoleucos*	1.5 (0–3)	1.5 (0–3)
Wood Sandpiper	*Tringa glareola*	26 (16–36)	211 (211)
Wader (sp.)		0.5 (0–1)	0.5 (0–1)
Oriental Pratincole	*Glareola maldivarum*	14 (6–22)	14.5 (1–28)
Rock Dove	*Columba livia*		2 (0–4)
Dove (sp.)		18 (11–25)	29 (19–39)
Red Turtle Dove	*Streptopelia tranquebarica*	7 (2–12)	18 (1–17)
Spotted Dove	*Spilopelia chinensis*		8.5 (3–14)
Zebra Dove	*Geopelia striata*	2 (0–4)	17 (3–31)
Lesser Coucal	*Centropus bengalensis*	7 (6–8)	14.5 (10–19)
Swift (sp.)		5.5 (0–11)	3.5 (0–7)
Swiflet (sp.)		9 (0–18)	
White-throated Kingfisher	*Halcyon smymensis*	1 (1–1)	
Common Kingfisher	*Alcedo atthis*	3 (1–5)	13.5 (2–25)
Blue-tailed Bee-eater	*Merops philippinus*	134 (123–145)	43 (21–65)
Peregrine Falcon	*Falco peregrinus*	0.5 (0–1)	
White-breasted Woodswallow	*Artamus leucorynchus*	5 (0–10)	2 (0–4)
Brown Shrike	*Lanius cristatus*	41.5 (37–46)	43.5 (30–57)
Long-tailed Shrike	*Lanius schach*	16 (16–16)	20 (9–31)
Shrike (sp.)			1 (0–2)

(continued)

Table 3.2 (continued)

Common name	Species	5-to-2 mean (Range)	4-to-2 mean (Range)
Philippine Pied Fantail	*Rhipidura nigritorquis*	0.5 (0–1)	8 (2–14)
Large-billed Crow	*Corvus macrorhynchos*	0.5 (0–1)	9 (8–10)
Oriental Skylark	*Alauda gulgula*	0.5 (0–1)	13.5 (6–21)
Yellow-vented Bulbul	*Pycnonotus goiavier*	9.5 (7–12)	22 (4–40)
Pacific Swallow	*Hirundo tahitica*	12 (2–21)	21 (8–34)
Swallow (sp.)		1,100 (890–1,310)	597 (314–880)
Striated Swallow	*Cecropis striolata*	4 (0–8)	1.5 (0–3)
Striated Grassbird	*Megalurus palustris*	49 (47–51)	58.5 (33–84)
Zitting Cisticola	*Cisticola juncidis*	3 (1–5)	23.5 (1–46)
Golden-headed Cisticola	*Cisticola exilis*		3.5 (0–7)
Creasted Myna	*Acridotheres cristatellus*	6.5 (0–13)	8 (6–10)
Rhobdornis (sp.)			1 (0–2)
Pied Bush Chat	*Saxicola caprata*		19.5 (0–39)
Sunbird (sp.)		7.5 (0–15)	10 (5–15)
Eurasian Tree Sparrow	*Passer montanus*	787 (460–1,114)	419.5 (331–508)
Scaly-breasted Munia	*Lonchura punctulata*		0.5 (0–1)
White-bellied Munia	*Lonchura leucogastra*		0.5 (0–1)
Chestnut Munia	*Lonchura atricapilla*	11.5 (3–20)	124 (63–185)
Munia (sp.)		15.5 (8–23)	46.5 (44–49)
Eastern Yellow Wagtail	*Motacilla tschutschensis*	0.5 (0–1)	8.5 (5–12)
Grey Wagtail	*Motacilla cinerea*	11.5 (3–20)	24 (20–28)
Wagtail (sp.)		68.5 (28–109)	92 (28–156)
	Total	2,611.5 (2,422–2,801)	2,136 (1,592–2,680)

bird individuals recorded in the 5-in-2 fields (mean = 356, range = 335–377) was substantially lower than in the 4-in-2 fields (mean = 546, range = 511–581). This outcome is most likely due to the shortened interval between planting and harvest in the 5-in-2 fields, compared to the 4-in-2 fields, which reduced the duration of preferential wet conditions and vegetation cover per cropping season. Generally, a similar number of species was observed in the two cropping systems (Table 3.3),

Table 3.3 Mean number of species recorded between an intensified crop (5-in-2) and a traditional crop (4-in-2), across four fields at two sites per cropping method. Species categorization of all birds, including those only identified to family level, during the 15 months of data collection. Cumulative number of species recorded per site is given in parentheses. Sixty surveys were conducted per site

Species category	5-in-2 cropping system	4-in-2 cropping system
Water birds (incl. water associated species)	22 (17–27)	21.5 (15–28)
Granivorous	3 (3–3)	4 (3–5)
Other	19 (14–24)	23 (18–28)
Total	44 (34–54)	48.5 (36–61)

which suggests that the change from 4-in-2 to 5-in-2 had little effect on the overall avian diversity during the survey period.

These field results provide useful insight into the likely response of the avian fauna to the adoption of an intensified cropping system in the Philippines. If such intensification of rice cropping was adopted nationwide, then we predict a reduction of water bird populations but a substantial increase in the number of Eurasian tree sparrows. This, in turn, would require an increased need for measures to control Eurasian sparrow populations in 5-in-2 rice-cropping systems. The findings provide key insights into the potential major changes in avian biodiversity because of large-scale agricultural intensification and highlights the need for further studies to understand the long-term effects.

3.5 Rodents

3.5.1 Introduction

Rodents cause substantial losses to cereal production globally (Meerburg et al. 2009a) and are carriers of human diseases that have major health impacts in rural communities (Meerburg et al. 2009b). In Asia, losses caused by rats to rice production is a major economic burden to smallholder farmers (John 2014) and can lead to severe impacts on food security in years when regions encounter severe population outbreaks of rodents (Singleton et al. 2010; Htwe et al. 2013).

The pest species of rats and mice belong to the order Rodentia. Hence the term "rodents." There are approximately 2,552 species of rodents, which constitute about 40% of known mammal species (Burgin et al. 2018). Rodents therefore play a crucial role at an ecosystem level (see Dickman 1999). Widespread use of poisons to control pest species of rodents in agricultural systems do not discriminate between pest and non-pest rodents. The positive ecosystem services provided by the latter can therefore be severely diluted. This is of major concern given that less than 10% of rodent species cause significant negative impacts to rice and other cereals in Asia, Africa, and other continents (Singleton et al. 2007). We need to take positive efforts to protect the other 90% of rodent species. In this section, we provide case studies of the potential benefits that native non-pest rodent species can provide to farmers in the Philippines.

Also, rodent pests have been identified as a key factor that can influence whether a farmer adopts certain best practices for rice production. As described in Chap. 4, the implementation by smallholder farmers of alternate wetting and drying (AWD) of their rice crop will substantially reduce methane gas emissions (Lampayan et al. 2015). Many farmers, however, are concerned that drying their crop mid-season will encourage rats to enter their crop and will lead to significant economic damage to their crop (Rica Flor, pers. comm.). We briefly summarize a study that examined whether famers in Indonesia and the Philippines have a legitimate concern of increased rodent damage associated with the adoption of AWD.

3.5.2 Case Study 1: Rodent Diversity in the Philippines

The Philippines is an oceanic archipelago that is recognized for its high rodent diversity and endemism with over 72 murid rodent species described (Heaney et al. 1998; Rickart et al. 2019). Of these, only six are considered pests. These are also non-native in origin and tend to thrive in habitats that have been heavily disturbed by humans, such as agricultural and urban habitats, whereas the native species live predominately in natural forest (Heaney et al. 2016). However, in diverse agricultural landscapes that are commonly found across the Philippines and include a mixture of habitats such as agroforest, grassland, riparian, rice and various other crops, both native and non-native rodent species coexist (Heaney et al. 2005; Stuart et al. 2008). On Luzon Island, these species commonly include the endemic non-pest species *Rattus everetti* (common Philippine forest rat) and *Chrotomys* spp. (striped shrew-rats) and the invasive pest species *Rattus tanezumi* and *Rattus exulans.*

Interactions of rodents with the ecosystem are diverse, often complex, and not always apparent. These interactions are often overlooked when applying control measures against rodent pests. To better understand the ecology of the native rodents in complex rice-based agricultural landscapes of the Philippines, two studies were conducted—one in the upland rice-based agroecosystems in the Ifugao Rice Terraces (IRT), northern Luzon (Stuart et al. 2007) and another in the lowland rice-based agroecosystems of the Sierra Madre Biodiversity Corridor (SMBC), northern Luzon (Stuart et al. 2008). In both studies, *Chrotomys* spp. were trapped within rice fields. Stomach-content analysis and spool-and-line tracking provided evidence to support previous suggestions that they prey on golden apple snails (*Pomacea* spp.), a major invasive pest of young rice seedlings. In addition, in the IRT, *Chrotomys* spp. were confirmed to feed on large non-native earthworms (*Pheretima* spp.), another major pest that causes water seepage and erosion due to their deep-burrowing activities through rice terrace walls (Joshi et al. 2004).

In both the upland and lowland sites, another native species, *R. everetti*, was trapped in high numbers in the forest and agroforest habitats adjacent—or in close proximity—to rice fields, but few were trapped in coconut groves or rice fields. On the other hand, the abundance of *R. tanezumi*, a non-native pest species, was substantially lower in forest and agroforest habitats than in the more disturbed rice field and coconut-grove habitats. Due to the close proximity of agroforests to rice fields and their similarity in habitat complexity to coconut groves, the findings suggest that *R. everetti* may inhibit *R. tanezumi* from establishing in forest and agroforest habitats.

To further examine this, we conducted a 6-month experiment that involved monthly trapping and removal of *R. everetti* individuals from two replicate agroforest grid sites over a 3-month period to study the effects on the *R. tanezumi* population ecology and habitat use (Stuart et al. 2016). The findings from this study indicated that *R. everetti* has a negative effect on the reproductive activity and survival of *R. tanezumi* and influences the microhabitat use of *R. tanezumi* through interference competition with the larger *R. everetti* competitively dominant over *R. tanezumi*. In addition, there was a significant difference in the use of canopy cover between these two species irrespective of the treatment. *R. everetti* selected a microhabitat with denser canopy whereas *R. tanezumi* selected a microhabitat with less canopy cover, which is indicative of a severely disturbed habitat with few trees.

3.5.2.1 Key Findings and Conclusion

The native species of rodents on Luzon Island, Philippines, provide important beneficial ecosystem services to rice-field ecosystems.

3.5.3 Case Study 2: Does AWD Increase the Risk of Rodent Losses?

Rice farmers in Vietnam (Rica Flor, pers. comm.) and the Philippines (Richard Smedley pers. comm.) expressed concern that intermittent drying of the fields will attract more rats to growing rice, thereby causing more damage to the crop. However, spatially and temporally replicated damage assessments done on AWD and control fields in Indonesia and the Philippines demonstrate that rodent-pest damage levels on standing rice crops were not affected by the water management scheme employed (Lorica et al. 2020). AWD assists the rice plant as it grows, as previous studies from Gambia, India, Thailand, and China indicate (Ceesay 2004; Gani et al. 2002; Mishra and Salokhe 2011; Pan et al. 2017), which may translate to better compensation in the event of rodent-pest depredation.

AWD also had no significant effect on the breeding performance and population dynamics of *Rattus argentiventer* in Indonesia and *R. tanezumi* in the Philippines (Lorica et al. 2020). Breeding of *R. argentiventer* is synchronized with the growth stages of rice (Brown et al. 1999; Jacob et al. 2003; Leung et al. 1999; Tristiani et al.

1998), while available resources dictate breeding by *R. tanezumi* (Htwe et al. 2012). Likewise, rodent activity and movement, examined using spool-and-line tracking, was not influenced by water level (Lorica et al. 2020). Both species tended to use the rice paddies over bunds regardless of water level indicating that something other than water affects their habitat use. We conclude that perceived risk of predation, not water, influences habitat use (Jones et al. 2017).

In the Philippines, a post-project survey of knowledge, attitudes, and practices (KAP) of farmers indicated that there was a significant shift from the pre-project belief that intermittent irrigation will attract more rats into the rice fields (Lorica 2019). After the farmers were presented with the findings of the study, they were less hesitant to implement AWD because of concerns that rats would be more active in their rice crops when water levels were low.

3.5.3.1 Key Findings and Conclusion

The population ecology, behavioral, and social science research on rodents and AWD generated encouraging outcomes given how important the application of AWD, or at least one mid-season drainage of rice fields, is to a substantial reduction of greenhouse gas emissions during the growing season of rice (Lampayan et al. 2015). In summary, the analyses of the population dynamics and spatial use of rodents indicate that AWD is not likely to increase rodent damage to the growing rice crop. In addition, pre- and post-social surveys indicate that farmers are prepared to change their beliefs on rodents and AWD when presented with field findings.

3.6 A Way Forward

Rice fields have the potential to support biodiversity across biological scales. From a conservation standpoint, rice fields should be managed in a way that supports biodiversity within these agricultural systems. The ecosystem services provided by species which inhabit rice field ecosystems, across many trophic levels, may provide feedback and support to the farming stakeholders to help promote and sustain biodiversity. Overall, the adoption of ecosystem service-promoting rice agricultural practices may benefit farmers and other stakeholders and improve rice-field biodiversity.

To maximize the role of rice landscapes in supporting biological diversity and maintaining thriving wetland habitats, we outline four key areas that future research and development projects should address: (1) build capacity of countries to scale-up use of proven practices that reduce rice farming's ecological footprint and conserve biodiversity, (2) increase investment in biodiversity research in rice production landscapes, (3) promote "Green Rice Value Chains" and "Agri-input Markets," and (4) monitor and evaluate the ecological benefits to biodiversity of broadscale promotion of sustainable rice production.

Smallholder farmers often lack access to knowledge and training on sustainable management and best management practices, which remains a major bottleneck to achieving wide-scale adoption. As highlighted in this chapter, the CORIGAP program has validated many solutions that can reduce agrochemical use in rice production and, in turn, maintain rice landscapes' capacity to sustain life. Such solutions, which include agroecological practices, such as rice-fish culture, ecological engineering, Integrated Pest Management (IPM), site-specific nutrient management, and conservation agriculture, deliver the same or higher yields as unsustainable practices prevalent across tropical Asia (Stuart et al. 2018a, b; Hung et al. 2022). CORIGAP has also demonstrated that, provided the right enabling conditions are put in place, smallholder farmers are able to adopt best management practices at scale (Flor et al. 2021). CORIGAP countries have been particularly successful in deploying best management practices through enacting enabling policies, building local extension system capacity, and establishing public–private sector learning alliances (Flor et al. 2017). CORIGAP countries have also benefited through developing integrated best management practice capacity development packages, which promote a combination of practices and technologies as a combined system. This enterprise has helped to maximize benefits to farmers and increased adoption rates in comparison with traditional development programs that have often focused on promoting a single practice or technology in isolation (Flor et al. 2021). Future research and development programs should build on the lessons learned from CORIGAP and continue to invest in sharing knowledge and building capacity to deploy sustainable best management practices across Asia.

In addition to boosting capacity-building programs and biodiversity-research investment, CORIGAP countries should also aim to leverage markets and create enabling conditions that incentivize the adoption of sustainable practices. Countries can review, phase out, and remove public programs that encourage rice production practices that are harmful to biodiversity. Rice is currently a major recipient of Asian agriculture subsidies and accounts for 15% of fertilizer and 35% of freshwater use globally. Some CORIGAP countries are already greening their public subsidy programs, resulting in significant positive impact. For example, in Guangdong province, China, the provision of subsidized agricultural inputs to rice farmers is now linked to their adoption of sustainable management technologies, known locally as "Three Controls" technology. Over 320,000 rice farmers have reduced fertilizer and pesticide use, while increasing yields by up to 10% (Xuhua Zhong, pers. comm.; Chapter 2 of this book). Policymakers can expand such reforms to subsidies and eliminate harmful subsidies wherever possible.

CORIGAP countries can also review regulations for their agri-input markets to accelerate registration of safer alternatives for pest management, phase out highly hazardous pesticides that are detrimental to biodiversity, and increase investment in manufacturing capacity for biopesticides and biofertilizers. These changes would benefit agriculture as a whole and enhance the capacity of rice landscapes to sustain life. Countries can also work with the private sector to apply sustainability standards, such as the Sustainable Rice Platform (SRP) Standard, which explicitly includes requirements to maintain biodiversity. CORIGAP-supported research has shown that urban consumers in Asian countries, such as Vietnam, are increasingly aware of the importance of sustainability and are willing to pay a premium for sustainably sourced rice (My et al. 2018). The SRP standard can embed sustainability across rice value chains and deliver sustainably certified rice products to consumers. Asian countries may consider establishing SRP national chapters and partnering with supply chain actors to adopt the SRP standard.

Finally, we recommend that future research and development programs should invest in monitoring and evaluation (M&E) to fully quantify and understand the ecological benefits to biodiversity of broadscale promotion of sustainable rice production. Collection of data to quantify benefits at both the farm and the landscape level will be highly beneficial for a number of reasons. First, better data will allow agricultural scientists and ecologists to further enhance and improve the design of best management practices to minimize trade-offs between achieving food security and preserving biodiversity. Second, M&E systems will provide capacity-building programs with better evidence upon which to evaluate and continually enhance their programs. And finally, the data generated through M&E can also help to build the investment case and help to unlock greater amounts of sustainable finance and private-sector investment in sustainable rice landscapes.

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Chapter 4
Innovations, Technologies, and Management Practices for Sustainable Rice Production

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Abstract One of the major barriers to improving the rice value chain in Asian countries is farmers' lack of knowledge and their limited access to good and scale-appropriate technologies and practices. This chapter reviews the main features, benefits, and potential barriers of technologies and practices developed

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and promoted under the CORIGAP project. These include One-Must-Do, Five-Reductions (1M5R); ecologically-based pest management; laser land leveling; mechanized crop establishment; and sustainable postharvest management practices. 1M5R (1M = certified Seed, 5R = reductions of seed rate, fertilizer, pesticides, water use, and postharvest losses) was introduced in Vietnam in 2004 and adopted on about 150,000 ha of rice production in the Mekong River Delta (MRD) of Vietnam. Ecologically based pest management is important for the sustainable production of rice. We provide an overview of CORIGAP research on eco-engineering for the management of insect pests and the continued development of ecologically-based rodent management. Laser land leveling and mechanized crop establishment help to significantly increase agronomic use efficiency. Applying LLL, combined with best management practices in rice production in Thailand (CROP), has improved farmers' net income, increased nitrogen use efficiency, and reduced pesticide usage. Best postharvest management practices play an important role in upgrading the rice value chain tailored to sustainability. The chapter also includes lessons learned from case studies conducted in Southeast Asian countries, including Vietnam, Indonesia, Myanmar, and Thailand.

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Keywords Contract farming · 1Must Do, 5Reductions (1M5R) · Pest management · Mechanization · Harvest and postharvest management

4.1 Small-Farmers, Large-Field Model, Contract Farming, and One-Must-Do, Five-Reductions

4.1.1 Small Farmers, Large Field (SFLF)

The "Small-Farmers, Large-Field" model originated in a "Single-Variety Field" initiated by the Department of Agriculture and Rural Development in Can Tho, Vietnam, in 2004, to apply and promote good rice cultivation practices. The "Single-Variety Field" model was piloted with a field size of 50–100 ha, and best practices for seed rate, fertilizer use, and pest management were applied under the descriptor "Three Reductions, Three Gains" (3R3G). Another key feature was the use of certified rice seeds. The scaling out of 3R3G and hence SFLF began to be implemented during Phase 3 of the Irrigated Rice Research Consortium (IRRC) via the integration of technical agricultural knowledge and social science approaches relating to the use of mass media (Heong et al. 2010). In 2009, during the last phase of the IRRC, best practices to reduce water use and postharvest losses were added to 3R3G. The new package was promoted as 1-Must-Do (certified seed) and 5-Reductions (reduce seed rates, fertilizer use, pesticide use, water use, and postharvest losses) (1M5R) and launched in An Giang province in the MRD.

The advantages of the SFLF program, such as land consolidation, uniform varieties, best rice-management farming practices, and synchronized crop calendar and management, resulted in cost reductions and yield increases for smallholder farmers (Rosellon 2015; Thang et al. 2017; Flor et al. 2021). On the other hand, it also encouraged enterprises to sign farming contracts with farmer groups in SFLF rather than individual farmers (Ba et al. 2019). The SFLF has been successfully adapted in other countries, such as India (Mohanty et al. 2018). SFLF covers two major farming practices that are "contract farming" created in 2002 (PM 2002) and "One-Must-Do, Five-Reductions" (1M5R) (Prime Ministerial Policy for Mekong Delta region of Vietnam 62/2013/QD-TTg, 25 October 2013; Flor et al. 2021).

4.1.2 Contract Farming

Vietnam's government enacted a decision to promote contract farming in 2002 (PM 2002). The decision consists of articles encouraging enterprises of all sectors to engage in contract farming, associating agricultural production with processing and consumption, ultimately promoting sustainable development. The decision gave details of the contract form, encouragement policies, and responsibilities of the

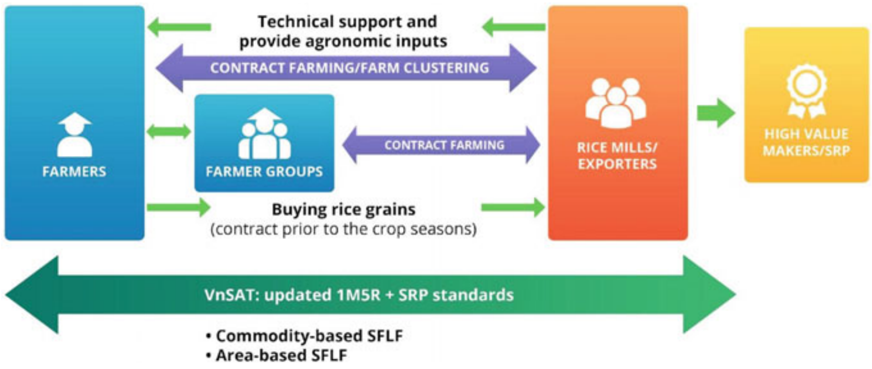

Fig. 4.1 A common rice-contract farming model that integrated the Small Farmers, Large Field Model (SFLF) in the Mekong River Delta

involved entities, and support from the government institutes. Contract farming was adopted in 63,000 ha in the MRD by 2020 (Flor et al. 2021). A typical contract farming model between enterprises and farmers is shown in Fig. 4.1 (Nguyen et al. 2020c).

4.1.3 One-Must-Do, Five-Reductions (1M5R)

As described above, 1M5R was leveraged from a previous good-practice package named "Three Reductions, Three Gains" (3R3G). In 2002, a pilot field was established in Can Tho province that encouraged farmers to work in groups and practice integrated pest management (IPM), reduce excessive use of agrochemicals, including seed rate and fertilizer and pesticide uses (3R) associated with increased rice yield, lower production cost, and higher income (3G) (Huan et al. 2005). In 2007, seed rate and seed quality were recognized as the key elements of 3R3G. During Phases 1 and 2 of CORIGAP, 1M5R, as a foundation for SFLF, was promoted in six provinces in the MRD. The 1M5R model became the main foundation of the SFLF development (MARD 2014; PM 2013). The 1M5R approach was ratified by the Ministry of Agriculture and Rural Development in 2013. Farmer groups had to demonstrate they were following 1M5R best practices to receive support under the Vietnam Sustainable Agricultural Transformation Project (VnSAT), a World Bank-funded initiative implemented in the MRD from 2017 to 2021 (see Flor et al. 2021) for details.

1M5R includes the following major criteria:

One-Must-Do: certified seeds:

The seeds are certified by MARD based on:

- Cleanliness: ~99%;
- Impurity from different varieties: ~0.3%;
- Weed seeds: no more than 10 weed seeds kg^{-1} seeds;

- Germination: ~80%;
- Moisture content on a wet basis: ~13.5%.

Due to the challenges of the availability of certified seeds, 1M5R accepts two levels of certified seeds as follows:

- Certified seed–level 1: certified by MARD, usually produced and supplied by the seed companies;
- Certified seed–level 2: The seeds were produced from registered or certified seeds and satisfied all the criteria of cleanliness, purity, limited weed seeds, germination rate, and moisture content. All these criteria are verified by a standard seed-testing agency (eligibility certified by MARD). This type of seed is usually produced and supplied by farmer organizations, i.e., farmer groups and cooperatives.

Five-Reductions: seed rate, fertilizer use, pesticide use, water use, and postharvest losses (Fig. 4.2).

1. Seed rate: not higher than 100 kg ha^{-1}. This is dependent on crop establishment (CE) methods. In current practices in the MRD, transplanting uses <60 kg while broadcast seeding, which is a common practice in the MRD (applied across more than 60% of the rice production area) uses >150 kg ha^{-1}. To be realistic and to encourage farmers to meet this criterion, the 1M5R was updated in 2020 to set the acceptable seed rate at 120 kg ha^{-1} (Flor et al. 2021).
2. Fertilizer use is set for Nitrogen (N), at not higher than 100 kg ha^{-1}.
3. Pesticide use is set for insecticides and fungicides based on the maximum applications per season (1 and 2, respectively) and the period when to apply pesticides. The latter includes no application of insecticide within 40 days after sowing and no application of fungicide after flowering of the rice crop.
4. Water use: the best practice is alternate wetting and drying (AWD)—see Lampayan et al. (2015) for details. However, to be realistic for MRD conditions, this criterion required at least one or two drainages mid-season (re-irrigating before the subsoil water level reaches 15 cm) during the wet and dry seasons, respectively.
5. Postharvest losses: The focus is on optimal harvesting using combine harvesters and the timing of the rice harvest.

There are various solutions to support 1M5R, such as mechanization, precision farming, digital agriculture, etc. Most of these approaches are described in the following sections.

4.1.3.1 Benefits of 1M5R

The benefits and adoption of 1M5R have been captured in CORIGAP studies. Applying 1M5R in the MRD can improve farmers' benefits by increasing net income by 19% while cutting costs by 23% (Chi et al. 2013; Stuart et al. 2018). An impressive number of smallholder farmers have shifted from conventional to 1M5R practices

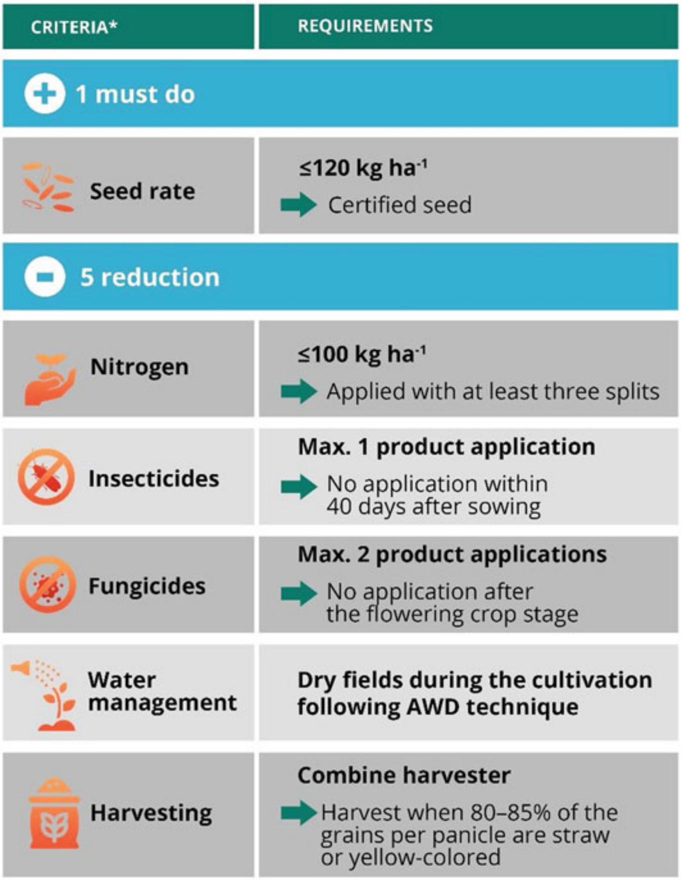

Fig. 4.2 Requirements of 1M5R

covering at least 113,870 ha (Flor et al. 2021). Reduction of postharvest losses by using combine harvesters was the most adopted practice (>99% of farmers), followed by reducing seed rate (85.6%), with reducing water use being the least adopted of the technologies (45.4%) (Connor et al. 2021).

Approximately 37% of farmers, from a cross-section of farmers interviewed in An Giang and Can Tho provinces in the MRD, adopted all six requirements, which doubled from 16% reported in 2011 (Connor et al. 2021). This successful adoption and qualification of 1M5R were significantly supported by AWD and mechanization. With the application of 1M5R and mechanized transplanting, farmers can reduce inputs while having no reduction in yield and profit increased by 7–20% or 600–1,000 USD ha^{-1} season^{-1} more than other farmers (Nguyen et al. 2020c). Despite the clear benefits of adopting 1M5R, some farmers are still reluctant to adopt some practices for various reasons, including lack of technical equipment, e.g., seeding machines and laser land leveling machines, lack of access to certified seed, concerns over possible pest outbreaks or extreme weather events, and lack of access to a reliable source of irrigation water or drainage (Tuan et al. 2021).

4.2 Ecologically-Based Pest Management

Chapter 3 introduced and explained the ecological dimension of the CORIGAP project concentrating on faunal biodiversity in rice-dominated wetlands. While CORIGAP predominately focused on introducing best management practices in the form of mechanization and improved agronomic methods, in the last phase of CORIGAP, the project also designed pathways for an agroecological transition toward sustainable food systems. Food-system sustainability is a complex issue, combining sustainable production and consumption with agroecological practices being one avenue to improve food system sustainability in low- and middle-income countries (Ng'endo and Connor 2022). In this section, we will provide an overview of progress during CORIGAP of two sustainable pest management approaches: ecological engineering (EE) to manage insect pests and ecologically-based rodent management (EBRM) to manage mice and rats. The two approaches urgently require greater attention in intensive rice-growing systems (Sattler et al. 2021; Singleton et al. 2021).

4.2.1 Ecological Engineering

Ecological engineering is defined as the design of sustainable ecosystems, in this case, sustainable rice agroecosystems that integrate human society, i.e., rice farmers with their natural environment, to benefit both (Mitsch 2012). In the context of pest management in rice ecosystems, one of the avenues for ecological engineering is to increase landscape and habitat diversity to support natural pest regulation and lessen the need for pesticide inputs (Gurr et al. 2017; Sattler et al. 2021). Over the last decades, rice production in Southeast Asia has intensified drastically, as has agrochemical inputs, especially fertilizers, and pesticides (Sattler et al. 2018). The overuse of pesticides has been associated with biodiversity loss in rice-growing areas (Peng et al. 2009). Therefore, a variety of approaches have been designed to counteract farmers' overuse of pesticides to enhance beneficial arthropod populations in rice fields. EE by which farmers plant additional flowering plants in rice bunds, i.e., small dikes surrounding rice fields to keep the water level in the field, has been shown to be a promising method. Sattler et al. (2021) found that withholding pesticide use did not decrease yields in either EE treatment or control plots. However, parasitoid abundance was higher in both treatments during the wet season. The authors concluded that pesticide use is likely the main driver causing low arthropod abundance. The study used an experimental design consisting of a multi-method approach based on feedback from farmers on the preferred types of plants that they either cultivate or collect for consumption. In order to be suitable for inclusion in the EE experiment, these plants had to meet several criteria, such as that the plants could grow on rice bunds, had flowers that could potentially provide additional food sources for insect species (flowering plants), and have a growth duration that was shorter or equal to that of the rice crop (annual plants). The experiment used a treatment–control design described in detail by Sattler et al. (2021). This case study will focus on a side experiment during the 2019 wet season from July to October in a lowland rice ecosystem in Prey Veng province. The aim of this case study was to identify which insect species were present the rice bunds that are the focus of EE habitat modification and which four functional groups they belonged to, i.e., detritivore, parasitoid, pollinator, and predator.

The experiment used sponge gourd (*Luffa aegyptiaca* MILL.) and chili (*Capsicum annuum* L.), which were the preferred plants by the interviewed farmers in addition to mung bean (*Vigna radiata* (L.) R. WILCZEK) and sesame plants (*Sesamum indicum* L.) that have been shown to have positive effects on insect natural enemies (Gurr et al. 2016; Horgan et al. 2019). The EE fields, which had additional crop plants on bunds, were not treated with pesticides and were compared to fields where farmers usual practice (FP) were applied. In the FP fields, rice crops were treated with pesticides and had no vegetables growing on their bunds. Other growing practices, such as fertilization, rice cultivar, and water management were the same in both fields. Three rice fields were selected, each serving as a replicate for each treatment. Fields were located at least 100 m away from one another to account for a buffer zone. The bund plants were planted after the rice crop had been established to ensure growth duration was parallel for the rice and vegetable crops. The two vegetable crops were planted alternately on each side of the bund (as shown in Fig. 4.3). In total, there were six sampling sites, of which three sites were for EE, and another three sites were for FP.

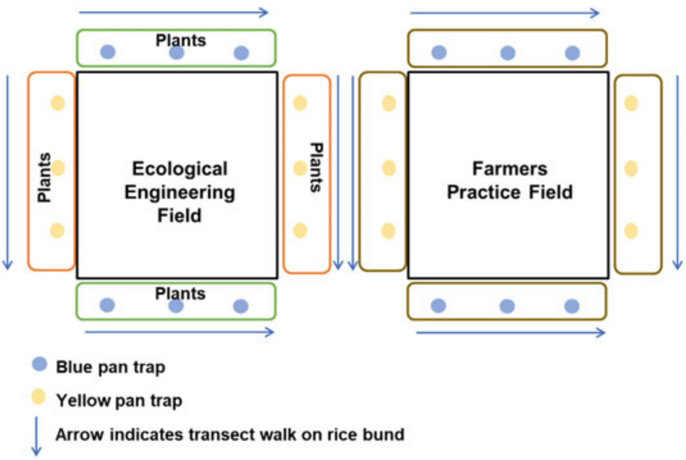

Fig. 4.3 Layout for one replicate of the ecological engineering (EE) experiment. Pan traps were placed at sampling points on the bunds both in EE and farmer practice (FP) fields

To investigate insects visiting the selected plants in the rice bunds, pan traps were used in the color of the selected plant flowers. The bunds around the EE and FP fields were used as transects for placing the pan traps. Three pan traps were placed on each bund of a field. No traps were placed on the corners because this would conflate data as there were different vegetable crops on each side of the fields (Fig. 4.3). This meant a total of 40 sampling points covering all EE and FP sites. To capture the insects in the pan traps, the trap contained a mixture of 150 ml of water, detergent, and fungicides. Sampling was conducted starting at the flowering stage of the vegetable crop. The pan traps were left in the field for 48 h. Insects collected were stored in vials containing 80% ethanol. The collected insects were identified to the family level and assigned to their functional group. Functional groups were compared between EE and FP fields applying linear models.

In total, 3,252 specimens were collected in the pan traps. Some 2,033 specimens were collected in pan traps next to FP rice fields, and 1,219 specimens were collected in the pan traps next to EE fields. Samples were dominated by the detritivore dipteran family Phoridae and the predatory dipteran family Dolichopodidae. When comparing the functional groups between ecologically engineered and farmers' fields, we found significantly higher detritivores in FP than in EE treatments. No differences were found between the two treatments for the abundance of predators, parasitoids, and pollinators (Fig. 4.4). Noticeable was that some taxa such as the detritivore fly Phoridae, parasitoid fly Pipunculidae, the parasitoid wasp Scelionidae, and the predatory fly Dolichopodidae were twice as abundant in pan traps located on the bunds of the FP fields (as compared to those retrieved from the EE fields).

Results from the EE experiment showed no differences in the abundance of natural enemies and pollinators between farmers' practice (FP) and EE field. A number of possible explanations arise: insects may be attracted by the pan trap color regardless

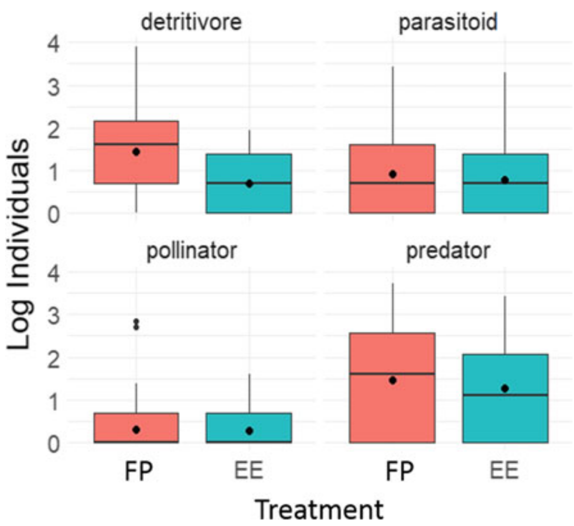

Fig. 4.4 Functional groups collected in pan traps next to farmers' rice fields (FP) and ecologically engineered rice fields (EE)

of whether vegetable crops were on the bunds; the experiment might have been too short for vegetation growing on rice bunds to provide maximum advantage for beneficial insects; and finally, the landscape structure might be too homogenous to generate significant differences at field level (Gurr et al. 2012). This could also explain why single taxa occurred in higher numbers next to FP fields compared to pan traps next to EE fields. Furthermore, the experiment might have been too short for vegetation growing on rice bunds to provide a maximum advantage for beneficial insects. Results of an experiment using string beans on rice bunds also showed a similar trend of no difference in natural enemies on the bunds sampled of EE fields versus control (Horgan et al. 2017).

Nevertheless, the connected study by Sattler et al. (2021) showed that EE did not reduce rice yields despite withholding pesticides. Indeed, the study indicated that the absence of pesticide use on EE fields contributed to increased abundance of parasitoid fauna compared to conventional practice at least in wet season. These results indicate that omitting pesticides does not negatively influence rice yields and that applying EE farmers have a better cost–benefit ratio. Farmers save costs for pesticide and labor use. Furthermore, farmers can either earn additional income from crop plants on the bunds or use them for their own household consumption and are able to diversify their food intake. Applying EE is a useful method to reduce pesticide applications without reducing rice yields. Cultivating a variety of other crop plants on the otherwise barren bunds will increase floral biodiversity and may reduce negative impacts on faunal biodiversity. However, it must be noted that using color pan traps alone to assess arthropod biodiversity may not be sufficient and other methods, such as net sweeping or blow-vac suction, should also be used.

4.2.2 Ecologically-Based Rodent Management

The concept of EBRM was developed in the late 1990s (Singleton 1997; Singleton et al. 1999) primarily from research on the management of house mice, *Mus domesticus*, in Australian wheat fields and rice field rats, *Rattus argentiventer*, in lowland irrigated rice in Indonesia and Vietnam (Singleton et al. 2007). EBRM was subsequently adopted as a national policy for the management of rats in rice crops in Vietnam in 1999 and Indonesia in 2002. In Myanmar, activities on rodent population ecology and management under CORIGAP led to adopting EBRM as a national policy in 2015–2016.

During the CORIGAP project, the international profile of EBRM was raised internationally via multiple conference presentations, peer-reviewed publications, and media coverage. The adoption of EBRM is currently documented to be the main approach for managing rodent problems in agricultural systems in 37 countries (G.R. Singleton, unpublished data, Table 4.1). Some of the key research activities on EBRM under CORIGAP include:

Table 4.1 Adoption of ecologically-based rodent management (EBRM) globally as of January 2023

Region	Countries implementing EBRM
Asia	Indonesia, Vietnam, Philippines, Laos, China, Cambodia, Myanmar, Bangladesh, Pakistan, Thailand
Australasia and the Pacific	Australia, New Zealand, Samoa, Solomon Islands, Fiji, Vanuatu
Europe	Belgium, Germany, England, Scotland, Ireland, The Netherlands, Denmark, Finland, Norway
Africa	Tanzania, South Africa, Swaziland, Namibia, Ethiopia, Mozambique, Sierra Leone, Zambia
The Americas	The USA, Canada, Mexico, Argentina

- research on postharvest losses in grain stores in Myanmar (Htwe et al. 2017) and Sri Lanka (Htwe et al. 2021);
- a detailed replicated experimental study on rodent-weed interactions and their associated impacts on rice crops (Htwe et al. 2019);
- the interactions between habitat use of rodents and the use of AWD of lowland irrigated rice crops (Lorica et al. 2020);
- the effectiveness of the contraceptive hormones quinestrol and levonorgestrel, on the fertility of the rice field rat (*R. argentiventer*) in Indonesia (Stuart et al. 2022); and
- the effectiveness of community-based management of rodents in lowland irrigated rice in Cambodia (dominant rodents were *R. argentiventer* and the *R. rattus* complex of species) (Stuart et al. 2020).

A major review of the progress of EBRM in Asia covers the key findings from these studies (Singleton et al. 2021).

An additional major impact of EBRM has been reported in the tidal rice systems of South Sumatra. Rodent and weed pests restricted rice to be planted on only 30 ha in the dry season of 2012. In 2013, a successful demonstration of EBRM and weed management was established for the dry-season crop (Sudarmaji, pers. comm.). In 2014, 300 ha of dry-season rice was grown successfully. This led to strong financial support from the provincial government for establishing EBRM, particularly using a trap-barrier system (see Singleton et al. 2003). In 2015, there were 17,000 ha of dry-season rice grown, increasing to 93,500 ha in 2016 (Budi Raharjo pers. comm.; Singleton and Quilloy 2017).

The progress of EBRM internationally since 2010 has been impressive. Research supported by CORIGAP has been a key driver of the increased adoption and parallel activities across several projects in southern and eastern Africa (see Swanepoel et al. 2017). Together, these studies in Asia and Africa have led to a marked reduction in the use of rodenticides and an increase in yields and profit for smallholder farmers (Singleton et al. 2021; Makundi and Massawe 2011).

Further progress is required because rodents remain a major economic burden on smallholder farmers (John 2014). Some of the key challenges ahead include the following.

- There remains a paucity of knowledge on the biology of most species of rodents in developing countries.
- Long-term data must be collected, especially in upland rice-based systems where sporadic population outbreaks occur. Such data are required to develop forecasts of what are often massive rodent outbreaks that have major food security impacts at a local level (Singleton et al. 2010).
- Better estimates of losses caused by rodents in fields and in grain stores to enable rigorous economic analyses of the cost and benefit of EBRM (see Ngoc et al. 2016).
- In Southeast Asia, the mean rice holding of a family is 1–1.5 ha. Rodents do not respect the borders of fields. Hence, community action is the key to effective management. More sociological studies are required to recommend the most effective approach to coordinate community action given the specific context of cultural and farming systems.
- Quantitative data are urgently needed on the likely effects of climate change on rodent pest populations.
- Very little is known about the impact of rodent-borne diseases that affect humans in an agricultural context. We require quantitative data on the effects of rodent diseases on the rural livelihoods of smallholder farming communities.
- Finally, we need to provide more consideration on how rodent populations are likely to respond to changes in intensive production to meet increased food demands. Rodent experts need to be active in providing advice to policymakers on this issue.

4.3 Mechanization

Rice production in Asia and Africa has faced labor shortages and climate-change issues such as unanticipated droughts and floods that cause unstable yields and a high risk of crop losses. Low farming efficiencies (high energy and labor costs and agronomic input-use) are mainly caused by poor land consolidation, lack of precision land leveling, crop establishment, and crop care. Laser land leveling (LLL) and mechanized crop establishment help to significantly increase agronomic use efficiency.

4.3.1 Laser Land Leveling

Small-sized and uneven fields can cause poor management and low efficiency of agronomic inputs. Poor field leveling can cause difficulty in crop establishment

Fig. 4.5 **a** Difficulty in crop management, **b** Poor water management, **c** Crop lodging, and **d** High harvest and postharvest losses caused by crop lodging and poor water management

(Fig. 4.5a), adverse water management (Fig. 4.5b), and crop lodging at maturity (Fig. 4.5c). Lodging of rice plants and non-uniform growth of the rice paddy at the maturity stage leads to high postharvest losses (Fig. 4.5d).

LLL is used for precision land reformation in rice cultivation to optimize water and crop management. It increases yield and input-use efficiency of water, energy, and agronomic inputs. A laser-controlled leveling system is shown in Fig. 4.6a, b. Assisted by a laser controlling system, this technology can reduce the unevenness of the field surface to a 1–2 cm height difference, even in a large field of 3 ha. In this case, the field slope can be set to 0.02% for draining the field.

4.3.1.1 Benefits of LLL

Several studies reported this technology's benefits (Nguyen et al. 2022a; Jat et al. 2015). This application can help to increase land use efficiency by 3–6% when consolidating several small fields into one large field, save irrigation water by 20–40%, increase fertilizer and pesticide-use efficiencies by 10–13%, and increase rice yield by 10–13%. The benefits of LLL are summarized in Table 4.2.

LLL is applied to reform the field in dry-soil conditions. It is best practice to conduct laser leveling once every five years (Nguyen et al. 2022a). The benefits of

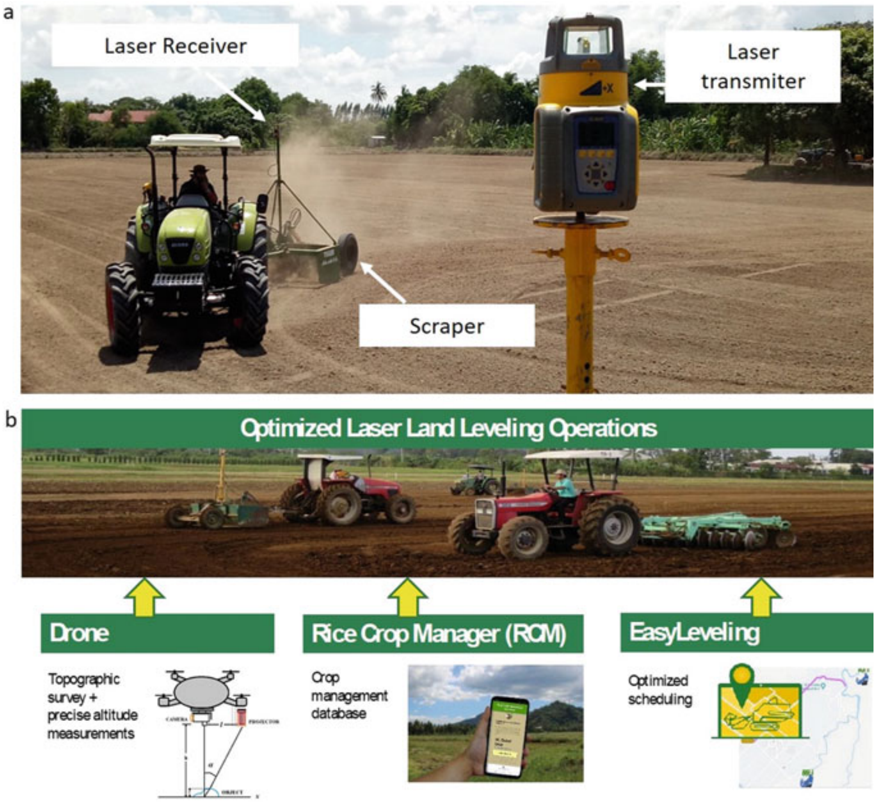

Fig. 4.6 Laser land leveling system (**a**) and drone and digital tools supporting laser leveling (**b**)

LLL are affected by many factors, such as soil conditions, equipment quality, operation of the technology, etc. As presented in Nguyen et al. (2022a), LLL can increase energy efficiency by at least 27% and reduce carbon footprint by at least 14% in rice production. Furthermore, precision land leveling enables the consolidation of small fields into larger ones by reducing the slopes of land incline and unevenness. Well-leveled fields are critical for mechanized crop establishments such as mechanized transplanting and direct seeding, which can increase farming efficiency and reduce the rice carbon footprint (Nguyen et al. 2022b).

On the other hand, there are challenges in promoting LLL, such as high cost, lack of service availability, and lack of scale-appropriate technology adoption interventions. LLL can be more effective if integrated with other supporting technologies, such as drones for field topographic surveys (Anguiano-Morales et al. 2018) and optimized scheduling of service providers (IRRI 2020). The LLL technology was promoted in the MRD, Vietnam, and the central plains of Thailand during the CORIGAP project.

Table 4.2 Benefits of Laser Land Leveling (LLL); adapted from Nguyen et al. (2022a)

Production factors	Benefits (%)			
	Secondary data	Primary data (Vietnam)[e]	Selected benchmark for analysis	Factors resulting in benefits
Increased land use efficiency	3–6[a,b,c]	2–5	2	Land consolidation (bund removal or enlarged field size)
Reduced water use	10–40[a,b,c,d]	18–50	10	Enable optimized water management (less pumping)
Reduced seed	30–50[b,c,d,e]	27–46	27	Avoid the practice that farmers use high seed rate for the unleveled field to compensate for seed and seedling loss
Reduced Fertilizer	10–13[a,b,c,d]	10–20	10	As a consequence of the lower seed rate
Increased yield	5–15[a,b,c,d]	3–25	3	More uniform, better grain quality
Decrease in postharvest losses	2–5[b,c,d]	5–10	2	Reduce the risk of lodging causing harvest and postharvest losses

a = RKB (2017), b = Jat et al. (2009), c = Jat et al. (2015), and d = Phan-Hieu-Hien et al. (2014)
[e]Key performance interviews of 18 farmers in Vietnam in 2020

4.3.2 *Mechanized Crop Establishment*

Scale-appropriate and site-specific precision sowing options, including mechanized direct seeding and mechanized transplanting, can help increase seeding precision, vigor of seedlings, and yield. Compared with broadcast-seeding practices such as manual broadcast, blower, and drone seeding, these practices also reduce seed rate, fertilizer and pesticide use, water use, and carbon footprint.

4.3.2.1 Mechanized Transplanting

Transplanting rice is a process of planting young rice seedlings either manually or using a machine. Manual transplanting is a traditional practice requiring about 100–200 labor hours per ha (Quilty et al. 2014; Nguyen et al. 2019) and almost the same labor for producing seedlings. Moving from manual to mechanized transplanting has been happening in the MRD, particularly for seed production, due to its advantages of increased yield, reduced risks of pests and diseases, reduced postharvest losses, and better conditions for rogueing in seed production. Mechanized transplanting employs two separate operations: seedling production (Fig. 4.7a, b) and transplanting

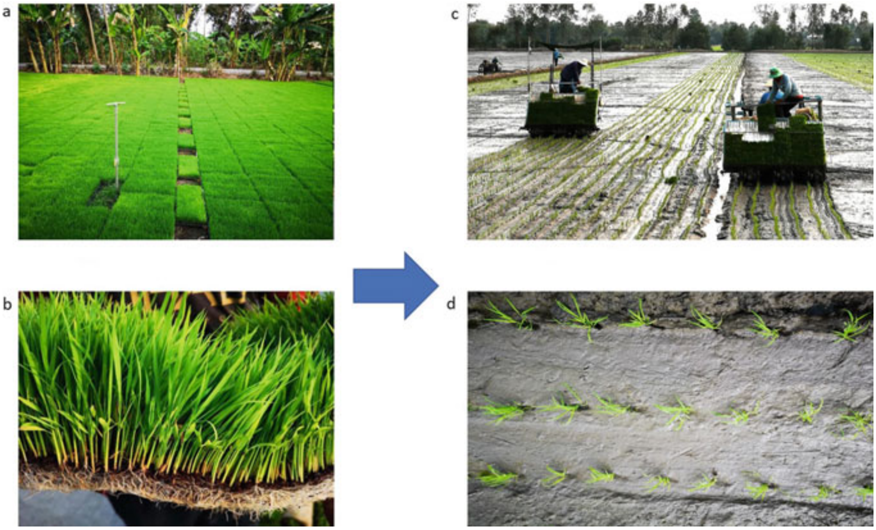

Fig. 4.7 Two major steps of mechanized transplanting—seedling production and transplanting. **a** Seedling growing, **b** Seedling ready for transplanting, **c** Mechanized transplanting, and **d** Transplanted seedlings

(Fig. 4.7c, d). The use of machines for both operations is discussed in a training manual developed during the CORIGAP project (Nguyen et al. 2020a, b).

The benefits of mechanized transplanting were captured via a case study in the MRD of Vietnam conducted under the CORIGAP project (Nguyen et al. 2022a). Compared to the broadcast-seeding method, mechanized transplanting has the following advantages:

- Reduced seed rates (40–60%): A lower seed rate is achieved with transplanted rice as it can be properly controlled and managed during the raising of seedlings in the nursery and through the regular spacing of seedlings when transplanted.
- Lower risk of seeds being eaten in the field by birds and rats.
- Better weed control. Rice seedlings have a head start compared to the weeds in the field, so weeds will be a lesser problem. This is further supported by the proper leveling of the land. Weeds can easily be controlled with better water management when the field is well-leveled.
- Allows deeper anchoring of roots into the soil, thus, lodging is less likely throughout the growth of the crop, and this leads to a postharvest loss reduction of about 5–10%.
- Rogueing in seed production is easier in transplanted rice.

When labor is limited and expensive, using machines for transplanting is more advantageous. Around 20–30 persons are needed for the manual transplanting of rice to cover 1 ha day^{-1} compared to mechanical transplanting, which would only need two or three operators to accomplish transplanting 1–2 ha day^{-1}. Advantages that can be derived from the use of a mechanical transplanter in establishing rice in the field are:

- Efficient use of resources by saving labor costs;
- Timely transplanting of seedlings at optimal age;
- Reduced transplanting shock;
- Ensured uniform spacing and optimum plant density (26–28 hills m^{-2});
- Higher yield compared to the traditional method (e.g., manual broadcasting);
- Lower drudgery and health risks for farm laborers; and
- Improved employment and entrepreneurship opportunities for rural youth and women through custom service provision.

4.3.2.2 Mechanized Direct Seeding

Direct-seeded rice (DSR), especially wet seeding, is a common practice in Asian countries to respond to labor-, water-, and energy-intensive problems (Kumar and Ladha 2011). Of these, manual broadcast seeding and blower seeding are widely adopted (Nguyen et al. 2022b). These broadcast-seeding practices use a high seed rate, usually higher than 150 kg ha^{-1}, due to its non-uniform seeding. Therefore, mechanized direct seeding (mDSR) for more precise seeding has been promoted to address the problems of broadcast seeding.

There are two main types of mDSR, including dry and wet seeding. Dry-mDSR is a mature technology recently adopted in several countries such as India, China, etc. (Kumar 2023). Responding to the demand and aligning with the development, mDSR has been introduced, tested, and promoted during the CORIGAP project in some SE Asian countries, including Cambodia, Sri Lanka, Thailand, the Philippines, and Vietnam (see Nguyen et al. 2022a). Some typical mDSR machines are shown in Fig. 4.8a, b.

On the other hand, the wet-mDSR is still at the adaptation stage, particularly for the high demand for wet irrigated rice in the MRD of Vietnam and Cambodia. The

Fig. 4.8 Mechanized dry seeding, **a** Mechanized dry seeding in India, **b** Rice seedlings at 15 days after mechanized dry-seeding

Fig. 4.9 Typical wet-mDSR machines being tested in the MRD **a** Line seeder, **b** Hill seeder, **c** Seedlings at 20 days after line seeding **d** seedlings at 20 days after hill seeding

major challenges for this practice are that it requires a well-leveled field and land preparation and the risk of seeding losses caused by unpredicted rain. Some typical wet-mDSR machines tested in the MRD of Vietnam are in Fig. 4.9a–d.

A case study under CORIGAP and the OneCGIAR Excellence in Agronomy Initiative (Kumar 2023) demonstrated the benefits advantages of mechanized wet-direct seeding for rice production in the MRD of Vietnam over the broadcast-seeding method. Compared to the broadcast-seeding method, mechanized transplanting has the following advantages:

- reduced seed rate by 2–3 times compared with broadcast seeding,
- seeding costs amounting to 1/3–1/2 of mechanized transplanting,
- reduced fertilizer use by 20–30% and reduced risk of pest and diseases,
- no yield penalty,
- reduced postharvest losses by decreasing risks of lodging and increasing grain quality and uniformity, and
- Less water use than transplanting (for seedlings).

However, compared to mechanized transplanting, mechanized DSR still needs to use herbicides for weed management (before seeding). In contrast, weeds can be controlled by water management after sowing by using stagnant water.

4.4 Harvest and Postharvest Management

Poor harvest and postharvest management cause high postharvest losses. More than 10% of grain produced is lost physically, and poor practices can markedly reduce grain quality (Gummert et al. 2018). Of these processes, harvesting, and drying are the major causes of both physical and quality losses. Recent research conducted under CORIGAP indicated that 70% of farmers who grow a pulse crop after their wet-season rice crop practice manual harvesting and stacking of the unthreshed rice in piles (field stacking) in the Ayeyarwady Delta. This can cause up to 40% physical loss and 7% discoloration, representing major quantity and quality losses (Gummert et al. 2020). CORIGAP's in-country collaboration with national partners and the private sector promoted the introduction of mechanical harvesting and/or mechanical threshing in the region to address this issue.

Sun drying losses average 2–5% and are mostly caused by improper handling and poor physical conditions for drying the rice (RKB 2013). In addition, both physical and quality losses can be severe due to delays in harvesting and poor logistics that delay drying, which are the major postharvest challenges in Vietnam. A delay in harvesting leads to over mature rice grains, which can cause shattering losses of more than 5%. Delays to wet paddy drying of more than 24 h can also lead to significant quality losses of up to 1% day^{-1} from discoloration, mold, and broken grains (RKB 2013). This section covers several mechanization and postharvest solutions tested and extended to local smallholder farmers to address the challenges and problems. The partnerships under the CORIGAP project between IRRI scientists and NARES country partners have produced major outcomes and benefits for postharvest management. In addition, LLL and mechanical transplanting have begun to gain favor in partner countries. Figure 4.10 shows a typical postharvest process and some solutions to support sustainable rice production. Optimized timing of harvesting and use of technology, plus improvements in paddy logistics, drying, storage, and milling management, significantly reduce postharvest losses and maintain grain quality.

4.4.1 Harvesting

Best practices for harvesting are mainly achieved through two criteria: optimal timing of harvest and best use of equipment available for harvesting the rice crop.

4.4.1.1 Timing of Harvesting

The timing of harvest is important to reduce losses in both quantity and quality. Grain losses in the field may occur from shattering, lodging, and pests such as birds, rodents, and insects. Premature or early harvesting will result in a higher percentage of unfilled or immature grains, which reduces the overall yield, increases grain breakage

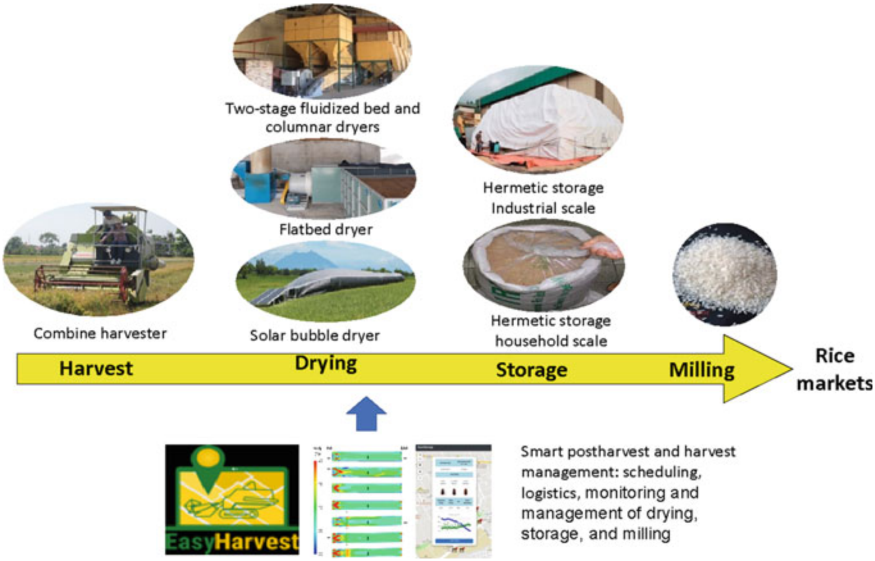

Fig. 4.10 Postharvest solutions to support sustainable rice value chains

during milling, and has a negative effect on seed quality. Late harvesting will result in increased physical losses in the field due to shattering, lodging, and birds and may decrease quality through weathering in the field and grain breakages at the mill. The timing of harvesting can also affect the germination potential of rice seeds. There are several ways to determine whether the crop is ready for harvest (SRP 2020). These include:

- Number of ripe grains per panicle: The crop should be cut when 80–85% of the grains are straw- or yellow-colored.
- Grain moisture: The proper grain moisture content for harvesting depends mainly on varieties and climate. Usually, the ideal grain moisture for harvesting is between 22 and 24%.
- Number of days after sowing: Generally, early duration varieties are ready for harvest 100–120 days after establishment, medium-duration varieties between 120 and 140 days after establishment, and long duration between 140 and 160 days. Transplanted crops will mature faster in the field than direct-seeded crops.
- Number of days after panicle initiation and flowering: The time taken from panicle initiation to ripening is similar for most rice crops. The optimum time of harvest is 55–60 days after panicle initiation or 30 days after flowering.
- Harvest management: The cutting time must be closely linked with threshing and drying capabilities. Threshing and drying should be done within 24 h of cutting. If cut panicles are left in stacks for more than 24 h, the grain will begin to heat up and discolor and increasing the risk of mold growth and losses to pests such as birds and rodents.

4.4.1.2 Technology Options

There are two practices commonly used for rice harvesting in South Asia (SA) and Southeast Asia (SEA): (1) manual cutting and mechanical threshing, and (2) combine harvesters. The first practice causes higher grain losses because of the delay in harvesting and transportation of rice plants between cutting and threshing. In some countries such as Myanmar, freshly cut rice plants are often stacked in the field to dry before threshing, which can cause up to 40% postharvest losses due to shattering, consumption by rodents, damage from insects and molds, and fissuring of grains and discoloration (Gummert et al. 2020). Hence, the second practice, combine harvesting, has been rapidly adopted in SA and SEA in response to the demand and avoiding the constraints of the first practice. A combine harvester allows for putting crop cutting, threshing, and cleaning in a one-pass operation (Figs. 4.11a, b). Grain is temporarily stored on board the combine before being discharged into a bulk wagon or into bags. Straw is discharged behind or to one side of the combine into a windrow. Some combines also have straw choppers and devices to spread the straw evenly. Proper use of combine harvesters can help to significantly reduce harvesting and postharvest losses by avoiding transportation losses between different stages of cutting and threshing and delay of harvesting.

4.4.2 Drying and Storage

Grain is hygroscopic and the final moisture content depends on the relative humidity of the surrounding air. This means that when the grain is in contact with high-humidity air, moisture content increases. This is a major problem in tropical areas during the rainy season when the relative humidity may reach 95–100%. Grains and seeds stored in tropical climates face the problems of discoloration or yellowing, molds, insects, and germination and vigor losses (for seeds).

Fig. 4.11 Small and big scale combine harvester **a** Small and medium scale combine harvester, lower than 2 ha per hour, **b** Big scale combine harvester, higher than 2 ha per hour

Drying is the process of reducing grain moisture content. Drying is the most critical operation after harvesting, and delays in drying or incomplete drying will reduce grain quality (quality loss) and quantity (physical loss). Drying and storage should be considered related processes and, in some instances, can be combined with in-store drying. Storage of high-moisture grain will reduce quality, irrespective of the storage facility.

Drying should begin as soon as possible after harvesting, as even short-term storage of high-moisture grain can cause quality deterioration. Ideally, drying should commence within 12–24 h after harvesting. For safe storage in a tropical country, paddy grains should be dried to reach a moisture content lower than 14%, while the moisture content of seeds should be lower than 12% (RKB 2013).

Here, we introduced several typical drying and storage technologies and good practices for paddy grains promoted by IRRI. Detailed information, such as the basics of drying, can be accessed at RKB (2013), and how to identify the best drying practices is presented in Nguyen et al. (2018).

4.4.2.1 Solar Bubble Dryer

The solar bubble dryer (SBD) (Fig. 4.12a), using only solar energy, was developed by IRRI, the University of Hohenheim, and GrainPro, Inc. This dryer has a capacity of 1-ton paddy grain with a drying time of about 16 h for the SEA climate. The SBD was further developed by IRRI for mushroom drying (Fig. 4.12b).

4.4.2.2 Flatbed Dryers

Figure 4.13a, b show two types of flatbed dryer widely used for paddy drying in SEA countries (Nguyen et al. 2018). Advantages of flatbed drying technology include low drying costs and suitability for both small and industrial scales. Drying costs, including machine depreciation, maintenance, labor, and energy, are about US\$6–12 t^{-1} of paddy grain dried.

4.4.2.3 Two-Stage Drying on Industrial Scale

A two-stage drying system, including a fluidized-bed and recirculating columnar dryers (Fig. 4.14), is suitable for industrial scale because it allows high capacity and mechanized and automatic operations. Wet paddy grain is dried by fluidized-bed dryers at the first stage, usually to reduce grain moisture content (MC) to 2–4%. In the second stage, the grain is dried for storage to an MC of 14%. Typically, a two-stage drying system with a fluidized-bed and 10 recirculating columnar dryers has a capacity of 300 t working day^{-1} (about 8 h). Its drying cost in SEA is about US\$5–10 t^{-1} of paddy grain dried.

Fig. 4.12 Types of dryers **a** Solar bubble dryer for paddy drying, **b** Solar bubble dryer for mushroom drying

4.4.2.4 Hermetically Sealed Storage

Sealed- or hermetic storage systems are very effective for controlling grain moisture content and insect activity for grain stored in tropical regions. By placing an airtight barrier between the grain and the outside atmosphere, the moisture content of the stored grain will remain the same as when the storage container was sealed. Respiration by the grain and insects reduces the oxygen level and increases CO_2, which, in turn, kills the insects. Hermetic systems can increase head rice recovery by 10% and double the viability of seeds.

Sealed-storage containers come in many shapes and sizes (Fig. 4.15). They may range from small plastic containers to more complex and costly sealed plastic commercial storage units with 1 to 1,000-t capacity per unit. Hermetic "Super bags" with 50 kg capacity are also commercially available and widely used.

Fig. 4.13 Flatbed dryer (**a**) and reversible air flatbed dryer (**b**)

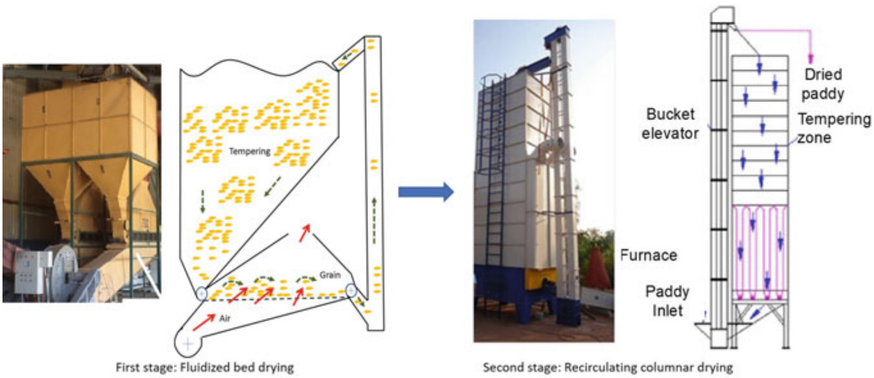

Fig. 4.14 Two-stage drying system at industrial scale

Fig. 4.15 Hermetic storage 50 kg bag (left) and industrial scale 300 t hermetic bag (right)

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Chapter 5
Carbon Footprint Reduction from Closing Rice Yield Gaps

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Abstract Rice production significantly contributes to greenhouse gas emissions (GHGE), especially methane (CH_4) emissions at various cropping stages. A major source of methane emissions is the decomposition of fertilizers and organic residues in flooded fields during the irrigation cycle. CORIGAP technologies and practices are mainly associated with closing yield gaps by increasing productivity and profitability but have been co-designed to address climatic challenges and to minimize negative environmental impacts. Therefore, over the last decade, the CORIGAP interventions not only helped to reduce yield gaps substantially but also resulted in a significant reduction of the carbon footprint (CF) in rice production. This chapter starts with an in-depth synthesis of scientific-based evidence and knowledge on challenges and constraints to reducing rice CF in CORIGAP countries. The chapter introduces solutions that have been proven to reduce GHGE, in particular, Alternate Wetting and Drying (AWD), rice-straw management, mechanization, and postharvest management. The latter two approaches include laser land leveling, mechanized direct seeding and transplanting, and paddy grain drying will be described in more detail. In addition, life cycle assessments will outline the quantification of the carbon footprint in rice production, for these specific technologies. The chapter presents three

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country case studies (Thailand, Indonesia, and Vietnam) from data collected through CORIGAP activities to estimate GHGE reductions associated with implementation of best practices for lowland irrigated rice production. Lastly, this chapter provides the outcomes related to GHGE reduction and offers specific recommendations that can be easily implemented in other countries.

Keywords Rice-carbon footprint · Greenhouse gas emission · Life cycle assessment · Vietnam · Alternate-wetting-and-drying

5.1 Challenges and Constraints Causing the Rice-Carbon Footprint in CORIGAP Countries

Rice is a staple cereal for half of the world's population (Sharif et al. 2014), but its production in flood-irrigated systems is one of the major sources of greenhouse gases (GHGs) responsible for 15.6% of the global GHG emissions (GHGE) (Laborde et al. 2021). The GHGs released in rice production are predominantly due to the continuous flooding condition (54.1%), inefficient fertilizer application (11.0%), and straw burning (13.5%) (Wassmann et al. 2021). Ahmed et al. (2020) suggested that the most effective methods to limit the carbon footprint of rice cultivation would include shifting from transplanting to dry direct seeding and improving the management of fertilizer, water, and rice straw, which, together, would be able to cut down more than 900 $MtCO_2e$ in global emissions by 2050. Since 2013, CORIGAP has been promoting best management practices (BMPs) to farmers in six rice-producing Asian countries (i.e., China, Indonesia, Myanmar, Sri Lanka, Thailand, and Vietnam) in order to improve regional food security while minimizing the carbon footprint of rice (FDFA 2021). The six CORIGAP countries are collectively responsible for 48% of the global CH_4 emissions from rice production (FAOSTAT 2019). By 2017, CORIGAP had reached 375,000 farmers across the six target countries, helping to increase yield from 14 to 30% (Ibabao 2018) while reducing from 5 to 30% of the rice-carbon footprint (Devkota et al. 2022). However, the adoption of BMPs is not without constraints and challenges (Connor et al. 2021b; Tuan et al. 2021; Wehmeyer et al. 2022).

CORIGAP technologies and practices are mainly associated with closing yield gaps by increasing productivity and profitability but were also co-designed to address all three pillars of sustainability (economic, social, and environmental). We start with an in-depth synthesis of scientific-based evidence and knowledge on challenges and constraints to reducing the rice-carbon footprint in all six CORIGAP countries. Furthermore, life cycle assessments will outline the quantification of the carbon footprint in rice production. We will provide case studies on specific technologies, e.g., Alternate Wetting and Drying (AWD), land laser leveling, and residue management at postharvest stages. The outcomes related to GHGE reduction are spelled out, which will be the basis for providing specific recommendations that can be readily implemented in rice-growing countries.

5.2 Life Cycle Assessment Approach to Quantify the Carbon Footprint of Rice Production

Life Cycle Assessment (LCA) is an assessment tool for quantifying and evaluating the environmental impacts of certain practices throughout the life cycle of land preparation, crop production, and stubble management following the guidelines of the ISO (International Organization for Standardization) (2006a, 2006b). Databases of LCA-based carbon footprint (CF) conversion factors can be accessed at different sources such as Ecoinvent (2021) and IPCC (2019), which are incorporated in SIMAPRO software (SIMAPRO 2019). In order to quantify the carbon footprint for the case studies under CORIGAP, we used the LCA approach introduced by Nguyen et al. (2022a) with the boundary of rice production from land preparation to harvesting and the functional unit is kg of paddy grains normalized at 14% of moisture content. We considered rice straw when burned or removed to be carbon–neutral because the CO_2 emitted during the incineration comes from the atmospheric CO_2 that the plant has fixed during photosynthesis and off-field processing of straw is not included in this study of rice production. On the other hand, straw, when incorporated, emits GHGs and this additional emission is included in the CF_{soil} of the next season as GHGs are generated from the decomposition of the organic matter, which occurs during the land preparation of the next crop.

Equation 5.1 shows the total rice carbon footprint (CF_{rice}) $\left(\text{kg kgCO}_2 - \text{eq kg rice}^{-1}\right)$, consisting of four GHG components:

$$CF_{rice} = CF_{agro-inputs} + CF_{operation} + CF_{soil} + CF_{ricestraw} \left(\text{kgCO}_2 - \text{eq kg} - \text{rice}^{-1}\right) \quad (5.1)$$

1. $CF_{agro\text{-}input}$ emissions from the production of agronomic inputs, e.g., seeds and fertilizers;
2. $CF_{operation}$ emissions from mechanized operations;
3. CF_{soil} emissions from soil; and
4. $CF_{ricestraw}$ emissions from rice straw management.

The CF conversion factors are in Table 5.1.

Equation 5.2 shows the calculation for CF_{soil}, which consists of CF and CH_4 from pre-season soil management, water management, and rice straw incorporation and N_2O from the oxidation of N fertilizers.

$$CF_{soil} = Time_{grow} * 28 * EF_{default} * SF_{water} * SF_{pre} * SF_{ricestraw} + 265 * EF_{1FR} * F_{fertilizer} / Yield \left(\text{kgCO}_2 - \text{eq kg} - \text{rice}^{-1}\right) \quad (5.2)$$

Here, $Time_{grow}$ is the number of days from sowing to harvest. The numbers 28 and 265 are the global-warming potential of CH_4 and N_2O equivalent to CO_2, respectively. $EF_{default}$ is the default CH_4 emission factor for different rice-cultivation regions. SF_{water} is the scaling factor corresponding to the number of drainages throughout the

Table 5.1 CF conversion factors

Parameters	CF GHG emission		
	Unit or formula	Value	Sources
Seeds	$kgCO_2$-eq kg^{-1}	1.12	a,b,c
Diesel consumption	$kgCO_2$-eq L^{-1}	3.58	a,d
Gasoline consumption	$kgCO_2$-eq L^{-1}	3.13	a,d
N	$kgCO_2$-eq kg^{-1}	5.68	a,b,c
P_2O_5	$kgCO_2$-eq kg^{-1}	1.09	a,b,c
K_2O	$kgCO_2$-eq kg^{-1}	0.52	a,b,c
Soil emission (case studies for CORIGAP countries)			
$EF_{default}$ of CH_4	kg ha^{-1} day^{-1}		
for Southeast Asia		1.2	e
for South Asia		0.85	e
SF_{pre} for pre-season soil management			
Non-flooded pre-season <180 days		1.00	
Non flooded pre-season >180 days		0.89	
Flooded pre-season >30 days		2.41	
Non flooded pre-season >365 days		0.59	
SF_{water} for water management			e
Irrigated—Continuously flooded		1.00	
Irrigated—Single drainage period		0.71	
Irrigated—Multiple drainage periods		0.55	
Rainfed—Regular		0.54	
Rainfed—Drought-prone		0.16	
$SF_{ricestraw}$ for rice straw management	$(1 + Yield_{straw}*EF_{straw})0.59$		
$SF_{ricestraw}$ for burning or removal of rice straw from the field		1	
$SF_{ricestraw}$ for incorporation of rice straw			
$Yield_{straw}$			
EF_{straw}			
Straw incorporated shortly (<30 days) before cultivation		1	e

(continued)

Table 5.1 (continued)

Parameters	CF GHG emission		
	Unit or formula	Value	Sources
Straw incorporated long (>30 days) before cultivation		0.19	e
SFN for Nitrogen use	% N applied		
Continuous flooding		0.3%	c
Single or multiple aeration (e.g. mid-season drainage or AWD)		0.5%	c

a = Ecoinvent (2021), *b* = SIMAPRO (2019), *c* = IPCC (2013), *d* = *adapted from* Nguyen et al. (2022a), *e* = SRP (2021), *f* = Nguyen et al. (2020), *g* = IPCC (2006)

crop, excluding the drainage before harvest. SF_{pre} is the scaling factor for water management in the pre-season. $SF_{ricestraw}$ is the scaling factor for rice-straw management. EF_{1FR} is the N_2O emission factor when N fertilizers are applied in flooded rice systems. All scaling factors and corresponding references can be found in Table 5.1.

5.3 Technologies to Reduce Carbon Footprint in Rice Production

To address the main sources of GHGs emitted from rice production, i.e., flooded fields, Nitrogen (N) fertilizer application, and straw management, CORIGAP introduced BMPs for water, fertilizer, and straw management with subsidiary technologies in crop establishment and land preparation.

5.3.1 AWD

AWD is an economically efficient water management practice (Lampayan et al. 2015) that can reduce up to 70% of GHGE from rice production (Win et al. 2021) (Table 5.2) and was included in several training activities in all CORIGAP countries. When applying AWD, farmers need to let the field dry several times during the cropping season and re-irrigate when the water level drops to 15 cm below the ground level (−15 cm) (Bouman et al. 2007). Farmers can keep track of the water level with a perforated water tube installed in the field. This is a modified tube that combines a plastic ball and an indication sign, allowing farmers to observe the field water level from a distance (Fig. 5.1).

AWD applied at the −15 cm water level sometimes is called safe AWD because it will not cause any yield reduction while significantly reducing the CH_4 emitted (Htay et al. 2020; Liang et al. 2016) (see Sect. 2.5 about China). At a −15 cm water level,

Table 5.2 AWD effects on GHGE from rice production in six CORIGAP countries. This reviews existing studies (some conducted by CORIGAP partners) to show potential GHG savings through the application of AWD and safe AWD

Location	Crop season	Features of practice	% GHG reductions in rice production	Source
China				
Guang-dong	Apr–Jul and Aug–Nov 2014	AWD and AWD30 reduced irrigation times by 2–3, with no yield penalty (AWD) and lower crop growth rate for AWD30	AWD reduced 57.1–68.6% (CFL), 37.4–45.7% (FP) AWD30 reduced 77.5–84.3% (CFL), 61.1–77.1% (FP)	Liang et al. (2016)
Jiangsu, Anhui, Jiangxi, Zhenjiang, Shandong, Henan		AWD and AWD30	AWD reduced 48.6–67.2% (CFL) AWD30 reduced 73.1–99.5% (CFL)	Yang et al. (2017)
Hubei	Jun–Sep 2018	AWD and CFL with/without mid-season drainage	No reduction due to the trade-off between CH_4 reduction and N_2O peak	Liao et al. (2020)
Indonesia				
Central Java	Six consecutive crops 2013–2016	AWD and site-specific AWD (−25 cm or multiple drainages 7 days before fertilization). Can be effective during WS provided efficient drainages. Reduction in water use	AWD reduced 35–38% CH_4 (CFL) No significant increase in N_2O Reduction in water use, CH_4 and GWP	Setyanto et al. (2018)
Jakenan	Six crops 2013–2016	AWD, AWDS (7-day drainage before fertilization for 1st & 2nd crops, −25-cm threshold for later crops)	−37% CH_4 during DS (CFL) −36.1% GWP	Tirol-Padre et al. (2018)

(continued)

Table 5.2 (continued)

Location	Crop season	Features of practice	% GHG reductions in rice production	Source
Myanmar				
Mandalay	Feb–Oct 2017	AWD saved 10–19% water without compromising yield	−66–70% CH_4 (CFL)	Win et al. (2021)
Nay Pyi Taw	Wet season 2017–2018	AWD without yield compromising	−16–20% CH_4 (CFL)	Htay et al. (2020)
Thailand				
Prachin Buri	Five consecutive crops 2013–2016	AWD and AWDS (-10 cm-threshold). More effective during the dry season	−49% CH_4 (CFL) AWDS did not reduce CH_4 N_2O emission similar between treatments	Chidthaisong et al. (2018)
Prachin Buri	Six crops 2013–2016	AWD, AWDS (re-flooded to 10-cm level)	−31% CH_4 (CFL)	Tirol-Padre et al. (2018)
Vietnam				
An Giang	Early WS 2019, late WS–DS 2020	AWD, AWD_SD	AWD reduced life cycle GHG by 35–42% AWD_SD reduced life cycle GHG by 24%	Leon and Izumi (2022)
An Giang	Six consecutive crops 2015–2017	AWD with farmers' adjustments based on field conditions AWD increased yield by 22%	−35% CH_4 without any increase in N_2O	Uno et al. (2020)

(continued)

Table 5.2 (continued)

Location	Crop season	Features of practice	% GHG reductions in rice production	Source
Can Tho	Nov 2011–Nov 2016	AWD (re-watered before fertilization) with three different rice-straw BMPs (incorporate, burning and ash application, and removal)	−51% CH_4 N_2O significantly increased, but GWP decreased	Arai (2022)

Note CFL = continuous flooding, FP = farmers' practice, AWD = re-water at the threshold of −15 cm, AWD30 = re-water at the threshold of −30cm, AWDS = site-specific AWD which implements different methods across sites, AWD_SD = drain mid-season once when AWD was impossible due to weather condition; features of specific AWD practices and the compared practice are given in the parentheses in their respective columns

Fig. 5.1 Modified Alternate-wetting-and-drying (AWD) tube using buoyancy to show the water level

the rice root system is robust and can supply sufficient water to sustain reproduction and growth activities. The GHGE-reducing effect of safe AWD is generally more profound during the dry season (DS) (31–70%) (Tirol-Padre et al. 2018; Win et al. 2021) than in the wet season (WS) where GHGE can be reduced to 16–20% (Htay et al. 2020) depending on the amount of precipitation (Table 5.2). However, the amount of CH_4 reduced can be offset by the increased Nitrous oxide (N_2O) emission, even at a low level of N fertilizer at 90 kg ha^{-1}, suggesting the field should be flooded during the time of N fertilization for an effective application of AWD (Liao et al. 2020).

However, there are modifications of AWD, including one where the water threshold is lowered to -30 cm (Liang et al. 2016; Yang et al. 2017). At this level, CH_4 can be reduced by 99.5% in comparison to continuous flooding, although there was some yield compensation recorded. Therefore, under the scope of CORIGAP, we recommended a safe level of -15 cm for farmers in the target countries, otherwise known as safe AWD. See Lampayan et al. (2015) for findings from the early stages of CORIGAP.

5.3.1.1 Case Studies of CF Reduction from AWD in Vietnam

AWD was introduced to Vietnam in an integrated technology package termed "One must-do, Five reductions" (1M5R). This package includes the use of certified seeds (one must-do) and five reductions in the use of fertilizers, water, pesticides, seed rate, and postharvest losses (see Chap. 4). It was disseminated through a training-of-trainers workshop for provincial extension and government officials, who would later train farmers on the BMPs integrated into the package (Tuan et al. 2021). Even though CF reduction is not stated as one of the main objectives of the technology package, the application of improved practices such as AWD does contribute to reducing the carbon footprint of rice production and therefore contributes to sustainability, which is a core focus of 1M5R. Here, we calculated the total CF from rice production for two crops (winter-spring and summer-autumn) in 2018–2019 under farmers' practices with two types of water management, i.e., continuous flooding and AWD (Nguyen et al. 2022a). In both crops, AWD reduced the amount of GHG emitted during the cropping season by 37% or 2,100 kg CO_2-eq ha^{-1} for the winter-spring and 3,422 kg CO_2-eq ha^{-1} for the summer-autumn season (Fig. 5.2). According to Connor et al. (2021a) and Flor et al. (2021), about 105,000 farmers in MRD were trained in 1M5R, covering more than 124,000 ha, with an adoption rate for AWD of 34.6% and another 10.8% reported to have been reducing their water use. According to the above figures, when 34.6% of the farmers with an area of 120,000 ha drained their fields at least twice and another 10.8% of farmers drained at least once, the water-saving practice would cut down the CH_4 emission from the soil by 0.1 Mt CO_2-eq for the winter-spring season and 0.2 Mt CO_2-eq for the summer-autumn season. If all of the trained farmers (100%) apply AWD (i.e., drain their fields mid-season at least twice over their 120,000 ha), the amount of CF reduced could reach 0.2–0.4 Mt CO_2-eq, equivalent to 0.7–1.2% of the country's total emissions from rice cultivation in 2020 (FAOSTAT 2019).

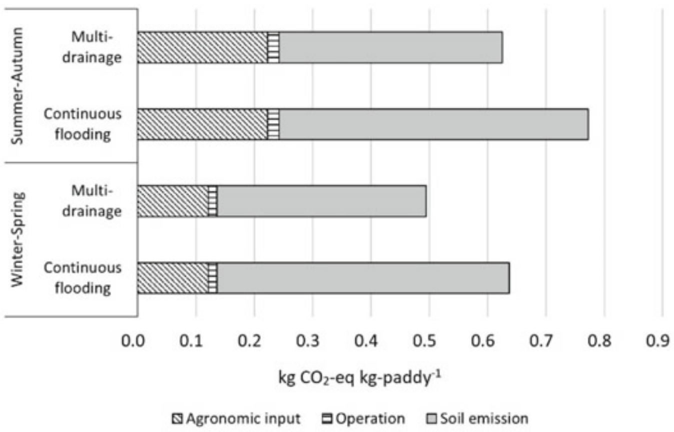

Fig. 5.2 GHGE from MRD rice cultivation under two water management scenarios

5.3.2 *Mechanized Postharvest Operations*

Postharvest processes can cause losses of up to 20–30% of the total production in rice production (Gummert et al. 2020). In traditional practice, after harvesting by hand cutting, rice would be threshed to separate grains from the straw, then sun-dried until it reached the desired moisture content and, if necessary, stored in granaries before being taken to milling facilities. Gummert et al. (2020) compared the losses incurred by traditional postharvest practices and the improved practices introduced in Myanmar under CORIGAP (i.e., flatbed dryer, IRRI super bag, lightweight thresher, and combine harvester). The improved (mechanized) postharvest scheme (Fig. 5.3) can help reduce 9–16% of postharvest losses. During the 2015 DS, from the yield (crop cut) of 4.8 t ha^{-1}, farmers who used improved practices obtained 3.0 t ha^{-1} of milled rice, in comparison to 2.7 t ha^{-1} using traditional practices. Similar figures were also observed during the DS of 2016 (from crop-cut yield of 5.4 t ha^{-1}, the milled rice was 3.6 t ha^{-1} (for improved practices) compared to 3.0 t ha^{-1} of traditional practices) (Gummert et al. 2020).

The improved postharvest processes reduced yield losses but raised concerns over environmental trade-offs with the additional consumption of fossil fuels, power, and the production, depreciation, and maintenance of machines and plastic containers. Gummert et al. (2020) reported that even with the additional GHGE from the above-mentioned processes, total GHGE from the improved practices was 8–43% lower than that of traditional practices for both WS (5,297 kg CO_2-eq ha^{-1} for improved practices compared to 5,734 kg CO_2-eq ha^{-1} for traditional practices) and DS (2,039 kg CO_2-eq ha^{-1} for improved practices compared to 2,933 kg CO_2-eq ha^{-1} for traditional practices). If calculated on kg of milled rice, the improved practices had a similar GHGE as traditional practices during the DS but emitted 28% less during the WS (Fig. 5.4) due to the higher milled rice yields in each season.

Fig. 5.3 Traditional and improved postharvest management in Myanmar

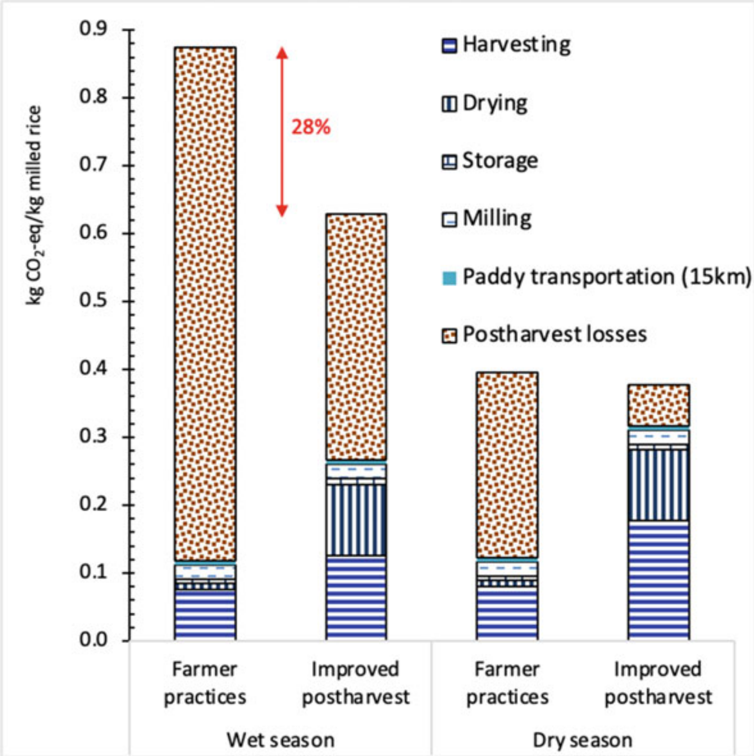

Fig. 5.4 GHGE from farmers' and improved postharvest practices

5.3.3 Straw Removal for Mushroom Production

Burning, incorporating, and removing are three common management practices of rice straw after harvesting. Given the amount of air pollutants generated in open-field straw burning (Le et al. 2020; Junpen et al. 2018; Phuong et al. 2022) and the surge in CH_4 flux in straw incorporation as fields are usually flooded to hasten the decomposition (Chareonsilp et al. 2000; Shen et al. 2014; Thu et al. 2016), other practices promoting straw decomposition under more favorable conditions, such as aerobic decomposition in composting or pyrolysis in biochar conversion, have been considered. Under CORIGAP, straw removal for mushroom production was promoted in Vietnam as a way to generate added value to rice while reducing GHGE and air pollution due to straw burning.

For this practice, rice straw is used as a substrate for *Volvariella volvacea* or straw mushroom, an edible type of mushroom, which is commonly consumed in Southeast Asia and is easy to grow with a 14-day growth duration (Thuc et al. 2020). In the rice straw mushroom production process described by Thuc et al. (2020), rice straw is first collected from the field, best immediately after harvesting to minimize the risk of contamination and the straw should not contain chemical residues from rice production. Afterwards, the collected straw needs to be soaked in $CaCO_3$ solution (3–5%w/w) for 10–15 min. After being soaked, the straw is cleansed with water to remove the remaining $CaCO_3$, piled, and tightly wrapped in plastic and exposed to sunlight for 3 days to increase the temperature of the pile for the first incubation. During this stage, the temperature of the pile should reach 65–75 °C; the pile should be turned once or twice to ensure homogeneity. When the incubation finishes, mushroom spawn can be added alternatively to layers of straw with a layer of straw on top as a cover.

In the following step, the straw pile enters the second incubation (10–14 days) where the optimal level of temperature (30–35 °C) and moisture content (75–85%) for the development of the spawn should be maintained. Here, a net or plastic can be used as the topmost cover to increase the temperature. After the first 5 days of the second incubation, mushroom pinheads will appear. At this pinning stage, the straw pile should be slightly watered every 2–3 days to maintain the desired moisture content and avoid damaging the mycelium and small mushrooms. Twelve to 15 days after the spawn inoculation, the mushrooms are ready to be harvested. The mushrooms suitable for harvest should be large and round with their cap not yet opened (Thuc et al. 2020).

Mushroom production from rice straw can be done in an open field or in growing houses. The breakdown of costs and benefits of the two management practices (open field and growing house) is shown in Table 5.3. For an average straw yield of 2 t ha^{-1} (moisture content of 28%) and a production rate of 0.8 kg of mushroom per 1 kg of dry straw, farmers would earn around USD \$120 ha^{-1}, in comparison to \$14 ha^{-1} if selling fresh straw (Can Tho City extension staff, pers. Comm.) or no additional income if burning or incorporating straw. In addition to the increased income, according to Arai et al. (2015), rice straw for mushroom production generated 107–637 g CO_2-eq. kg dry $straw^{-1}$ or 0.95 t CO_2-eq. ha-$paddy^{-1}$ $year^{-1}$, which is less GHGE than produced during straw burning.

5.3.4 Land Laser Leveling

There are further mechanization options that can help reduce carbon footprint, such as laser land leveling (LLL) (Nguyen et al. 2022b). Inputs and outputs of the operations are reviewed in this section. The inputs of mechanized operations mainly include fuel consumption, machine production and depreciation, and operating labor while the outputs can be accounted for the increase of farming efficiency, agronomic input use efficiency, and yield and grain quality (Fig. 5.5).

Laser land leveling is a technique using a laser to guide a drag bucket, whether to scrape up soil or to release it, to create a flattened field surface (IRRI 2019; Jat et al. 2006). A system of LLL contains five main components, namely a drag bucket, laser transmitter, laser receiver, control box, and hydraulic system with a pulling tractor. Before the leveling process starts, the field should be plowed when the soil is

Table 5.3 Comparison of costs and benefits of mushroom production from rice straw in an open-field and a growing house. The percentage of each parameter over the total input/output is in parentheses (Adapted from Thuc et al. 2020)

Parameters	Open-field		Growing house	
	\$US m^{-2} of land used	\$US kg^{-1} of mushroom	\$US m^{-2} of land used	\$US kg^{-1} of mushroom
Inputs				
Land used (rental)	0.04 (3.2)	0.15 (11.7)	0.35 (3.2)	0.16 (11.7)
Rice straw	0.38 (30.9)	0.51 (39.8)	3.33 (30.9)	0.54 (39.4)
Net, pump, depreciation of growing house	0.54 (43.9)	0.03 (2.3)	4.76 (44.1)	0.03 (2.2)
Lime, fertilizer and pesticide	0.07 (5.7)	0.12 (9.4)	0.6 (5.6)	0.13 (9.5)
Spawns	0.1 (8.1)	0.14 (10.3)	0.83 (7.7)	0.15 (10.9)
Watering (power consumption)	0.02 (1.6)	0.03 (2.3)	0.21 (1.9)	0.03 (2.2)
Labor	0.08 (6.5)	0.3 (23.4)	0.71 (6.6)	0.32 (23.4)
Total inputs	1.23 (100)	1.28 (100)	10.79 (100)	1.37 (100)
Outputs				
Mushroom	1.67 (73)	1.67 (71.1)	14.58 (72.8)	1.78 (70.9)
Spent rice straw	0.1 (4.4)	0.15 (6.4)	0.83 (4.1)	0.16 (6.4)
Total outputs	2.29 (100)	2.35 (100)	20.04 (100)	2.51 (100)
Net profit	1.06	1.07	9.25	1.173

Notes The table compares the cost to produce 1 kg of mushroom and the investment per 1 m^2 of the growing area between an open field and a growing house. Costs per 1 kg of mushroom of the practices were similar. Investment per m^2 in the growing house was higher because in the house, there are multiple layers of rice straw, therefore requiring more input than one layer of straw in an open field

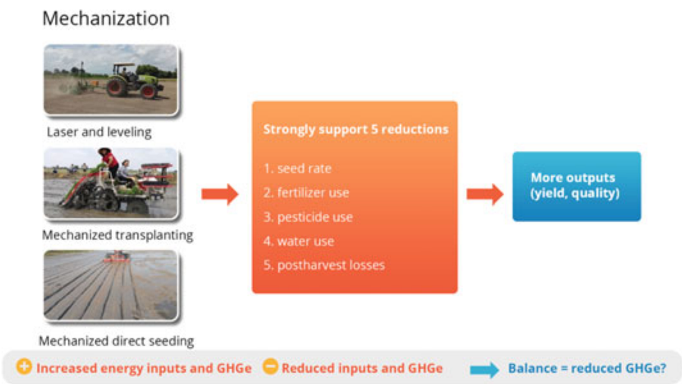

Fig. 5.5 Inputs and outputs of mechanized rice production

slightly moist. At the beginning of the leveling process, the laser receiver is attached to the tractor and the transmitter with the base plate is put on an even ground. After that, a topographic survey is conducted to record the height of the field at different points. The tractor should move from highs to lows according to the amount of soil contained in the bucket. At the end of the leveling process, the field should be re-surveyed to ensure the desired level is achieved. LLL can improve the effectiveness of water and nutrient management as well as improve the accessibility for other machinery, e.g., mechanized transplanters and row and hill seeders by maintaining a uniform condition of the field.

A study on LLL in Vietnam, Thailand, Philippines, Cambodia, and India indicated that, although there was an increase in the GHGE due to machinery operation, the total GHGE was reduced due to reductions in water use, agronomic inputs, and an increase in yield. Specifically, LLL can help to save at least 10% of agronomic inputs, 20% of irrigation water; reduce at least 2% of postharvest losses caused by rice plant lodging, and increase at least 5% of grain yield (Nguyen-Van-Hung et al. 2022b). A net reduction of at least 10% of GHG emissions was obtained on average, which offset the increased carbon footprint from machines and operations, as shown in Fig. 5.6.

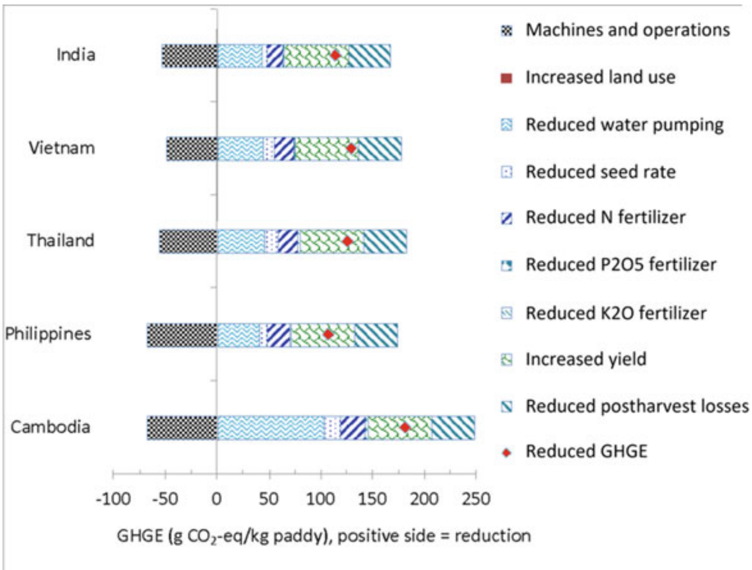

Fig. 5.6 Effect of laser land leveling on greenhouse gas emisisons (GHGE) in five Asian countries (Adapted from Nguyen et al. 2022b)

5.3.5 Mechanized Direct Seeding and Transplanting

During the CORIGAP project, field demonstrations helped promote direct seeding (DSR) in regions such as the MRD in Vietnam. DSR entails sowing seeds directly to the field instead of transplanting (TPR) seedlings from nursery beds (Farooq et al. 2011). DSR includes three crop establishment methods: (1) dry seeding (dry seeds into dry soil), (2) wet seeding (pre-germinated seeds into wet soil), and (3) water seeding (seeds into standing water). In comparison to TPR, DSR has the advantages of less labor and less water consumption, plus the crop matures 7–10 days earlier due to no transplanting shock. Overall, the outcome is less GHGE.

In contrast, transplanting consists of two processes—seedling production and transplanting—whether manually or by machines. After being grown in seedlings trays or nursery mats for 14–18 days, seedlings are rolled out in the trays and loaded into the transplanters. There are two types of transplanters, walk-behind and self-propelled transplanters. Both can adjust the row distance, hill-to-hill spacing and seedling rate per hill, using a seed rate of around 50–70 kg ha^{-1}. By being transplanted into the field during the seedling stage, rice will have a competitive advantage over the weeds and will have a lower risk of being eaten by birds, snails, and rats (Nguyen et al. 2020).

In addition, Nguyen et al. (2022a) reported that mechanized crop establishment reduced GHGE by addressing the problem of excessive use of agronomic inputs. The study compared the performance of broadcast seeding and mechanized transplanting in a two-cropping season field experiment (2018–2019) in Can Tho. Mechanized transplanting reduced the seed rate by 40% and pesticide use by 30–40% in the WS cropping season without any yield penalty. While mechanized transplanting does consume additional fuel and machinery costs, its net energy balance, net income, and total GHGE were on par with those of non-mechanized crop establishment methods (Fig. 5.7). Therefore, we suggest that mechanized transplanting can be promoted in the MRD for the improvement of the economic and environmental sustainability of the region's rice production (Nguyen et al. 2022a).

5.3.6 Site-Specific Nutrient Management

Site-specific nutrient management (SSNM) is a dynamic nutrient management that utilizes a model to quantify the amount of additional N, P, and K fertilizers to reach the target yield, given a specific indigenous nutrient supply (INS) (Dobermann and White 1998). The proposed procedure of SSNM includes five steps: (1) estimation of the INS of N, P, K; (2) estimation of the nutrient requirements based on yield target and the INS; (3) through the growing season, optimize the amount and timing of N application with the assistance of additional tools; (4) estimation of N, P, K removed from the field, thus changes in INS after harvest; and (5) incorporating the new data into the model for the next crop estimation.

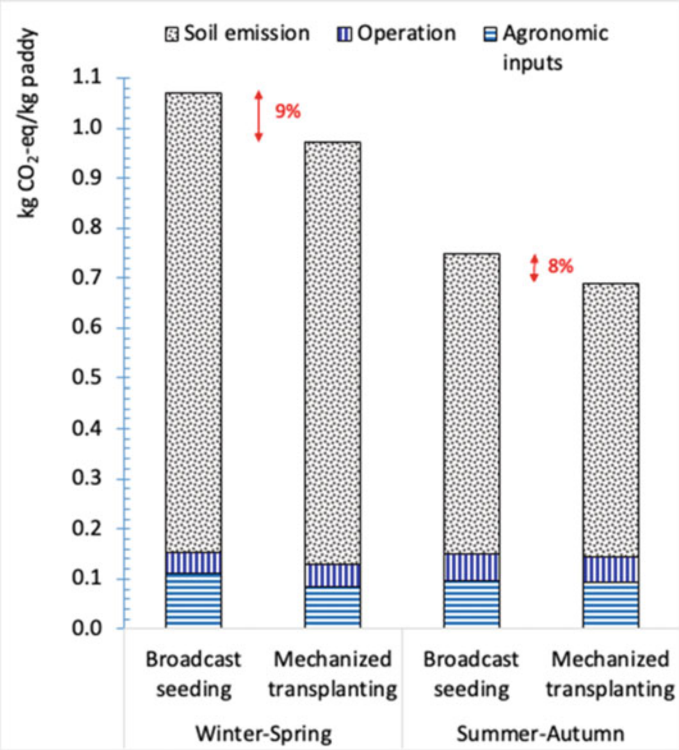

Fig. 5.7 Greenhouse gas emissions (GHGE) from rice cultivation under two crop establishment methods, broadcast seeding and mechanized transplanting (Adapted from Nguyen et al. 2022a)

For the first step, soil testing can be used to assess the INS. However, this approach requires uniformity in sampling and analytical methods as well as a well-developed infrastructure and quality control (Dobermann et al. 2003), which may not be available in developing regions or affordable for small farmers (Schut and Giller 2020). In such cases, nutrient omission trials were conducted where either of the three main macronutrients would not be added to the plot while the other nutrients would be adequately supplied (Chivenge et al. 2022). This approach will take one cropping season to determine the INS of the soil.

In addition to the crop-, field-, and season-specific requirements calculated at the beginning of the crop season, other tools are developed to address the dynamics of crop growth under the variable conditions of biotic and abiotic stresses such as heavy rainfall, drought periods, or pest and disease occurrences. One such tool is a leaf color chart, a plastic strip with four to six color panels ranging from yellowish green to dark green, which indicates the leaf color at different N content stages (Witt et al. 2005). Based on the greenness of the leaf, farmers can adjust the N fertilizer to reach the desired yield level. Other digital tools were also developed, adapting the initial model for rice in Asia to other regions and crops, providing farmers with a user-friendly interface and straightforward nutrient management recommendations, such as the Rice Crop Manager (Buresh et al. 2019), Nutrient Expert (Pampolino et al. 2012), RiceAdvice (Zossou et al. 2020).

5.4 Case Studies of the Carbon Footprint of Rice Production in Selected CORIGAP Countries

5.4.1 Carbon Footprint of Rice Production in Indonesia

For Indonesia, the main sources of GHG were the flooded rice production and the decomposition of organic fertilizers and rice straw under submerged conditions, especially during the DS (Carlson et al. 2017; Setyanto et al. 2000). To mitigate those sources, a range of techniques was introduced to Indonesian farmers (e.g., water-saving techniques, drum seeders, postharvest management), allowing farmers to grow double or triple crops, with 93,000 ha planted in the 2017 DS compared to only 30 ha in the 2012 DS (Singleton and Quilloy 2017).

The techniques require specific inputs, which sometimes are not available (fertilizers usually arrive late for the application schedule or are not the right type) or not suitable for farmers' use (e.g., the drum seeders being too heavy given the soil conditions) (Flor 2016). Another constraint was associated with collective decisions for community actions such as pest management, or irrigation management where farmers usually hired service providers who have little or no knowledge of AWD or water-saving techniques. As such, usually only farmers who irrigate by themselves applied some kind of water-saving practices.

A study by Connor et al. (2021a) showed that time constraints, labor shortage, and incompatibility with the farming pattern were the main reasons for farmers to discontinue their use of BMPs after 1–3 years of implementation. AWD was the most popular practice with an adopted rate of 80.6% and a continuation rate of 55.2%, with the reasons for discontinuation being difficult to apply and time constraints. In comparison, the IRRI Superbag (postharvest management) was the least popular, adopted by 46% of introduced farmers and continued by one farmer (16.7%). The reasons given were the technique's incompatibility with the field conditions and cropping pattern. Furthermore, many farmers opted to sell their wet paddy directly from their field.

5.4.1.1 Calculation of Carbon Footprint (CF) from Rice Production in Indonesia

We used the methods described in Sect. 5.2 to calculate the CF from rice production in Indonesia. The management practices of rice straw, water pre- and mid-season, as well as yield were collected from farmer questionnaires. Other parameters such as crop duration were assumed as the average duration of all commonly grown varieties in the study site. Qualitative answers about the amount of straw used for each management practice in the questionnaire (i.e., 1 = none at all, 6 = all of the straw) were converted to percentages as 1 = 0%, 2 = 20%, 3 = 40%, 4 = 60%, 5 = 80%, 6 = 100%. We assumed that rice straw was the only organic matter incorporated and straw composted before being incorporated was categorized as rice straw incorporated for more than 30 days pre-season.

In Indonesia, the baseline study in 2014 reported that the CF of DS and WS were 0.6 kg CO_2-eq kg-grain^{-1} and 1.1 kg CO_2-eq kg-grain^{-1}, respectively (Devkota et al. 2019). After 7 years, the endline survey conducted in 2021 showed that the BMPs integrated into CORIGAP have reduced CF in WS rice by 39%, to 0.8 kg CO_2-eq kg-grain^{-1}, increasing yield by 7%. However, for the DS, while BMPs increased yield by 9%, the CF also increased by 41% to 0.9 kg CO_2-eq kg-grain^{-1}. The rising of CF in the DS maybe due to the increasing use of irrigation water. In the endline survey, 29 of 52 farmers (56%) responded that their fields were kept flooded continuously. In a study by Devkota et al. (2019), Indonesia was the country that irrigated the least in terms of both number of irrigation applications and mm of irrigation applied. This result further stresses the importance of improved water management practices such as AWD for smallholder farmers in lowland irrigated rice systems in Indoneisa.

5.4.2 Carbon Footprint of Rice Production in Thailand

In Thailand, the main challenges for rice farmers include the overuse of inputs, which results in environmental damage, increasing input and labor costs, decreasing paddy prices, and water scarcity (Stuart et al. 2018). Rice production generates 58% of Thailand's total GHGE (Devkota et al. 2019), or about 3.65 t CO_2e ha^{-1} year^{-1} (Maraseni et al. 2018). While other major rice producers (e.g., China and Vietnam) have been increasing their yields, and at the same time, decreasing their rates of carbon density (Maraseni et al. 2018), Thailand's performance in reducing its carbon footprint was the lowest compared to other major rice producers in the region such as India, China, or Vietnam (Maraseni et al. 2018). Field emissions (70%) and farming (20%) are the two main contributors to the life cycle GHGE of rice production (Yodkhum et al. 2018). BMPs that help reduce GHGE (e.g., mechanized direct seeding with drum seeders, LLL, SSNM by soil analysis, and AWD) were introduced in Thailand.

The use of drum seeders reduced seed rate by 60–67%, which in turn reduced the rates of fertilizers and pesticide application and, consequently, roughly 50% of production cost with no reduction in yield (Stuart et al. 2018). Using the equations introduced in Sect. 5.2, we estimated that, with the reduction in agronomic inputs achieved when farmers followed the BMP, together with AWD, as detailed in Stuart et al. (2018), the GHGE would be 45% lower than that of FP in both the WS and DS. The total GHGE per kg of paddy grain reduced from 0.83 kg CO_2-eq kg-paddy^{-1} to 0.48 kg CO_2-eq kg-paddy^{-1}. Notably, in the BMP schemes, the amount of fertilizers applied can be as little as a third for N (43.47 and 121.53 kg ha^{-1}), and a tenth for P

(4.39 and 43.76 kg ha^{-1}) compared to FP, and yet no significant difference in yield was observed. In other words, applying fertilizers heavily to rice fields in Thailand does not always translate to more grain yield, rather it would reduce farmers' net income due to rising costs of fertilizers and pesticide applications (Stuart et al. 2018; Pame et al. 2023) and significantly increases GHGE as per our calculation.

The application of laser land leveling had been shown to increase yield while reducing inputs (seed, water, and fertilizers) and postharvest losses and GHGE (Nguyen et al. 2022b). SSNM greatly reduced fertilizer input (51–54%) and its costs (\$79 ha^{-1}) and also reduced GHGE at the rate of 363.52 kg CO_2-eq ha^{-1}, while maintaining or increasing yield in farmers' field trials (Arunrat et al. 2018; Attanandana et al. 2010). Similar to SSNM, AWD aims to generate profits for farmers by reducing inputs while applying no damage to yield. Maneepitak et al. (2019) reported that AWD increased grain yield by 7–15%, and reduced water input by 46–77%. This practice is also reported to help mitigate the carbon footprint of rice cultivation by 144.5 CO_2-eq ha^{-1} (Arunrat et al. 2018).

Despite the visible benefits, some of the advanced practices are not widely adopted in Thailand; for example, there are only eight LLL units in Thailand covering merely 530 ha (Nguyen et al. 2022b), even though a flattened field surface is recommended for effective implements of other techniques. As for other practices, the reported limited factors include weed management and fear of yield reduction (Maneepitak et al. 2019; Ngo et al. 2019).

5.4.3 Carbon Footprint of Rice Production in Vietnam

Most of the most productive provinces in Vietnam are located in the two major deltas of the Mekong and Red River and a minor central delta. This is not surprising as increasing productivity has been the focus of the Vietnamese government's policies for rice production, especially in MRD, for the nation's food security. While this emphasis did make Vietnam a leading rice exporter, it also resulted in soil degradation, overuse of fertilizers and plant protection chemicals, and low grain quality (Thai and Giang 2015). Methane emission from Vietnam was 230% higher than IPCC defaults for Southeast Asia (Vo et al. 2020), while the country is 3.7 t ha^{-1} crop^{-1} behind its yield potential (Yuan et al. 2022).

To improve yield and mitigate GHGE, best practices, including AWD, LLL, and rice straw management, have been implemented in Vietnam and shown promising results. Studies in the MRD region showed AWD reduces 35–72% of CH_4 emissions in rice production with no yield penalty or even increases yield (Khai et al. 2018; Uno et al. 2020). From our own calculation, AWD can lower the carbon footprint of rice production by 37% in both the WS and DS. AWD requires precise timing of flooding; as such, a flattened field surface is of crucial importance. LLL was introduced to Vietnamese farmers and helped increase land use efficiency, yield, and reduce inputs and postharvest losses (Nguyen et al. 2022b).

The alternative use of rice straw for mushroom production provides growers with an additional profit of \$30 ton-straw^{-1} cycle^{-1} (Trúc and Huong 2016) while emitting 1 t CO_2-eq. ha-paddy^{-1} year^{-1} less (Arai et al. 2015). However, in the MRD, the main management for rice straw was burning (Cuong 2019), even though the incineration generates less energy and more GHG pollutants, plus increases respiratory health risks of farming families, than other management practices (Nguyen et al. 2019). Connor et al. (2020) reported that farmers were most aware of direct uses of rice straw and also practiced those (burning, incorporation, and collection), while practices utilizing rice straw as input material for other productions were less well-known and adopted by only half of the farmers (compost, mushroom production) or even fewer farmers when considering biogas or fodder production. Farmers were well aware that straw burning is a high-risk, low-benefit practice, and were in favor of other straw management practices. However, straw burning offered a quick and simple removal of the straw in the field, which is crucial when the fallow period usually lasts only a month for farmers practicing three rice-cultivating seasons. A lack of enforcement in prohibiting straw burning and available alternatives, especially in the winter-spring season, contributed to farmers opting for straw burning.

Using the method described in Sect. 5.2, it is calculated that by the end of CORIGAP, GHGE from rice production in MRD was 2.3–2.5 t CO_2-eq crop^{-1} ha^{-1}, or approximately 0.5 kg CO_2-eq kg-grain^{-1}. Compared to the GHGE reported for the baseline survey in Devkota et al. (2019), which was 5.4 t CO_2-eq ha^{-1} for the WS and 3.9 t CO_2-eq ha^{-1} for the DS, the GHGE ha^{-1} was reduced 54% for the WS and 41% for the DS, while increasing mean rice yield by 7%.

Despite the potential benefits, the implementation of advanced practices in the MRD is currently limited by various factors. For AWD, farmers' choice to use a pumping service is the major constraint as irrigation water will be delivered to individual fields at a fixed cost at the same schedule (Le 2021), in addition to other constraints, such as AWD being deemed too difficult to implement, incompatible to farmers' cropping pattern or weather conditions (Connor et al. 2021b). Access to machines is the major constraint to LLL (Tuan et al. 2021). Lack of capital resources is also a main constraint for mushroom production from rice straw (Truc and Huong 2016). Minas et al. (2020) reported that additional costs in gathering and transporting straw for off-field use could prevent farmers with limited financial capacity from adopting alternative straw management, in addition to a lack of access to technical and financial support.

5.4.3.1 Carbon Footprint Reduction with One Must-Do, Five Reductions (1M5R) in Vietnam

We used the method described in Sect. 5.2 to calculate the CF from rice production for farmers following the 1M5R technology package or FP presented by Nguyen et al. (2022a). In our calculation for the case of rice production in the MRD of Vietnam, the parameters other than the target criteria of 1M5R were considered to be the same as of FP. The differences between FP and 1M5R are listed in

Table 5.4 Key input values of farmer practice (FP) and One must-do, Five reductions (1M5R) in Can Tho, Vietnam (2018–2019)

Input	Unit	FP	1M5R
Seed rate	kg ha^{-1}	150	100
N	kg ha^{-1}	130	100
Pesticide	times spray	10	6
Water management	times drained	0	2
Postharvest losses	%	5	2

Table 5.4. Implementation of 1M5R practices effectively reduced GHGE by 41–42% in irrigated rice production because of reduced use of seeds, N fertilizers, pesticides, and CH_4 emission from flooded soil (Fig. 5.8). In total, applying 1M5R can help cut down the CF by 0.36 and 0.59 kg CO_2-e kg $paddy^{-1}$ in the winter-spring and summer-autumn seasons, respectively.

FP as surveyed by Nguyen et al. (2022a), 1M5R followed One must-do, Five reductions criteria.

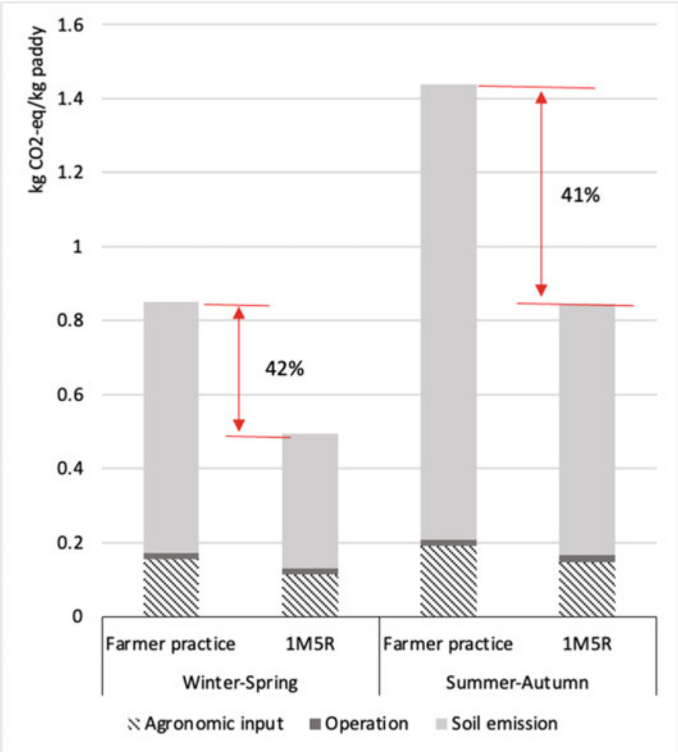

Fig. 5.8 GHGE from rice production in the MRD, Vietnam, applying 1M5R and farmers' practice

5.5 Summary and Recommendations for Further Application

The climate risks and adverse farming practices in rice production, particularly in the CORIGAP countries, cause high carbon footprint or GHG emissions per kg of rice produced. Following are common constraints and possible solutions.

- Irrigated rice–flood-prone with continuous stagnant water is a common practice in the Mekong Delta and other delta and lowland regions, which causes high methane emission. Water-saving solutions (e.g., AWD) can reduce up to 50% of methane emissions in rice production (Chidthaisong et al. 2018; Arai 2022). However, the AWD application usually requires the support of interventions such as inbound and efficient water management systems to enable drainage of the fields and land leveling. Possible solutions include better coordination of water use by farming communities plus the introduction of the "internet of things" to provide real-time feedback on field water levels.
- Adverse rice-straw management practices can generate a high CF. Rice-straw burning causes losses of nutrients contained in the straw and environmental pollution that indirectly generates and increases the carbon footprint of rice. On the other hand, the incorporation of rice straw combined with flooded fields causes high methane emissions. There are solutions for sustainable rice-straw management introduced by Gummert et al. (2020) such as biogas production, mushroom production, and harvest of stubble for stock feed.
- High agronomic input use for rice production due to lack of mechanization and precision farming is an ongoing challenge. This issue can be addressed by improving scale-appropriate farming systems and practices. For example, precision crop establishment and fertilization requires an integrated system of precision land leveling, mechanical transplanters or seeders, soil-nutrient-based nutrient management tools, etc. (Nguyen et al. 2022a, b).
- High postharvest losses due to poor technologies and management also cause a high carbon footprint for each kg of rice produced (Broeze et al. 2023). The solutions for reducing postharvest losses can be addressed by the practices covered in Chap. 4, such as the use of combine harvesters, mechanical dryers, hermetic storage bags, and EasyHarvest for smart postharvest management.

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Chapter 6
Partnerships and Approaches Used for Scaling: An Assessment of the Process for Rice Postharvest Technologies in CORIGAP

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Abstract In agriculture, many technologies are co-produced by research and a variety of other stakeholders, including farmers. Large-scale implementation of such technologies requires not only the distribution of the material components of a technology but also the replication of the social network, typically provided through facilitation of stakeholder involvement. Within the Consultative Group on International Agricultural Research (CGIAR), the now common procedure to enable stakeholder involvement is the creation of innovation platforms. The multi-stakeholder engagement initiated by these platforms enables the use of locally adapted technologies. This implies that the introduced technologies are not merely copied but require unpacking and repacking. In other words, a process of re-establishing the interconnectedness of the technology with varied socioeconomic arrangements and

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policies that enable its use. Understanding the process of scaling technologies thus requires analysis of the network that effectively catalyzes synergistic change and supports the adoption of technologies. However, the nature of the network, the types of partnerships, and the communication processes are situational and dynamic. It can take many years before newly introduced technologies become integrated into the routines of farming and accepted as a 'normal' technology. In this chapter, we provide a qualitative assessment of the partnerships and networks initiated by the Closing Rice Yield Gaps project (CORIGAP). Many of the CORIGAP partnerships were initiated during the predecessor project, the Irrigated Rice Research Consortium (IRRC). CORIGAP facilitated partnerships in different modalities, depending on the context of the countries and partners. This included partnerships with private-sector partners who, for example, provide services or inputs in return for subsidies or other financial arrangements. We reflect on the types of partnerships, how they are conceptualized, and how they created the needed connections and conditions to support the scaling of technologies introduced by CORIGAP. We also present cases of private-sector partnerships as examples of engagements with industries. We then dive into an approach that had been employed in several CORIGAP sites to facilitate the creation of a network for learning, innovation, and scaling of technologies. A case of using this approach in the Lower Ayeyarwady Delta of Myanmar is presented. We close the chapter with insights on the incentives these CORIGAP partnerships have enabled for scaling.

Keywords Scaling · Learning Alliances · Public Private Partnership · Ayeyarwaddy Delta

6.1 Conceptual Overview of Networks, Partnerships, and Communication

Historically, the dominant perspective within research for development is that technologies are developed or curated by scientists and then spread across various types of adopters. This perspective is elaborated in Everett Rogers' Diffusion of Innovation model (Rogers 1983). A major criticism of this model is the division between, at one end, science as an innovation producer and knowledge provider. On the other end, farmers are considered to be information receivers and innovation adopters. The limitations of this model have been repaired by introducing network and system perspectives that perceive innovation and knowledge production as a multi-actor process without predefining the agency of actors and the way knowledge and innovation flow within a network or system (Yang et al. 2022). A knowledge network or innovation system is enmeshed in a complex environment where individuals jointly generate innovations and share knowledge.

Within CGIAR, different concepts have been proposed to characterize the co-production of knowledge and innovation. Besides Multi-Stakeholder Platforms

(MSPs), these are Learning Alliances (LA) (Lundy et al. 2005), Living Labs (Dutilleul et al. 2010), and Learning and Innovation Hubs (Jiménez and Zheng 2021). These approaches are all based on the idea that an appropriate design requires an arrangement for stakeholder participation that results in an effective innovation process and a conducive environment for a technology to function. The set of actors involved and the institutional environment they create is called an Innovation System (Leeuwis 2004; Oria et al. 2014). The institutional environment consists of formal and informal rules that affect practice, e.g., shared labor agreements between farmers or established payment arrangements. Innovation is not only new technology and knowledge but also the re-design of technical practices and ways to organize them (Leeuwis 2004; Dormon et al. 2007). Thus, a heterogeneous and interdependent network of actors in an innovation system operates at different levels and maneuvers the organizational and institutional structures to enable innovation (Kilelu et al. 2013).

MSPs mostly involve a variety of international and local stakeholders representing various organizations and interests. These stakeholders organize, discuss, and generate joint learning in order to tackle specific technological, organizational, and institutional challenges and increase the adoption of best management practices (Lundy et al. 2005). For example, a Learning Alliance (LA) focuses on communication processes for generating and spreading knowledge and improved practices. In other words, an LA is based on the assumption that the learning of stakeholders enables innovations.

Another variant of MSPs emphasizes the role of the private sector. Known as Public–Private Partnership (PPP), this model assumes that a variety of roles and activities typically provided by the public sector can be taken over by private-sector actors. The underlying assumption is that PPPs create a double win by making services more efficient and providing stakeholders with higher returns on investments (Marbaniang and Kharumnuid 2020). Varied forms of such partnerships are engaged in research for development. Depending on the nature of the technology, the company and the research organization take different roles in the partnership.

A key component of MSPs is a communication process (Fig. 6.1). Implicit in the multi-stakeholder collaboration and co-production arguments of MSPs is a multi-directional communication process. Communication requires appropriate skills, media, activities, and dialogue in order to generate awareness, understanding, interest, and form opinions (Burns et al. 2003; Lewenstein 2003). In all MSP variations, the facilitation of multi-directional communication is given much attention. In the LA model, for example, communication catalyzes learning toward meaningful change. The LA model asserts that actors must be treated equally in the communicative process. Actors encode, interpret, and decode messages and engage in a dialogue that is considered a switchboard that reroutes information. What makes the LA model different from the typical communicative process is the systematized way of monitoring and evaluating research outputs in reflection meetings between stakeholders, forming the basis for the next learning cycle.

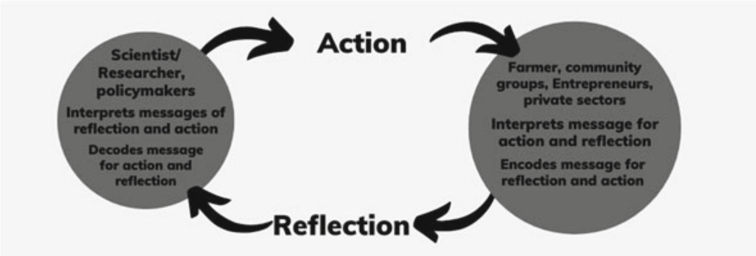

Fig. 6.1 Communicative Process in an LA (Adapted from the Osgood and Schramm communication model; Mcquail and Windahl 2015)

6.2 Multiplicity of Partnerships in CORIGAP

CORIGAP constituted a consortium that linked various partners with a shared interest in sustainable agricultural technologies. An example of the types of partners included in CORIGAP work in Indonesia and Vietnam is shown in Fig. 6.2. The partnerships varied across countries. Many partners were involved, including government agencies, various farmer groups, and industry and finance partners (Fig. 6.2). The composition for each type is also context-driven, varying alongside technologies of interest, the stakeholders in the country, policies in place, and how the industry is set up around the technology in the geographic scope. Underlying these are different modes of partnerships.

CORIGAP has involved varied modes of partnership with the private sector. Initially, during the IRRC phase, informal public–private cooperation was the only mode of partnership. Except for contracting partnerships, CORIGAP engaged with

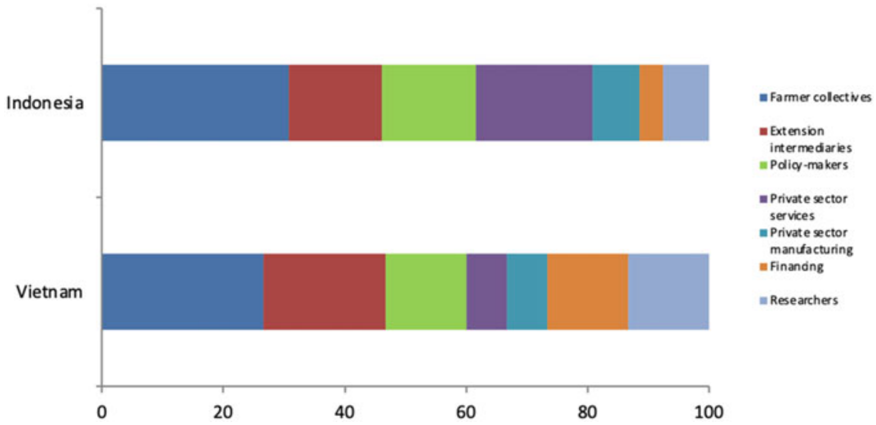

Fig. 6.2 Stakeholder composition in the networks engaged through CORIGAP in Indonesia and Vietnam

the private sector in all other forms of partnerships (Table 6.1). Some partnerships, e.g., with the Austrian company APV—Technische Produkte GmbH on direct seeding, had several components.

In the following, we will focus on informal commercializing partnerships implemented by CORIGAP to foster developing, adapting, and scaling out CORIGAP research products (Fig. 6.3). Moving from the left to the right in Fig. 6.3, the private partner becomes more engaged in the planning and implementation of activities and might also provide more funding. The partnership aims for a more equal relationship between the private-sector partners and other stakeholders, e.g., joint training events with farmers provided by researchers and company staff. Moving from bottom to top, the responsibilities and mutual benefits are higher and private-sector engagement moves from recipient of research to a partner in innovation. One example is the development of a rice dryer, where the company did the prototyping and the research institutions conducted simulation of the drying process as an input to the prototype design. The rice dryer case is illustrative of several activities.

Table 6.1 Forms of partnerships, characteristics, and examples from CORIGAP

Form of partnership	Characteristics	CORIGAP examples
Resourcing	The private sector contributes financial or human resources to the research project or program of the public agency	APV direct seeding
Contracting	Encompasses the outsourcing arrangement found in conventional public procurement	None
Research and technology development	Public- and private-sector actors contribute their specific expertise to jointly develop a new technology or optimize an existing one	Development of the Solar Bubble Dryer, GrainSafe™ Dryer, APV Direct Seeder
Commercialization	Technology already developed by the public sector exists, but is not widely used. Adaptation, extension to farmers, technology incubation, and initial commercialization are taken over by the private sector	Promotion of hermetic storage, laser-leveling systems modified for Asian rice agriculture
Sector/value chain development	Target adoption over a broad range of actors in the value chain	Introducing the flatbed dryer

Adapted from ASEAN (2017)

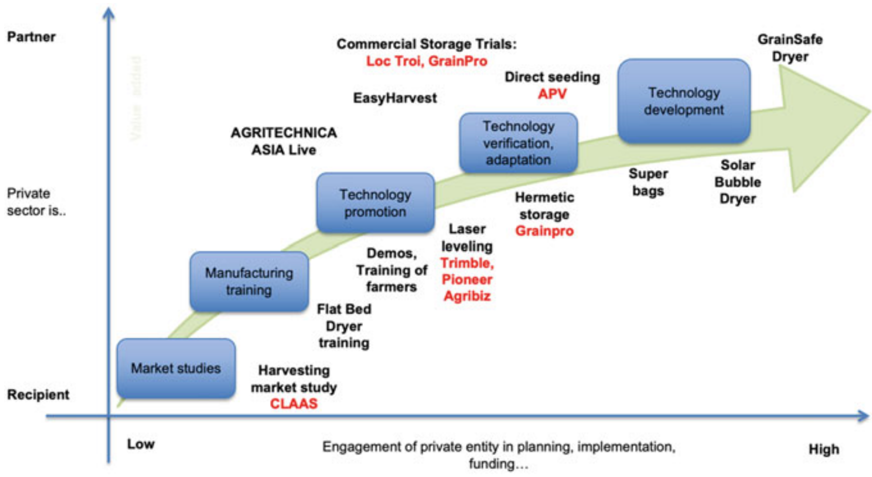

Fig. 6.3 Different levels of engagement with the private sector and some scaling effects

6.2.1 Market Studies

In 2014, the CORIGAP postharvest and mechanization teams conducted a needs assessment for combine harvesting in Myanmar, Vietnam, Indonesia, and Thailand, funded by and in cooperation with the international harvesting equipment manufacturer CLAAS. This was complemented by studies in the Philippines and Cambodia in cooperation with the national partners of the IRRC. The study provided complementary funding of US$60k to CORIGAP activities and led to important findings that resulted in the reduction of rice production costs and harvesting losses through the promotion of combine harvesting by the project. For the company, it provided insight into opportunities for selling small rice combine harvesters.

6.2.2 Manufacturing Training

During the IRRC and CORIGAP phases, several training courses were conducted for local manufacturers on the production, testing, and troubleshooting of new technologies. Examples are training on a new semi-automatic downdraft rice-husk furnace for rice dryers, manufacturing a flatbed dryer, and manufacturing components for laser leveling of fields. The flatbed dryer manufacturing training led to the successful and widespread introduction of such dryers in Myanmar, Indonesia, Cambodia, and the Philippines through local manufacturers and service providers, who often were also provided with follow-up advisory assistance on the technologies.

6.2.3 Technology Development

With some supplementary funding from the public sector (German Federal Ministry for Economic Cooperation and Development, BMZ) and the private sector, CORIGAP also engaged in the development of new technologies, e.g., the Solar Bubble Dryer™ (SBD). For this purpose, a public–private consortium consisting of GrainPro for material properties and prototyping, University of Hohenheim, Germany, for fundamental research, including modeling of the drying process and IRRI/CORIGAP for rice expertise, technology verification and adaptation to users' needs was developed (Gummert et al. 2014). This was funded with US$60k from BMZ, US$200k from GrainPro, and in-kind contributions from CORIGAP in the form of staff time and operating funds. The effective PPP model with clearly defined roles in which the partners could focus on their core expertise had effectively shortened development cycles and resulted in a completely new solar dryer within two years. Market testing was promising and the first commercial version was released on 30 September 2014. By December 2022, 690 SBDs had been sold (Plijter 2022).

6.2.4 Technology Promotion

This was usually done in close cooperation with actors from the private sector. An early example was the cooperation with Trimble Inc., a multinational manufacturer of laser transmitters and receivers, with the objective to adapt laser-leveling technologies to the conditions of small farms in Asia. During the project, Trimble provided three sets of leveling equipment for free to be used in project sites. Additional sets were sold with a price subsidy from the project. Trimble staff also joined technical seminars and field activities. The collaboration was not only with Trimble, and discussions with competing companies took place, but none of the competitors were willing to provide a similar contribution. National importers and distributors of Trimble products became partners, e.g., Pioneer Agribiz Co. Ltd in Myanmar, IdealFarm in Vietnam, and CropTech Asia in Thailand.

Seminars and exhibitions were also co-implemented with companies. This included exhibitions during the International Rice Congress conducted by IRRI every 4 years, in Bangkok in 2014 and in Singapore in 2018. There were several national events in CORIGAP partner countries and from 2017 to 2022 through a partnership with the German Agriculture Society (DLG) for conducting seminars and exhibitions under the AGRIFUTURE and AGRITECHNICA ASIA brands. In 2019, CORIGAP, DLG, and the Agricultural Mechanization Division of the Ministry of Agriculture in Myanmar organized the AGRITECHNICA ASIA Live field days, exhibition and seminar drawing more than 3,000 farmers, contract service providers, and extension workers (IRRI 2019a). In 2022, CORIGAP, DLG, and various departments of the Ministry of Agriculture and Rural Development (MARD) in Vietnam organized a similar event with 4,000 visitors (Anonymous 2022) in the

Mekong Delta of Vietnam. The latter was accompanied by national seminars, the CORIGAP Lessons Learned Seminar, and the CORIGAP Science Seminar, which were streamed online, disseminating the CORIGAP learnings to additional national and international audiences.

6.2.5 *Technology Verification and Adaptation*

The cooperation with GrainPro Inc. Philippines on the verification of hermetic storage systems is an example. It started with the CORIGAP team working with commercially available GrainPro Cocoons™ with a 5- to 20-ton capacity, and led, once farmers' feedback was collected, to the joint development of the 50-kg Super Bag (Ben et al. 2006). Similar to the Cocoons™, the Super Bags have been highly effective for safely storing seeds and grains and other commodities, such as cocoa and coffee for up to one year and have been included in the national activities of all CORIGAP countries. From 2013 to 2022, 32 million Super Bags have been sold worldwide by GrainPro (Plijter 2022), while local competitors from India and China are also selling similar bags, but often with lower quality than the original.

Through a collaboration among Grain Pro, Loc Troi Group in Vietnam, and IRRI, a technology verification of a 150-ton hermetic storage Cocoon™ for paddy grain was conducted in 2022. With a promising result and the advantages of private-research institution partnerships, the technology can be rapidly adopted on an industrial scale.

6.3 Insights from Collaboration with the Private Sector

6.3.1 *History of Collaboration with the Private Sector in CORIGAP*

The first collaboration involving international agricultural research scientists (IRRI's Agricultural Engineering Division, AED) and the private sector goes back more than 50 years. In 1977, IRRI released the IRRI Axial Flow Thresher (AFT) to several manufacturers in the Philippines (Chandler 1979). This addressed problems emerging from double-cropping rice systems, such as labor shortages, short turnaround times between harvesting and the next planting season, and rainy harvests, which complicate manual threshing. The mechanical thresher was quickly picked up by farmers in the Philippines from 1972, Pakistan from 1976 to 1978, Thailand from 1977 to 1980, Indonesia from 1980 to 1982, Vietnam in the 1980s, and in Laos from 1997 to 1998 (Gummert et al. 2013). Local manufacturers came up with different versions of threshers with capacities ranging from 0.6 to 3 tons. In Thailand, a combine harvester was developed in 1988 (Gummert and Phan 2013). All this was promoted by the USAID-funded Small Farm Machinery Development Program (SFMDP) implemented by IRRI (Khan 1985). After the program came to an end, AED anticipated that national research institutions would continue the dissemination of these machines. But this really did not happen and, in the 1990s, there were frequent proposals to close down the AED.

During the IRRC from 2000 to 2010 and the first phase of CORIGAP (2011–2015), IRRI had no longer had any significant cooperation with the private sector, except for one AED project that worked informally with local manufacturers by providing them machinery designs of a stripper harvester and training for local manufacturing (Douthwaite 2002). Only in 2008, during the time of the IRRC, the Hybrid Rice Research Consortium (HRRC) was established as an IRRI-managed public–private research platform with 38 public and private organizations (Rijsberman 2014). In 2003, the IRRC established the Postharvest Workgroup that, besides conducting research on loss reduction, was also tasked to assess how the consortium could better leverage the private sector to help scale out research outputs.

One CGIAR, which was formally launched in January 2022, has the ambition to 'deepen engagement with the private sector' as a key pathway to achieve greater impact at scale toward the achievement of the Sustainable Development Goals (SDGs) (Cummings and Dentoni 2021). Since the IRRC and CORIGAP have successfully piloted different types of private–public partnerships, there are valuable lessons for One CGIAR, but also for other projects and programs.

6.3.2 Facilitating Evolving Roles in Collaboration with the Private Sector

In CORIGAP, partnerships include local small- and medium-sized enterprises and not only large companies seeking to bring their products to the market. This could start, e.g., by inviting a private stakeholder to join in a training session and develop into joint activities for dissemination of new machinery. This was the case with GrainPro Inc. Philippines, a company producing hermetic storage Cocoons™, a type of sealed bag for rice that was already commercially available. By participating in the IRRC, a hermetic Super Bag was developed, and after that, a Solar Bubble Dryer™. The latter was developed by a consortium consisting of IRRI, GrainPro, and the University of Hohenheim (Salvatierra-Rojas et al. 2017).

Another example is the rice trader Dr. Myo Aung Kyaw in Myanmar. In 2004, IRRI worked with him in a postharvest training after which he started promoting improved postharvest management in Myanmar. In 2005, Dr. Myo participated in a flatbed dryer manufacturing training conducted by the IRRC in partnership with Nong Lam University in Vietnam. He then started manufacturing and installing these dryers in Myanmar. Dr. Myo became a CORIGAP collaborator by joining the training of farmers and extension workers in postharvest loss reduction, for which he founded the Pioneer Postharvest Development Group (PPHDG). In 2013, he established Pioneer

Agrobiz Co., Ltd, for dryer manufacturing and service provision for postharvest technology, including other CORIGAP technologies like hermetic storage, laser-leveling equipment, and the Solar Bubble Dryer (SBD). He also became an importer of other postharvest equipment such as re-circulating batch dryers from Taiwan and quality assessment and laboratory equipment. He is now a national distributor of Suncue, Kett, GrainPro, and Trimble. Through August 2022, he had installed more than 1,200 flatbed dryers across the country.

In 2019, the Austrian company APV demonstrated its direct seeding equipment at the AGRITECHNICA ASIA Live in Myanmar. After some discussions with the CORIGAP team, APV became a member of IRRI's direct seeded rice consortium (DSRC) and donated two machines, one for trials at the IRRI's Zeigler Experiment Station in Los Baños, Philippines, and one for CORIGAP field demonstrations in Vietnam. APV then got involved in the design of direct seeding equipment for the CGIAR Mechanization of Rice Breeding Program, with the cost of the development covered by the company. Furthermore, the mechanized APV seeding demonstrations in Vietnam got high interest from farmers and private and public sectors. By April 2022, a new direct seeder for rice was commercially released.

In 2021–2022, a cooperation between Loc Troi Group and IRRI aimed at getting the EasyHarvest APP (IRRI 2019b) for wet paddy logistics optimization piloted and tested. It is ongoing with a promising adoption at an industrial scale.

Innovation and knowledge are essential for fostering sustainable mechanization and postharvest. But technology generation is, in itself, not sufficient. It needs to be accompanied by commercialization and dissemination of the technologies, which is not the mandate and strength of research institutions and other public sector actors. Developing and implementing partnerships with the private-sector stakeholders that are active along the rice value chain is, therefore, essential to ensure that farmers can benefit from the new technologies and management options. In addition, synergies and efficiency gains can be created when the different stakeholders can focus on their core competencies and mandates.

6.3.3 Contract Service Provision

One of the CORIGAP partnership aims is to stimulate private companies and individuals to provide services to farmers. Typically, machines purchased by smallholder farmers through subsidized credit schemes end up abandoned when broken. In 2004, the IRRC and CORIGAP teams started with private-sector-driven contract service provision. Usually, when a technology is new and unknown, the project team and cooperating national institutions conduct demonstrations. Once benefits are observed, the service providers start to invest. There are five different business models observed for this:

- Farmer-ownership models are based on service provision on demand by individual farmers. This has the advantage of easy access although this model appears costly to the service provider. Moreover, farmer-operators are usually less skilled and more time-constrained than contract service providers focused on their business. In CORIGAP, this model was not promoted, except for the Super Bag.

- Collective ownership models involve farmer groups or cooperatives. IRRC/CORIGAP proposed this model for flatbed dryers, using existing cooperative structures in Balat village in Battambang province, Cambodia, and Bukidnon in the Philippines (IRRI 2011, 2012). The dryer in Balat was still used 10 years after the installation but not on a cooperative basis. The leader of the cooperative had appropriated the dryer, managed its maintenance and use, and charged a higher price to members and non-members. This allowed for coordinated use as well as for covering material costs and labor.
- Another business model combines the first and second models in that a single farmer invests in a new technology and hires it out to a group of farmers on a contract basis. As with the sole farmer ownership, this requires high upfront investment and, therefore, access to finance. An example for this model is Ms. Truong Thị Thanh Nhan from Vietnam, who bought the first laser-leveling set as a farmer and used it initially in her own 70-ha family farm. She then started providing a service to neighboring farmers (Gummert and Rickman 2013). The business model for her service provision was developed with assistance from the Vietnamese CORIGAP team.
- Two more models are specialized service agencies, fully public or fully private. Fully public services for agricultural machinery can be used for piloting new equipment where private-sector stakeholders are not existent. These require a clear pathway for commercialization. CORIGAP did not support the public model; however, it supported fully private services. Examples of the private specialized service agencies supported by CORIGAP are individuals and small- and medium-scale enterprises for land-laser leveling in Thailand supported by the Thai Rice NAMA (Nationally Appropriate Mitigation Action) Project (Nguyen et al. 2022). CORIGAP also promoted combine harvesting in Vietnam, which was taken up by private contractors (Gummert and Phan 2013). More than 90% of the rice fields in Vietnam are now harvested with combine harvesters.

The business models for machinery usage usually follow similar trajectories of development, as outlined below using laser leveling as an example. Usually, when a technology is new and unknown, service provision starts under a public-sector contract service provision model, as it did in the project through many demonstrations of laser leveling in farmers' fields conducted by the project team and cooperating national institutions. This is then often complemented by a government institution establishing a service like the Agricultural Engineering Department of the Ministry of Agriculture, Forestry, and Fisheries (MAFF) did in Cambodia. Once benefits for farmers and for machinery owners become more visible and demand for the operation is established, large-scale farmers such as Ms. Truong Thị Thanh Nhan in Vietnam, and private contractors start investing in the equipment. In order to speed up the introduction of a new technology, projects should include support to potential service providers from the beginning, as CORIGAP did.

6.3.4 Developing Equipment Supply Chains

Once farmers buy machines, supply chains, and after-sales services need to be established. Some equipment can be locally produced, such as flatbed dryers. Locally produced equipment has the advantage that it can be easily repaired in the area. These can be adapted to the location-specific needs of the farmers. For example, the flatbed dryer can be built for capacities ranging from 4 to more than 20 tons per batch and with different air-heating systems. Local production generates employment and R&D capacity among local manufacturers. Equipment produced by external manufacturers, often large multinational companies, requires locally established service providers. Components or spare parts can be locally produced, for example, the drag bucket for laser-leveling systems. CORIGAP assisted with the establishment of (service) supply chains for machinery through the following.

- Manufacturer training on new technologies such as the flatbed dryer and rice-husk furnace. This included developing training modules on maintenance and troubleshooting and piloting business models for use of the equipment and was followed up by technical advice on a need basis.
- Provision of design drawings, e.g., for the drag bucket for laser leveling to local manufacturers in Myanmar and technical advice during the manufacturing of the first prototype.
- Linking of international companies to potential importers and distributors in Vietnam, Myanmar, Thailand, and the Philippines.
- Including the private-sector players in the LAs, which facilitated networking.

6.4 Communication Process Within a Network: The CORIGAP LA as a Discursive Space

Here, we focus more on the communicative aspects of a multi-stakeholder platform of CORIGAP, the LA. The LA approach was initiated at IRRI for a postharvest project funded by the Asian Development Bank. It was successively incorporated into the IRRC and CORIGAP projects. This was started by conducting Participatory Impact Pathway Analysis (PIPA) workshops. PIPA is a method in which rice value chain actors collectively reflect on innovation-based problems, determine actionable points, and identify appropriate actors who can drive their desired impact. The LA was formed with network stakeholders relevant to specific technologies. The dynamic and flexible membership nature of an LA allows members to enter a discourse which, most of the time, entails and results in collaboration with other actors (Quilloy et al. 2015; Quilloy 2016; Flor et al. 2017; Gummert et al. 2022). At the end of each learning cycle, members share their reflections on the actions taken. These collective reflections build upon previous cycles, taking on new topics as they progress.

Communication within the CORIGAP LA cuts across varied stakeholder groups and, in many ways, is different from common outreach approaches used in research

(Table 6.2). Linear models are those that are one-way outreaches that researchers often use to inform end users or farmers about technologies (Leeuwis and Aarts 2011). Other approaches have increased feedback loops, such as the two-way transactional model (Leeuwis and Aarts 2011). In terms of the stakeholders engaged, the LA differed between the two in terms of the increased number and type of stakeholders as well as the temporary or emergent nature of their involvement (only when relevant to the topic). There is, however, a facilitator that enables sharing across these stakeholders. The LA also differed in the meaning-making process in that as different dialogues/learning are happening, these are brought to a broader group and, thus, the meaning is negotiated collectively (Table 6.2). A concrete example is when farmers test a technology on their farms and then the LA also discusses the timing and need for services. The service providers re-examine the costs and price of their service and the researchers share about the yield from the on-farm trial. Collectively, the LA members create meaning around what this technology entails. Although the same tools can be deployed in the LA, having a broad network entails other group learning and coordination tools.

6.4.1 Intermediary Outcomes from Using the PIPA and LA Approach in CORIGAP

For researchers, conducting a PIPA when starting activities in a country became common. It was implemented in Myanmar, the Philippines, and Vietnam. As an impact at the intermediary level, the facilitation of PIPAs by the CORIGAP team was then also requested from other IRRI projects in Bangladesh and Thailand. Conducting a PIPA to initiate activities proved highly beneficial for the project because, in addition to the intended output, the documented impact pathways, it produced three major outcomes:

- Understanding of the actor-specific impact pathways: The participatory process brings about a much more detailed understanding of the actor-specific impact pathways and measures for the project to support them than traditional planning processes.
- Ownership: Since all key stakeholders take part in this participatory process that usually takes at least 2 or 3 days, they develop through their contributions and participation a deep ownership of the project, even if the project does not have specific resources allocated to it. This constitutes a huge asset in the implementation of activities.
- Co-funding: The last point often leads to various partners co-funding activities that were jointly developed. In Vietnam, for example, after a PIPA was conducted in An Giang province, the An Giang Extension Service, and Loc Troi, both contributed

Table 6.2 Communication within the LA compared with common outreach models used in research (linear and transactional)

	Linear model	Two-way, transactional model	Communication in the LA
Stakeholders	Researchers and technology developers to farmers and end users via intermediaries	Researchers and technology developers to farmers and end users via intermediaries	Researchers, manufacturers, service providers, extension, companies, farmers, farmer collectives, private sector, government, and universities (membership is emergent and depends on the topic)
Meaning-making process	Meaning comes from the source (usually researchers or technology developers) and must be understood by the receiver (farmers)	Researchers obtain feedback from farmers. Meaning-making process is formed based on the interpretation of the farmers	Meanings can be co-created, where varied stakeholders, such as senders and receivers, engage in simultaneous dialogues. Through joint activities, this meaning-making process is facilitated, resulting in negotiated meanings for the collective
Activities	Technology training, field demonstrations, production of extension materials	Hands-on training, participatory, and adaptive research between scientists and farmers	Adaptive learning networks where multiple stakeholders have learning topics that go at plot/farm level and beyond (e.g., learning to coordinate and the price of machine services, finding incentive mechanisms)
Tools	Printed materials, radio, television, videos	Printed materials, radio, television, videos, interactive digital tools	Same tools, but there is facilitated learning and interaction to coordinate across stakeholder groups Participatory communication or group learning tools (e.g., visioning, opportunity assessments)

Adapted from Leeuwis and Aarts (2011)

33% each of the cost of the proposed activities to verify CORIGAP technologies in the Small-Farmer, Large-Field Program.

The LA approach has been used by CORIGAP in Vietnam, Cambodia, Indonesia, the Philippines, and Myanmar because it is a working methodology for facilitating the dynamic process of scaling out technologies using an impact pathway with different actors, which might require different partnership compositions at different times. Flor et al. (2017) concluded that including LA in adaptive research trials in Myanmar expanded the number of stakeholders with whom farmers interact. This broadened the learning agenda beyond the initial objectives of the project, which is often needed when scaling out mechanization and postharvest technologies.

6.5 Case Study: Socio-Technical Analysis of an LA for Adaptation of Flatbed Dryers in the Lower Delta, Myanmar

In what follows, we present results from a study addressing the question of how an LA supports self-organization in relation to the adaptation of flatbed dryers in Myanmar. The case study was based on participant observation during the activities of LA members, wherein monitoring of discussions was conducted. Observational data, exchanges with manufacturers, and project documents were the basis for the analysis of the technical and organizational re-design process. These were combined with focus group discussions and interviews with participants and non-participants in LA, covering laborers, traders, threshers, and reaper service providers, boatmen, NGO staff, researchers, and millers. In addition, 30 farmers from Kyee Chaung village, Mawlamyinegyun Township, Ayeyarwaddy Division, Myanmar, were individually interviewed on their involvement, practices, and management decisions as well as farming conditions within which they operate.

The initial concept of the flatbed dryer emerged in the 1960s in response to increased volumes of rice paddy from IR8 harvested during rainy periods (Douthwaite 2002). The yield increase created a bottleneck in the amount of paddy farmers could handle with sun drying (Ragudo 2011). In 2005, three representatives from Myanmar joined a training course on manufacturing dryers in Vietnam. From there, private-sector representatives built a large commercial dryer and a 1-ton IRRI dryer. They also started to locally produce Vietnamese-designed, 4-ton dryers. A private company, the Pioneer Postharvest Development Group (PPHDG), promoted these in Myanmar (see Sect. 6.3.2). This resulted in the installation of 47 dryers in the country by 2008 and 135 by 2011 (Kyaw and Gummert 2010). In 2013, IRRI, PPHDG, and NGO partners planned to introduce flatbed dryers of similar design through a project in the Lower Delta, Myanmar. The LA approach was taken on board to engage private, public, and civil-sector actors in an innovation network to jointly identify, share, and adapt suitable practices (Lundy et al. 2005; Stelling et al. 2009). Thus, a village-level LA was established with a focus on flatbed dryer technology.

6.5.1 Starting the Process: Network Building, Agreements, Shared Agenda

The starting group for the LA was a partnership involved in promoting agricultural technologies to benefit farmers in the Lower Delta (Table 6.3). They implemented activities with limited coordination. From the private sector, PPHDG, and Tin Oo Engineering, which had been producing dryers in other parts of Myanmar, were involved. Previously, Tin Oo Engineering made the components, while PPHDG promoted mechanical drying to government policymakers, rice millers, government staff, and farmers. By 2011, they had installed 135 dryers in the country. PPHDG, which represented the two companies in the LA, was operated as a business with an interest in corporate social responsibility (interview with PPHDG 2015). IRRI also collaborated with several NGOs in the Lower Delta that implemented community and livelihood support strategies for farmers. The organizations GRET (Professionals for Fair Development) and Welthungerhilfe were also involved in the LA. Both organizations had existing programs in the villages, including credit systems based on communally stored paddy.

One initiative emerging from the LA was to complement dryer operations with an existing credit system coordinated by the NGOs. Credit was provided to farmers when they stored part of their produce in communal storage. The collected grains were stored and managed by a committee of farmers for sale when prices were higher. The LA had an underlying objective to support farmers to obtain quality grains through timely drying and then storing communally to wait for a higher price. The set-up of the dryer, therefore, aligned with the interests of the NGOs and farmer groups involved in communal storage.

Farmers were aware of the organizational complexity of a shared dryer. This was not only with respect to the functioning of the device but also to changes in their relationship with millers. These concerns, listed in Table 6.4, influenced the agenda of the LA. Millers were part of the initial concerns of farmers because at that point farmers only had options to sell to traders or millers in Bogale and Mawlamyinegyun townships. If these millers controlled the price, the farmers would lose profit if they had to pay for drying services. The traders either lived in the village or came with their own laborers and transportation.

While convenient for farmers, traders coming to the village would pay low prices or have inequitable buying practices. The risk came from high reductions in price or weight as a penalty for wet grains, mixtures, dark grain color, or less-preferred varieties (interview with farmers, 2014). Millers could give better prices but were from 30 to 45 min away by boat, so farmers had to transport their rice when they wanted to sell. Road access was difficult between villages and town centers. Some roads were passable only by motorbike.

Many of the millers did not have dryers. Those who did have re-circulating batch dryers that were not suitable for drying small amounts of rice. Some had started to invest in parboiling machines (interview with millers 2014). The Myanmar Rice Federation (MRF), which regulates rice trade in the country, supported the increase

Table 6.3 Stakeholders involved at the start and through 2 years of activities compared with actors perceived by farmers to be part of the Learning Alliance network in Kyee Chaung, Mawlamyinegyun, Myanmar

Category	Village-level network*	Network at the start (2013)	Actors engaged by LA (2014–2015)
Private sector	Thresher operator	PPHDG (and Tin Oo Eng'g)	PPHDG
	Miller	Local millers	Local millers
	Trader	Village-based trader	Village-based trader
	Mechanic	Thresher operator	Thresher operator
	Boat owner	Town-based millers	Town-based millers
	Micro-finance		Thresher manufacturer
	Fertilizer seller		Fertilizer distributors and retailers
	Private lenders		MRPTA/Yangon-based traders
	Pesticide seller		Seed producers
	Seed grower		
Farmer group	Farmers	Farmers	Farmers
	Farmer leaders	Farmer leaders (representing 7 villages)	Farmer leaders (representing 8 villages)
	Laborers	Laborers	Laborers
NGO	GRET	GRET	GRET
		Welthungerhilfe	Welthungerhilfe
Research		IRRI	IRRI
			Local leaders
Government	Local leaders		DOA—township level

* Network of rice postharvest actors in the villages from stakeholder analysis by farmers in 2013

of parboiled rice exports (interview notes, 2014). With parboiled rice, millers were not strict about the color of the grains they bought. Farmers also said that millers around Bogale would buy any type of rice and would not provide a premium for good-quality rice grains (LA meeting notes, 2013).

There were actors influential in activities for drying rice whom facilitators of the LA had not considered but were flagged by farmers from the beginning. These were fertilizer sellers, micro-financiers, and private lenders. Farmers interacted with them at the start of the season to get a loan. These actors could impose repayment immediately after harvest, thereby limiting the selling options of farmers (FGD notes, 2014). The exchange was based on trust. Therefore, farmers were strongly pressured to meet payment deadlines if they wanted to get loans for succeeding seasons.

Table 6.4 Concerns discussed by farmer representatives[a] at an LA meeting in December 2013 on the establishment of a flatbed dryer

Need to clarify ownership (community or individually owned)
• There was experience of communally owned equipment that was not successful; concern by farmers that they could not access the equipment if ownership was unclear
• Suggestion for making a policy outline on the use; need to discuss this some more, GRET can help
• Can be privately owned but supports the community
• Suggestion: one person must own but partially pay for temporary investment
• Possible to explore a loan to be paid back within 2 years
Check if certification (FBD-dried rice) will lead to millers paying a higher price
Where to set up: start where there is communal storage, it might help to get it going
• Potential users make suggestions (in a future meeting)
• Someone from the project can participate in user-group meetings

[a]Farmer representatives were from five villages in Mawlamyinegyun and Bogale

6.5.2 Outcomes from Interactions

Interactions with market actors in Yangon continued in 2015 with farmers starting a small group that sold bulk grain there. Farmers also explored the difference if they sold in Mawlamyinegyun rather than Bogale. The dryer management committee explored boat rental, hauling labor, and warehouse services as additional services they could offer to increase the incentive for farmers to dry or to address observed constraints. Farmers also developed an interest in some varieties from an IRRI trial that they observed to be preferred at the wholesale market in Yangon. The LA continued to facilitate visits to seed farms to encourage farmers to find better sources of seed. PPHDG then linked the farmers to seed sources in other provinces in Myanmar.

Although the LA had an explicit agenda, members developed other linkages with synergistic effects that allowed actors to invest more in collaborative activities. IRRI and PPHDG introduced other postharvest technologies, including small threshers, solar bubble dryers, and hermetic storage options. IRRI, the NGOs, and farmers tried different varieties and crop production technologies (crop establishment, fertilizer, pest management). NGOs supported activities on credit and other livelihood improvements, for example, organizing and training landless women for rice harvesting. PPHDG and key farmers were involved in fertilizer retail. Interactions on fertilizer retail led to links with sources of pure seeds, although it also resulted in competing fertilizer recommendations.

There was interest from farmers to try the dryer. Mechanical drying is an option when the weather after the harvest does not allow sun drying. The tools and techniques farmers planned to implement in relation to LA topics are italicized in Table 6.5.

The reasons farmers mentioned for these choices related to the costs of mechanized drying. With a mean yield of 2.6 t ha^{-1} (S.E. Mean 152) sold at \$0.21 kg^{-1}, farmers obtained gross proceeds of US\$557 ha^{-1} (data from 47 parcels, assuming

Table 6.5 List of technical changes and percentage of farmers from Kyee Chaung who planned to implement them

Changes planned for 2015	N (30)	%
Use dryer	*7*	*23*
Use new variety	*5*	*17*
Use Bullock Head (brand) fertilizer	*3*	*10*
Plant Yadanar Toe (got seeds from Yezin through LA partner)	*1*	*3*
Thresh immediately after harvest	*1*	*3*
Change fertilizer application: at 15DAS use IRRI-rate but for 45 DAS add more	2	7
Compare Sin Thwe Latt with Sin Thukha	1	3
Use Integrated Crop Management (ICM)	1	3
None	2	7
Use drum seeder	1	3
Use alternate wetting and drying (AWD)	2	7
Use raised bed method	2	7
Use salt water for seed selection	1	3
Use seeds from 1 season before (not old seeds)	1	3
Stop using raised seed beds (takes more labor, too expensive)	1	3

Changes in italics are specifically related to LA topics; DAS = days after sowing

field-dry conditions, $n = 30$). They paid on average US\$70 ha^{-1} in total for post-production activities. Broken down, this was US\$27 ha^{-1} for harvesting, US\$22 ha^{-1} for threshing, US\$17 ha^{-1} for hauling, and US\$4 ha^{-1} for sun drying labor. With the use of the flatbed dryer, farmers said they had to pay an additional US\$20 ha^{-1}, based on \$11 ha^{-1} for drying service fee, US\$3 ha^{-1} for hauling labor, and US\$5 ha^{-1} for boat rentals. These were costs that had to be paid in cash when the service was provided.

Mechanically dried rice had no significant selling price difference from sun-dried rice. Price differences emerge over time and storage is a way to gain higher prices. One farmer noted a US\$15 t^{-1} increase in price after drying and storage. This translates to about US\$40/ha higher gross proceeds. Storing and waiting for a higher price, however, becomes difficult or even impossible if a farmer had debts to repay. The NGO initiative to buy grains, store communally with inventory credit, and then divide profit from a higher selling price was not implemented by the farmers interviewed. They said the warehouse was still at its trial stage and organizing for storage had just begun.

6.5.3 Outcomes on the LA Network and Its Activities

The LA network was formed with key organizations interested in the flatbed dryer. It included some actors at the village level, but not all the influential actors. A network with a specific scope, it expanded the rice postharvest network at the village through links with PPHDG, IRRI, DOA extension, millers and traders from Yangon, and other seed sources (Table 6.3). It also made use of already existing linkages, such as linkages between farmers and GRET, boatmen, or laborers (landless farmers and women).

Various activities targeted technical and social adaptation over time (Fig. 6.4). Notably, these activities happened simultaneously with some technical activities requiring a follow-up activity on the social aspects and vice versa. Moreover, while many in the networks were involved in these activities, various actors coordinated them (Fig. 6.4). They also put in their resources and engaged their own contacts external to the initial network. Some interactions around the dryer led to other activities that were synergistic and unplanned. These can be considered spin-off effects in that they were not controlled by LA facilitators. They also broadened the scope of the LA into other topics beyond the initial agenda. Bulk selling, additional services as a package with the drying service, sourcing of pure seeds, fertilizer retail, and new varieties are examples. These highlight the adaptive capacity of various actors in the network.

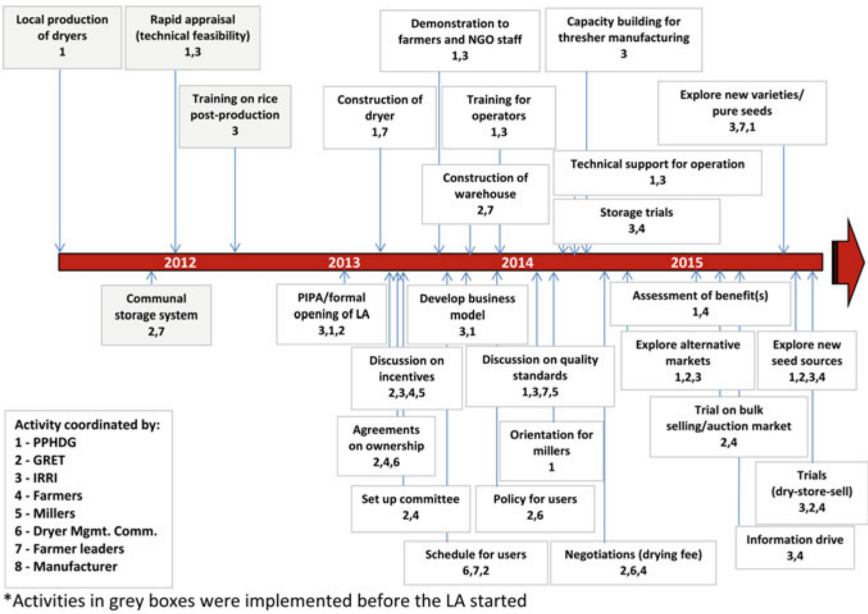

Fig. 6.4 Timeline with agenda around adapting a dryer: activities targeted for technical (top) and social (bottom) adjustments, and actors coordinating them (numbers), 2012–2015

The LA encountered conflicting interests. One is the linkages with wholesale markets that target higher prices for quality grains but also required producing only one variety in bulk. This contrasted with the interests of farmers to cultivate varieties suited to varying agro-ecological conditions of different parcels of land. Differences could be in elevation, location, duration of water flooding the fields (waterlogging), ownership, water level, and capacity to control water coming into the field from tidal effect or saline intrusion. Due to these, a farmer could plant rice in up to six different parcels in one season. This had implications for rice post-production.

Having different varieties required managing different grains at once in an effort to keep them separate. Possibilities for mixtures of grains were risks at different stages of post-production, particularly in drying. Moreover, farmers could not easily attain a bulk amount for a particular variety. Therefore, it required coordination with other farmers when using a 3-ton dryer. It also posed difficulties for marketing in bulk conditions. All these affected the socio-technical re-design process toward drying using flatbed dryers.

One effect of the LA observed by the project was its empowering nature. In the first LA meeting, the farmers had only participated quietly, mostly listening and only rarely providing an answer to a question when directly addressed. In succeeding meetings, they realized that their opinions were valued and that they could use the LA platform to start improving their conditions. They became very outspoken and started requesting information and activities, e.g., for learning from other villages or institutions.

The LA was on a good track to tackle the above-mentioned issues that were planned to be addressed in further LA learning cycles, but then unfortunately in some re-structuring of the project it was required to have a dedicated site for the project and not a site shared with other projects (e.g., LIFT and GRET) and CORIGAP project activities in Mawlamyinegyun Township came to an end by 2015. This was a pity because one batch of milled rice that had been dried in the flatbed dryer and was sold directly to the wholesale market in Yangon by the farmer group at a US\$120 ha^{-1} rice produced a price premium after deducting the costs for milling and transport. This just demonstrated how farmers' returns could be increased by improving postharvest and market linkages. The CORIGAP team is convinced that two more years of assisting the LA would have solved the remaining problems.

6.6 Discussion and Conclusions

The experiences from CORIGAP highlight various lessons for scaling technologies. There is a perception that scaling through partnerships is a linear process that can be planned and meticulously steered. Through the examples in this chapter, we can draw out some pillars that are useful for scaling. We can also see there are limits and boundaries that the context of the partnership creates.

6.6.1 The Private Sector and Its Role in Scaling

An important pillar is thinking systemically. There are various components that comprise a system, including technology, the network of relevant stakeholders, as well as policy or funding landscape. This automatically entails a diversity of partners. Moreover, it also entails that partnerships are selected to address change within the system. In this thinking, private-sector partnerships have varied roles to play. This is an aspect that should be systematically planned at the design phase of any research for development project looking to scale adapted solutions. While large multinationals are often targeted because of their financial capacity to co-fund projects, the experience of CORIGAP shows that there are many smaller companies that are often very innovative and local actors who can be essential for scaling out research results. There is no one-size-fits-all approach to public–private cooperation, and these smaller actors need to be included, possibly through facilitating a multi-stakeholder platform like an LA. To further the thinking, business accelerators can be a potential entry point to support private-sector stakeholders in scaling. These are recommendations for private-sector partnerships:

- **Start early**: Collaboration with the private sector should already be planned for in the project conceptualization phase and a budget needs to be allocated for facilitating the partnerships, e.g., through an LA and the initial activities during which the private-sector actors and the value proposition for the private sector might not yet be very clear. Partnerships need an understanding of the different partners. Therefore, a flexible budget that can be adjusted to needs and additional requirements that are identified once the project develops is of advantage.
- **Seek win–win**: Aim at a true partnership with the private-sector players in which they understand a clearly spelled out value proposition for them. This will result in co-funding from the private sector and ownership that will lead to sustainable scaling. Checkbook partnerships do not produce sustainable impact.
- **Seek synergies** by defining collaboration models in which each partner brings its strengths in terms of capacity, know-how, networks, and resources to the table and avoid duplication and competition. The development commercialization of the Solar Bubble Dryer by a public–private consortium as part of CORIGAP within a timeframe of less than 3 years demonstrates the potential of synergistic effects from such a partnership.
- **Understand partners' needs and capabilities**: Compared to the traditional partners of research projects like agricultural extension systems, e.g., are quite similar across countries and can work with similar approaches and messages. The private sector is very diverse ranging from a one-person business as a contract service provider to multinational companies. Each entity needs a different approach. Hence, time needs to be spent on understanding who the key potential private partners are, how they operate, and what their needs are. Involving private partners in an LA can facilitate this understanding.

- **Be quick in cooperation, but allow for sufficient time for scaling**: Private entities usually require quick actions and need a roadmap with a realistic medium-term outlook toward profitable sales of new products. With respect to dealing with private partners, urgency is usually required. However, in IRRC/CORIGAP, as well as previous projects of IRRI, it usually took a minimum of 10 years from the initial technology generation to broad, self-sustained uptake of mechanization, or postharvest technologies. The SBD was an exception, but in that case, the research and development relationships with GrainPro had long been established and the partners were already cooperating on other technologies. Nowadays projects are designed for three years or even shorter times, which is just not sufficient. If widespread adoption and impact are the aims of the project, plan for a phased project with a clear roadmap for the second phase for verification and scaling of technologies that have been developed and tested in the first phase and actively seek funding for the second phase. We appreciate because of the long-term commitment of SDC to fund first the IRRC and then CORIGAP for a total of 22 years scaling through the private sector could be conceptualized and successfully piloted.
- **Monitor and communicate successes**: This was a weak point in CORIGAP, and therefore, the impact of the successful public–private partnerships of the project was only documented on an anecdotal basis. As part of the monitoring and evaluation (M&E) system of the project and possibly initiated by a PIPA, design impact pathways and indicators for successful public–private cooperation and collect the information on a regular basis. New methods for measuring impact at the intermediary level might have to be developed.

6.6.2 Insights from Networks and Communication Within LA

Networks and communication among partners, as well as across varied levels, are another pillar. Consortia, platforms, and hubs are ways in which research engages varied partnerships. This has varied modes and purposes as seen in the CORIGAP experience. This could be the synergistic push for technology development, leveraging resources and capacities, enabling the spread of knowledge and access to technologies or services, or understanding business models that are working or can be adopted. Underpinning and often assumed or hidden behind partnerships is the communication that needs to happen in various forms, at different levels, and through different partners and groups. This is the social learning and negotiation aspect (Leeuwis 2004). Timing of actions is linked to the level of communication and thereby affects the sustained interest of different partners. Employing approaches, such as the LA, can support a learning process to align various social and technical adjustments.

CORIGAP piloted the PIPA and LA approaches for rice research for development and adapted it for use with different LA members, just researchers, and researchers and national extension agents and in Myanmar on the village level with farmers, local private-sector actors, such as traders and millers, NGO staff implementing complementary activities, and government extension workers. Besides the benefits outlined above, the two approaches also had significant benefits for project management.

6.6.3 Intermediaries and Finding Incentive Mechanisms for Change

Another important pillar for partnerships and scaling is the identification of important intermediaries. This could be related to extension or outreach but can also be services, equipment value chain partners, or even enablers of financial access. Thus, appropriate methodologies for engagement and exploring varied modes of collaboration could support scaling. The actions from this type of partner support farmers to deviate from their normal practices and try different options, such as new technologies, services, or markets (Pant and Odame 2009).

At the end of the day, the partnerships have to be seen as a niche within a broader system. It is often brought together through a shared interest in technology or practice. Partners that create or derive value from new technologies, processes, and linkages help the niche influence the broader system. Thus, the network is not the whole system. The technical adaptation is one thing that starts the formation of this niche, but for it to generate change and scaling, it also needs to extend toward social, organizational, and institutional re-design processes. Ensuring inclusivity and gender responsiveness is often assumed in the partnerships and networks being facilitated. This, however, needs to be emphasized to achieve equitable benefits for all stakeholders. Furthermore, incentive mechanisms are generated by different partners. It is important to identify who can create these incentives and how they can be harnessed to benefit farmers. Lastly, sustainable finance and accelerating business development or growth are important for various types of partnerships to flourish.

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Chapter 7
Incentive Mechanisms, Monitoring and Evaluation, and Communication of the CORIGAP Project

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Abstract In this chapter, we propose a framework of market-based incentive mechanisms for the adoption and scaling of sustainable production standards throughout rice value chains and review evidence of two mechanisms that have been piloted in Vietnam: "internalizing" and "embodying." The evidence suggests that sustainable production standards can be successfully "internalized" in rice value chains through policies (public governance) that provide an enabling environment for vertical coordination and private governance of standards (e.g., through contract farming). However, the major challenge policymakers and value chain actors face for this mechanism to succeed is to reconcile differences in contract preferences between contracting parties and solve trust and coordination issues (e.g., contract breach and side-selling). Market evidence suggests that sustainable production standards can be successfully "embodied" in rice products through certification and labeling. Vietnamese consumers were found to put significant price premiums on sustainable production certification and even more so if supplemental information is provided on certification and traceability. Both examples highlight the role policymakers can play in the adoption and scaling of sustainable production standards throughout rice value chains by creating an enabling environment for vertical coordination and private sector investment in certification and information campaigns. We conclude by discussing how policymakers can overcome the challenges for these mechanisms to succeed and identifying

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areas for future research. Furthermore, we provide a detailed description of the monitoring and evaluation process of CORIGAP activities. We explain the development from paper-based to computer-assisted survey tools, the evaluation of changes that farmers perceive and provide a case study on impact evaluation using econometric analysis. It becomes clear that a multidimensional project like CORIGAP needs a variety of means to assess the changes on different levels. We found that farmers in all CORIGAP countries perceive positive changes. Their yields and profits have increased, and the project has exceeded its target reach in all countries. This was also due to other funding schemes that supported CORIGAP technologies and practices, such as the rollout of 1M5R in Vietnam and the 3CT in China. The project used a variety of dissemination strategies to communicate the outputs and outcomes to a plethora of different stakeholders. Among the most successful were social media campaigns, including informative videos about CORIGAP technologies and practices. The chapter closes with some anecdotal evidence of how, especially postharvest technologies, influenced policies in the CORIGAP countries. We provide lessons learned from the project to be taken care of in future projects that aim to introduce sustainable agricultural practices and technologies to improve natural resource management.

Keywords Rice value chain · Knowledge management · Impact assessment

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7.1 Incentive Mechanisms for the Adoption and Scaling of Sustainable Production Standards Along Rice Value Chains: Evidence from Vietnam

Vietnam's agriculture sector has been a key driver to its economic growth and concomitant to poverty reduction. The sector contributes to around 14% of Vietnam's GDP, employs 38% of the national workforce, and has played a major role in reducing poverty to less than six percent (World Bank 2022a). Vietnam has positioned itself as a global producer and net exporter of rice for many years. This status has created opportunities for Vietnamese rice as a main export product and driver of its agricultural growth over the years. Rice production in 2020 was estimated at 28 million metric tons (FAOSTAT 2022), of which 5.6 million tons were exported to Africa and rice-importing countries in Asia, earning the country around US$3 billion in export revenue (UN Comtrade 2022). Vietnam has long maintained the status as a producer of low-quality rice (Demont and Rutsaert 2017), and rice exports face strong competition from India, Thailand, and Pakistan.

Despite the impressive growth in the sector, the country faces a trade-off between generating foreign exchange from rice exports and ensuring environmental sustainability. Vietnam's agriculture sector is the second main contributor to the country's greenhouse gas emissions (GHGEs) and about half (48%) of the GHGEs and more than 75% of methane emissions come from rice (World Bank 2022a). Growth in output and yield has also plateaued in the last decade, attributed to the adverse impacts of climate change and environmental degradation. Rice farmers receive lower net incomes compared to other farming households cultivating other crops (World Bank 2022a). This plateau in rice yield is expected to be further exacerbated by climate change. By 2030, climate change impacts may result in reductions in rice yields of over 6% and reach up to more than 13% by 2050 (World Bank 2022a).

This calls for urgent action for rice value chain actors to transition to more sustainable production practices, which would eventually provide an opportunity for Vietnam to raise its status as a producer of high-quality and sustainable rice and meet the rising global demands for sustainably produced products.

Here, we present a framework of entry points for introducing and scaling up sustainability along rice value chains. The succeeding sections dig deeper into two market-based incentive mechanisms that were piloted in Vietnam to understand how sustainable production practices could be robustly scaled up. We conclude by identifying key policy messages.

7.1.1 Spearheading Sustainable Rice Value Chain Development

In recent years, sustainability has been at the forefront of the development agenda through the Sustainable Development Goals (UN 2015). Achieving sustainability in food value chains requires a holistic approach by ensuring sustainability not only from an economic perspective but also from social and environmental points of view (FAO 2014). A sustainable food value chain is defined by FAO (2014) as "the full range of farms and firms and their successive coordinated value-adding activities that produce particular raw agricultural materials and transform them into particular food products that are sold to final consumers and disposed of after use, in a manner that is profitable throughout, has broad-based benefits for society and does not permanently deplete natural resources." The implication is that strong linkages and well-coordinated activities among actors from production to consumption need to be in place to upgrade food value chains.

Improving value chains, also referred to as value chain upgrading, thus requires a holistic approach engaging with the different actors depending on the identified bottlenecks along the value chain and potential for improvements. Marketlinks.org defines five different types of upgrading. CORIGAP-specific examples where the project contributed to the introduction of more sustainable practices working toward sustainable production standards will be given in the definitions below.

Process upgrading increases the efficiency of production either through improved technology or through better organization of production. An example from CORIGAP is the development and introduction of hermetic storage systems to replace traditional seed and grain storage systems and the losses incurred in those.

Product upgrading improves product quality and value for customers. The SRP sustainability standard, which is one tool co-developed by CORIGAP, is one tool to facilitate product upgrading by introducing certified SRP rice.

Functional upgrading is the entry of a player into a new, higher value-added function or level in the value chain. It can also include a restructuring of roles in the value chain, e.g., in contract farming schemes. CORIGAP did not engage in facilitating or supporting functional upgrading but extensively studied examples in Vietnam and captured the lessons learned as described below.

Channel upgrading occurs when an actor enters one or more new end markets with the same basic product. Examples are enabling farmers to sell high-quality rice in the retail market in Yangon instead of low-quality rice to local millers in Myanmar (see also Sect. 2.1) or working with farmers and millers in Vietnam to produce Sustainable Rice Platform (SRP) certified rice (see below).

Intersectoral upgrading is the entry of an actor into a completely new value chain or industry, assisted by CORIGAP, e.g., through the support of sustainable rice straw management, which is required to develop and pilot value chains for rice straw products.

Consumers in international food markets are increasingly paying attention to how food is produced. Intent to purchase products that meet certain standards, such as inclusiveness, reduced environmental footprint, and safety, is undoubtedly growing. Sustainably produced products and organic foods are generally perceived by consumers to have higher nutritional value and be safe to consume. Consumers demand safer and higher-quality products. Value chain actors can capture this economic opportunity from these growing market trends by upgrading value chains by improving product quality, processing, and diversifying varieties, products and by-products, and market channels. Smallholders can tap into higher-quality markets by adopting sustainable production standards.

Sustainability in the rice sector is promoted through the SRP Standard for Sustainable Rice Cultivation, the world's first voluntary standard for producing sustainable rice. The Sustainable Rice Platform (see www.sustainablerice.org) is a global multi-stakeholder alliance convened in 2011 by the UN Environment Programme (UNEP), the International Rice Research Institute (IRRI), and German Agency for International Cooperation (Deutsche Gesellschaft für Internationale Zusammenarbeit, GIZ). The standard sets more efficient standards for rice cultivation and includes requirements that assess the sustainability of a rice cultivation system via 41 requirements which fall under eight broad themes. In 2010, IRRC scientists were involved in initiating the SRP by conducting four studies on the rice value chain in Thailand, which included a Participatory Impact Pathway Analysis (PIPA) workshop on sustainable rice production in cooperation with UNEP and the Thai Rice Department. CORIGAP scientists and national partners then worked on the definition and verification of the sustainability indicators for rice and on the development of a field calculator for sustainable rice.

Mainstreaming rice sustainability standards implies understanding the mechanisms that can be used to encourage the uptake of sustainable production standards along rice value chains. Ideally, an optimal mix of multiple strategies should be implemented to upgrade value chains. Figure 7.1 proposes a portfolio of eleven entry points along rice value chains which could be targeted for upgrading strategies that aim at enhancing their sustainability and making them more responsive to emerging market opportunities in this space: breeding, agronomy, postharvest, by-products, contract farming, markets, finance, policy, input provision (seeds), service provision, and credit markets.

Breeding. Breeding is the very first entry point that can be tapped into for building sustainable rice value chains. For example, rice breeding programs can strategically incorporate market intelligence across the three dimensions of sustainability (economic, social, and environmental) into product design. In value chain upgrading jargon, this is termed "product upgrading" (Demont et al. 2020). Market-driven, gender-intentional, and climate-resilient target product profiles (TPPs) can guide rice breeding programs in varietal development (Polar and Demont 2022) and hence help build ("pushing") sustainability in rice value chains at their very basis.

Agronomy. There are significant yield gains and environmental benefits that can be achieved through improved agronomy. Even with the best available sustainability-enhancing rice varieties developed through breeding, poor agronomic practices at farm level remain important bottlenecks for the success of value chain upgrading, as they may result in poor quality of paddy and, consequently, poor quality of milled

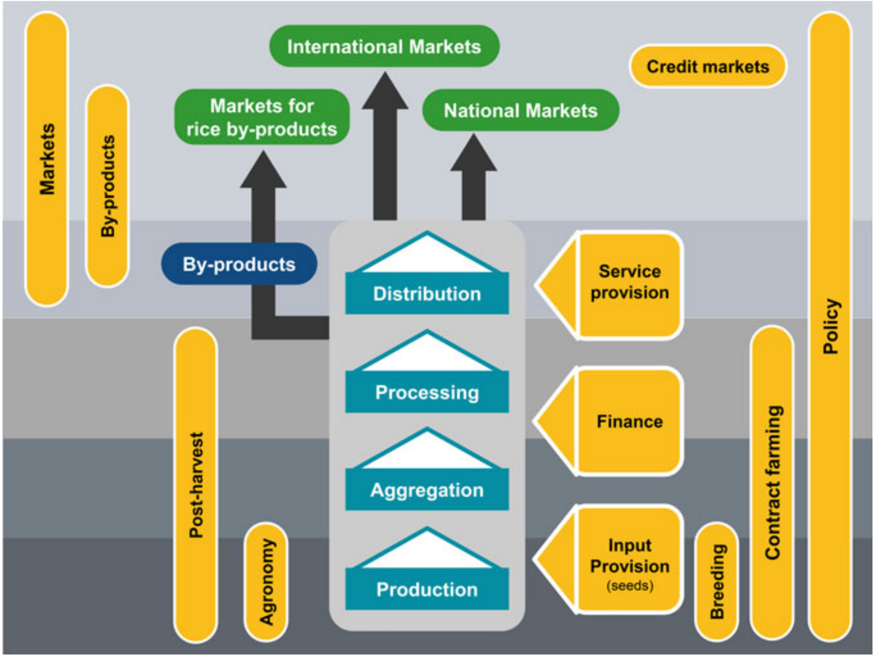

Fig. 7.1 Entry points for sustainable production standards in rice value chains (adapted from FAO 2014)

rice, which can affect the marketability of rice produced. Targeting agronomy as an entry point for sustainability could be through "process upgrading" by developing and encouraging the adoption of sustainable and climate-resilient production practices such as proper land and water management and the use of seed and climate-responsive technologies. Voluntary standards such as the Vietnamese Good Agricultural Practices (VietGAP), Global Good Agricultural Practices (GlobalG.A.P.), organic, and Hazard Analysis and Critical Control Points (HACCP) are being offered for uptake in the Vietnamese food market (My et al. 2017, 2018a, 2021). These standards were introduced in the food market to respond to food safety issues (My et al. 2021). VietGAP is a national GAP standard which comprises cultivation practices that ensures food safety and quality of various crops, including rice, whereas GlobalG.A.P. is a widely applied cultivation practice for agricultural products (My et al. 2017, 2021).

There are agronomic technologies available for farm-level uptake that could help in reducing GHG emissions and increase farmer incomes. For example, in recent years, the Vietnam government has been putting substantial efforts into encouraging farmers to adopt sustainable practices through the implementation of "One Must Do, Five Reductions (1M5R)" (see Chap. 4), a technology package which recommends the use of certified seeds ("One Must Do") and reductions in seed rate, nitrogen application, pesticide use, water use, and postharvest losses ("Five Reductions").

Recent research by Connor et al. (2021a) in Vietnam showed that the main drivers of adopting the whole 1M5R technology package at the farm level are: ease of implementation, education, satisfaction, and non-rice income. It is worth noting that farmers opt to follow selected components of the technology package, with most of them following the requirements on the reductions of pesticide and postharvest loss and the use of certified seeds. On the other hand, they tend to face constraints in adopting the requirements for the use of fertilizer, water use, and seed rate. Farmers reported encountering difficulty in adopting these practices citing challenges such as practices not coinciding with their cropping pattern and weather conditions.

Postharvest. Postharvest "process upgrading" is another entry point for sustainability that can be targeted by focusing on improving practices that reduce losses and contribute to value-addition to farmers and other value chain actors. Reduction in losses incurred could be addressed through improvement in postharvest equipment used for threshing, milling, drying, processing, and storage for grains (see Chap. 4). Needs and opportunity assessments could be conducted in each region to understand underlying gaps in the practices, especially unsustainable practices and to make sure that the technologies and innovations developed are catered to the needs of each area. Postharvest can also include "product upgrading," e.g., if quality-ensuring postharvest technologies like hermetic storage systems or mechanical dryers are introduced to comply with the SRP standard.

Input Provision. The provision of inputs is usually seen as the responsibility of the private sector. This works well for fertilizer and agrochemicals, for which profit margins are attractive enough for companies to engage but is still lacking for quality seeds. The seed replacement rate (SRR) for rice, which is defined as the percentage of area sown out of the total area of crop planted by using certified or quality seeds rather than farmers' own seeds, is typically below 20% in Southeast Asia (unpublished data). Strengthening national seed systems is, therefore, still an important entry point, especially since the use of quality seed is a precondition for maximizing yields and input use efficiency and such important for closing the yield gaps. While working on seed systems was not a formal activity in CORIGAP, CORIGAP scientists have contributed to national efforts, e.g., by promoting hermetic storage systems, especially the Superbag, for public and private seed processors in all countries, developing a concept and business plan for a community seed processing center in Cambodia and providing assistance to community seed centers in Cambodia.

Service Provision. Contrary to new varieties that can be disseminated through existing seed multiplication processing and dissemination channels, the sustainable introduction of machines for fostering mechanization and upgrading postharvest is different. It requires a mix of setting up or supporting an equipment supply chain, financing (see below), and the establishment of training and after-sales services. Machinery that is beyond farmers' reach, this supply chain also requires the design, verification, and piloting of business models for providing a machinery service to farmers, particularly when the technology is new and the benefits are not yet obvious for the end users or contract service providers. Examples from CORIGAP are the installation of flatbed dryers and the business models for farmer groups in Myanmar and Indonesia, and pilots for contract services with laser leveling equipment in Vietnam and Thailand (see Sect. 6.3 for collaboration with the private sector).

By-products. The common practice of burning rice straw left in the field adds to pollution and greenhouse gas emissions (Nguyen et al. 2019; see Chapter 5). However, despite many prohibitions, it remains to be widely practiced by farmers who consider it as waste material. In Vietnam, the improper management of rice by-products, such as rice straw and husk, is one of the key contributors to greenhouse gas emissions (World Bank 2022a). Therefore, diverting by-products to more sustainable uses can be a powerful entry point for increasing the sustainability of value chains, e.g., by developing new products ("product upgrading"), expanding existing markets ("channel upgrading"), and developing new markets ("intersectoral upgrading"), supply chains and processing technologies ("process upgrading") for rice by-products to reduce unsustainable practices (e.g., Nguyen et al. 2016, 2019; Demont et al. 2020). Policymakers can encourage the diversion of straw utilization from unsustainable practices to more sustainable uses, thereby ultimately contributing to the mitigation of climate change. For example, rice straw can be used in many ways, either as an input to other food or non-food value chains such as for mushroom production, fodder production, or as mulching material (Nguyen et al. 2016; Demont et al. 2020).

Contract farming. The more value chains evolve from traditional, fragmented "supply chains" (with many intermediaries operating through arms-length transactions with little coordination) toward value-focused chains that are vertically coordinated by agri-business firms, the more a potential emerges for deploying private governance through vertical coordination (e.g., contract farming, which can be classified under "functional upgrading" in value chain upgrading jargon) as an entry point for internalizing sustainability (Demont and Rutsaert 2017). Through production contracts with farmers, agri-business can govern product quality and practices more effectively. In Africa, farmers sometimes resort to contract farming to access finance (Soullier et al. 2020). Vertical coordination between agri-business and farms engenders transaction costs and, therefore, often requires a critical level of horizontal coordination among farms to generate economies of scale for it to become profitable (Ba et al. 2019), which is illustrated through the case of Vietnam below.

Markets. Consumer demand in end markets is a powerful entry point for "pulling in" sustainable production standards along rice value chains. "Embodying" sustainability in the product (as part of "product upgrading") through labels and encouraging consumers to consume certified sustainably produced rice through product labels and certification is a well-known market-based incentive mechanism for sustainability in value chains (Demont and Rutsaert 2017). Building consumer trust and confidence in sustainable quality standards can be facilitated by using quality labels and certifications as communication tools. Strategies to convey the information to consumers should be effective in providing consumers with comprehensive information on the quality aspects certified by sustainability labels.

Finance. As mentioned, insufficient access to finance often constrains value chain upgrading (Soullier et al. 2020). The availability of financial services along value chains facilitates the adoption of improved production technologies and improves linkages among actors. Making access to finance conditional upon the adherence to sustainable production standards could incentivize value chain actors to comply with these standards (e.g., green bonds).

Policy. Public governance through policy has been traditionally used by governments to incentivize (the so-called carrot) the adoption of sustainable practices and disincentivize (the "stick") the adoption of unsustainable practices. By providing the right mix of incentives and disincentives, farmers can be nudged toward the adoption of sustainable production practices. The CORIGAP predecessor project Irrigated Rice Research Consortium (IRRC) influenced policy informally by making sure that IRRC scientists visited national policymakers during their travel and updated them on project progress, and lobbied for linkages to national programs. The IRRC and CORIGAP also had an advisory committee in which high-level research managers and policy members from all partner countries were represented. There were a few dedicated events for fostering a policy dialogue. In 2007, a seminar was conducted for policymakers in Indonesia. During CORIGAP, seminars targeting policymakers were conducted in Vietnam on laser leveling (2013), hermetic storage (2017), and sustainable rice straw management (2018). Project outputs and outcomes were also communicated to policymakers through the IRRC publication RIPPLE and during CORIGAP, in particular during the final phase through the various communication channels (see Sect. 7.5.1).

The IRRC started as a research project and moved into scaling out with CORIGAP. Influence on policy was significant but could have been larger with more efforts on policy dialogue. New projects should, therefore, include the facilitation of a policy dialogue at the planning stage and also develop an M&E system for capturing the impact on the policy level.

Credit markets. In case rice markets and value chains provide little incentives for embodying and internalizing sustainability, a last resort would be to "disembody" the sustainability claim from the product through credit markets, such as, for example, through carbon credit markets or "Book & Claim" mechanisms (Demont and Rutsaert 2017). The principle is that a credit buyer acquires credits for the sustainable production of rice, which are transferred to certified farmers or agri-business firms that produce the rice and market it through the existing supply chain as conventionally produced rice, i.e., without segregation or identity preservation. This requires little changes in vertical coordination between farmers and agri-business, but the disembodiment of product and production standards entails challenges in terms of building consumer trust.

The entire rice production system can be conceptualized as a socio-technical system in that it includes a network of actors, materials or tools, knowledge, norms, regulations, and standards for behavior (Geels 2004). In a socio-technical system, there is a regime which is the current, widely adopted, or dominant technology, along with the practices and routines that hold it in place (Geels and Schot 2007). The entry points described in Fig. 7.1 target change in aspects of the socio-technical regime. Changes across multiple entry points can enable sustainable practices to become mainstream thereby reconfiguring the current socio-technical regime. When the regime has changed, this entails changes not only in the techniques, tools, and knowledge but also in the social mechanisms that enable its sustained and widespread use.

7.1.2 Internalizing and Scaling Sustainable Production Standards Through Contract Farming

Facing rising labor and input costs, the Vietnamese rice sector can no longer sustain its status as a low-cost, low/medium-quality rice exporter in the international market. Therefore, the Vietnamese government is strategically investing in an enabling environment for vertical coordination in rice value chains with the aim of encouraging value chain upgrading to increase product quality and reduce poverty (Demont and Rutsaert 2017; Ba et al. 2019). Since the early 2000s, the Vietnamese government has been implementing policies that encourage rice exporters to directly engage with farmers through contract farming (as opposed to relying on traders in spot markets). In 2002, Decision 80/2002/QD-TTG was crafted and served as a legal and regulatory framework for contract farming. This policy, however, faced constraints limiting the adoption of contract farming, such as high rates of contract breach, and the policy was not inclusive as it encouraged the participation of large-scale farmers instead of smallholders (Ba et al. 2019). To address the scale bias, in 2013, Decision 80 was revised and augmented by Decision 62/2013/QD-TTG with the inclusion of the "Small Farmers, Large Field" (SFLF) program that aimed at generating economies of scale by encouraging land consolidation and horizontal coordination among smallholder farmers. Decision 62 was designed to address the issues of low adoption and contract breach. In 2018, Decree 98/2018/ND-CP was implemented, which included incentives for farmer organizations that would formally engage in the SFLF scheme. The Vietnamese government further supported a large-scale program of Sustainable Agricultural Transformation (VnSAT). This included institutional strengthening to support agricultural transformation and support of sustainable rice-based systems (World Bank-Vietnam 2016). VnSAT also provided mechanisms by which groups of farmers are incentivized to implement sustainability standards and benefit from these through linkages with contract companies (Flor et al. 2021).

These policies successfully encouraged rice farmers' participation in contract farming. Data show increasing rates of participation in contract farming since 2013 in Can Tho province, where most rice exporters are based. In 2022, the area devoted to contract farming in Can Tho attained 19%, a considerable increase from the four percent rate recorded a decade earlier in 2013 (Table 7.1).

To robustly scale up the implementation of contract farming, it is essential to determine what drives farmers' participation in order to devise strategies for developing inclusive contracts between farmers and exporters. Empirical research by Ba et al. (2019) carried out in the south of Vietnam showed that the main drivers that influence

Table 7.1 Rice farmers' participation in contract farming (CFa) in Can Tho, Vietnam, 2013–2022

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Total planted rice area (ha)	236,539	232,336	237,950	240,023	240,126	237,326	225,143	222,999	222,376	216,385
Area under CFa (ha)	10,304	15,612	17,441	19,107	22,672	29,606	35,368	38,437	39,716	40,465
Area under CFa (%)	4%	7%	7%	8%	9%	12%	16%	17%	18%	19%
Number of households	8,536	9,973	12,933	13,515	15,762	21,061	27,197	27,763	28,072	28,872
Rice volume (t)	68,625	103,976	116,157	127,253	150,996	197,176	235,551	255,990	264,509	269,496
Productivity (t ha^{-1})	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66	6.66

Note Rice volume was calculated by multiplying the area under contract farming by the average yield of 6.66 tons per hectare
Source of data Ms Pham Thi Minh Hieu of DARD Can Tho

farmers' participation in contract farming are: perceived access to secured markets and membership in the SFLF program. Membership in the SFLF program boosts participation in contract farming from 46 to 73%. Other factors influencing participation in contract farming include public training, age, family size, and membership in farmer associations. Conversely, a lack of trust in export firms is a serious hurdle for farmers to engage in contract farming.

In a more recent study, Quilloy et al. (2021) set up a negotiation exercise between farmer groups and export companies to design an inclusive rice farming contract that could encourage farmers to adopt sustainable production standards. The authors found that there needs to be a safe space for both parties in order to negotiate mutually beneficial contract terms. At the end of the negotiation exercise, participants reached a consensus on different contract attributes. Both parties agreed on a seven percent price premium and pre-financing of a package of essential inputs (branded seed, fertilizers, pesticides, and/or credit). Producing medium-quality rice following standards set by export companies was also amenable to both parties. Some heterogeneity on the optimal level of pre-financing was also noted during the workshop; buyers prefer "total" pre-financing (i.e., a fixed package of seed and chemicals), while some farmer participants prefer "partial" pre-financing to allow for some flexibility in the choice of the chemical dose and brands (to reduce input costs). At the end of the negotiation exercise, however, both parties agreed on total pre-financing under the condition that it would be under the control of the farmers' group (indicating a strong preference for farmer sovereignty). It was worth noting that farmer groups and export companies were receptive to the idea of adopting sustainable production standards such as VietGAP and GlobalGAP as long as compliance is rewarded through price premiums.

Underlying these contracts are the enablers wherein techniques, tools, and skills are scaled to many farmers. This, for example, includes the knowledge outreach and sharing of technologies that allow farmers to meet the standards. It also includes the monitoring and peer influences that enable the implementation of sustainable practices. This alignment between knowledge outreach and contract mechanisms creates a push-and-pull approach for knowledge dissemination and scaling of innovations (Totin et al. 2019).

7.1.3 Embodying and Scaling Sustainable Production Standards Through Product Labels and Certification

Rice consumers exhibit different preferences regarding the quality attributes of rice that they consume (Bairagi et al. 2020, 2021; Calingacion et al. 2014; Cuong et al. 2022; Custodio et al. 2016, 2019; Xu et al. 2018). These preferences differ in terms of both extrinsic and intrinsic quality attributes of rice. Rice consumers do not only take into account grain appearance, cooking quality, and sensory characteristics of rice grains (Custodio et al. 2016, 2019) but also put a premium on extrinsic attributes, such as labels and brands (e.g., Bairagi et al. 2020; Cuong et al. 2022; My et al. 2018a, b; Xu et al. 2018). Xu et al. (2018) found that extrinsic product attributes like an informative label on rice packages and brands influence consumers' decisions to purchase. Products featuring informative labels are a main factor influencing consumer purchase of rice and were the second highest rated factor of consumers following the taste of rice. In addition, consumers who have higher incomes are more likely to purchase branded rice. In Vietnam, consumers' perception of extrinsic product attributes such as packaging and labeling and certification affect their decision to purchase organic products (Luu 2019).

In order to encourage the adoption of sustainable production standards, sufficient knowledge of consumer awareness, acceptance, and willingness to pay for products that are sustainably produced need to be analyzed (My et al. 2018a, b). Sustainable production standards are credence attributes which means they only add value if consumers trust them (Barcella et al. 2018), indicating the importance of communicating them through product labels and certifications, which could aid in their purchase decisions (Demont and Rutsaert 2017). When it comes to buying food products, food labeling can serve as an important channel in conveying information to consumers, thereby influencing their purchase decisions (Verbeke 2005; Demont and Rutsaert 2017). With the right packaging, attributes such as quality, traceability, and production practices could be effectively communicated to consumers (Bairagi et al. 2021).

Recent research in Vietnam suggests that if consumers are knowledgeable and are given sufficient information about sustainability, they can recognize the importance of sustainably produced rice and will be willing to pay a premium for it. The study done by My et al. (2018a, b) was designed to draw out consumers' WTP for certified sustainably-produced rice. Using the Becker, DeGroot and Marschak (BDM) auction mechanism, they examined the effects of gradually increasing information levels provided to consumers. The study found strong evidence that consumers put price premiums on sustainable production certification, and the mean values increased as additional information was presented to them. Consumers who are knowledgeable about food quality certification were willing to pay more for quality rice compared to consumers who do not trust the certification system. In other words, consumers have a positive attitude toward purchasing sustainable rice when there is sufficient information about the product. The study also revealed that consumers who read food labels when they purchase food were also found to be willing to pay more for quality rice compared to those who do not always read food labels. In addition, wealthier consumers were also prepared to pay higher price premiums. This is consistent with the findings of some studies in China, which found a positive relationship between the willingness to pay for organic foods and the consumers' purchasing power (Gan et al. 2016; Xu et al. 2018). Consumers who believe sustainably produced rice features health benefits and provides "good value for money" were also found to be willing to pay price premiums.

Connor et al. (2022) conducted a study within the same vein and looked into the perception of consumers about sustainable rice production and knowledge about climate change and determined how these factors influence willingness to pay for certified SRP-labeled rice. The results showed that consumers are willing to pay a

29% price premium for SRP-labeled rice. Consumers' willingness to pay for sustainably produced rice was influenced by their household income and their knowledge about CO_2 and the greenhouse effect. They also added that knowledge about climate change consequences could also be included as a predictor of consumers' willingness to pay for SRP-labeled rice.

More recently, Cuong et al. (2022) investigated how consumers make trade-offs between sustainability and health attributes in their purchase of rice. Using choice experiments, the authors determined consumer preferences and attributes for sustainability and health attributes by using four certification labels, namely, low-emission, eco-friendly, ethically-produced, and low glycemic index. The estimated price premiums were in the range of 28–66%, with the highest premiums recorded for the low glycemic index label and the lowest for the low-emission label. These results suggest that consumers put more value on attributes that affect personal health than attributes that affect planetary health and the welfare of others.

7.1.4 Conclusions

Here we proposed a framework of market-based incentive mechanisms for the adoption and scaling of sustainable production standards throughout rice value chains. We proposed eleven entry points, i.e., breeding, agronomy, postharvest, by-products, contract farming, markets, finance, policy, input provision (seeds), service provision, and credit markets, and reviewed evidence of two mechanisms that have been piloted in Vietnam.

Contract farming can be used to encourage farm-level uptake of sustainability standards in rice value chains as long as participation is inclusive of smallholders. Success also crucially hinges on informing value chain actors of the benefits of sustainable production standards. The case of Vietnam has shown that judicious public governance can trigger private governance of rice value chains, which provides an efficient entry point for "internalizing" sustainability in rice value chains. This further shows an alignment of elements that create a shift in the current socio-technical regime that enables sustainability standards to scale. These elements in the case highlight potential entry points through technical knowledge, incentive mechanisms, coordination and linkages, markets and regulatory mechanisms.

Consumers, especially in the international markets, are developing preferences for products that meet sustainable production standards. They are increasingly becoming health and environmentally conscious, more knowledgeable about production standards and exhibit demand for extrinsic quality attributes. Rice value chains can tap into these economic opportunities by adding value to products through product upgrading. To capture the market share for sustainably-produced products, consumers need to be adequately informed about their benefits. Labels and certifications can be used as communication tools to respond to the emerging demand for sustainably produced products, and messaging can focus on climate change as the most salient reason for change.

Moving forward, it will be important to build market-based mechanisms to reward value chain actors for adopting sustainable production standards. Policymakers and value chain actors can simultaneously target multiple entry points along rice value chains with multiple upgrading strategies (e.g., product, process, functional, channel, and intersectoral upgrading). Depending on the context, the challenge will consist in finding the "optimal" investment portfolio of upgrading strategies along the "pull" and "push" continuum that maximizes the sustainability of rice value chains. Breeding is an obvious first upstream entry point for "pushing" sustainability throughout value chains by ensuring varieties are developed that are market-driven, gender-intentional, and climate-resilient. There are varied actors that influence agronomic practices of farmers. Here, contract farming is an important coordination mechanism for ensuring knowledge outreach, enabling access to technical support, and the regulatory aspect for sustainability standards. Further, the more rice value chains are "pulled" by downstream consumers thanks to increasing incomes and stringent standards in international markets and buyers that are conscious about social and environmental challenges, the more "embodying" sustainability through product upgrading has a chance to pay off and subsequently incentivize upstream process upgrading at farm level and beyond. Market studies with both domestic and international consumers have to be conducted to assess the level of "pull" incentive for downstream rice value chains that can be generated in these markets. The more rice value chains are vertically coordinated, the more potential exists for "internalizing" sustainability mid-stream through private governance if agri-business firms can be incentivized (e.g., through downstream consumer demand for certification) to invest in sustainable production standards. The higher the levels of marketable surplus and spatial consolidation of the supply of rice and hence its by-products (which is typically the case in the Asian Mega Deltas), the higher the potential for intersectoral upgrading ("push") by developing markets and supply chains of by-products to divert unsustainable practices toward more sustainable uses. Hence, as rice value chains develop, entry points for sustainability naturally emerge following a trajectory from process upgrading to product upgrading and further to functional, channel, and intersectoral upgrading. In other words, there is no one-size-fits-all and future research needs to be conducted to determine the optimal policy mix that can accelerate rice value chain upgrading toward increasing sustainability.

7.2 The Evolution of CORIGAP Data Collection Mechanisms for Monitoring and Evaluation, Learning, and Assessment of Changes

The CORIGAP project has implemented best management practices and technologies in its partner countries to improve food security and gender equity and to alleviate poverty through improved production and sustainable natural resource management. Such ambitious outcome targets require that all key stakeholders contribute to achieving desired results and have aligned their tools and processes in monitoring performance indicators. To effectively monitor and evaluate project interventions, it is imperative to capture high-quality data in a timely and coordinated manner. This enhances the support for informed decision-making for national partners and policymakers.

Qualitative and quantitative methods are equally essential tools for collecting information. Qualitative data collection tools include online forums, in-depth interviews, and focus group discussions collecting non-quantifiable information, such as feelings, perceptions, and reasons. Quantitative data collection, however, gathers measurable information and is administered through face-to-face, online, mail, or phone interviews. Traditionally, data collection was conducted using pen-and-paper personal interviews (PAPI). With technological advancement, data collection evolved quickly and made computer-assisted personal interviews (CAPI) more popular.

Household surveys were conducted at various intervals to gather a comprehensive set of socio-demographic and agronomic data of farmer groups operating in lowland rice ecosystems. This data-led activity provides estimates of changes in practices, input costs, production, and perceptions before, during, and after project intervention. The team conducted baseline, midline, and end-line household surveys in Myanmar, Thailand, Vietnam, and Indonesia between 2014 and 2022. The baseline surveys were implemented before introducing the interventions. In contrast, the midline surveys were completed five years into the project, and the end-line surveys were conducted after seven years of uptake. In addition, cross-sectional single-point surveys were also conducted in Vietnam, Thailand, Myanmar, Indonesia, and China to investigate farmers' perceptions of change due to technology and practice adoption.

In 2012, we used pen-and-paper personal interview (PAPI) for the baseline data collection in Myanmar. However, for the remaining surveys, covering baseline, midline, end-line data periods, and cross-sectional surveys, computer-assisted personal interviews (CAPI) were used. CAPI is a method of collecting data using tablets or smartphones. In the following part, we will share the lessons learned from the experience of collecting data via PAPI and will also cover the learnings from the Irrigated Rice Research Consortium (IRRC) project, which preceded CORIGAP and had similar project interventions, funded by the Swiss Agency for Development and Cooperation (SDC).

7.2.1 Case 1: Pen-and-Paper Personal Interview (PAPI)

The process of paper-based data collection we used in our household surveys is illustrated in Fig. 7.2. The process started with designing and printing the survey questionnaires. Designing questionnaires involved inputs from different scientists and National Agricultural Research and Extension Services (NARES) partners. The questionnaire was translated into the local language of the survey sites. Measurement units were adjusted to local measures (e.g., pyi instead of kg in Myanmar). Pre-testing

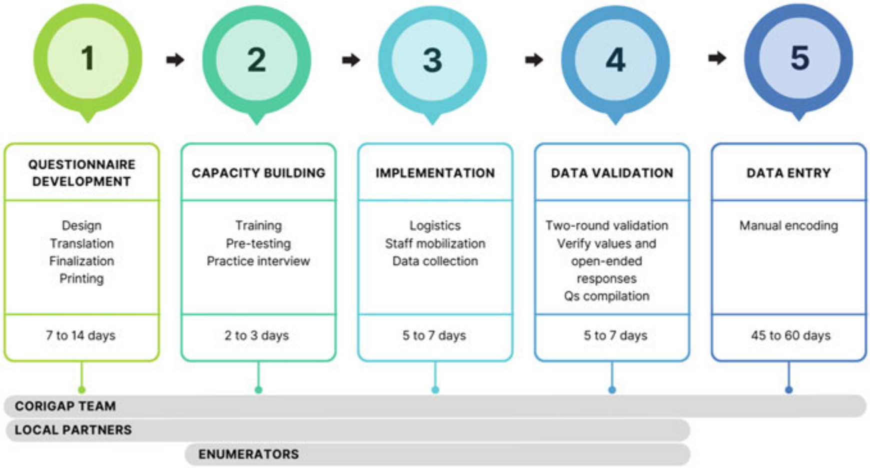

Fig. 7.2 Data collection and quality control using PAPI

was conducted to ensure that all necessary information was captured and unnecessary questions were excluded. Pre-testing ensures that the questions are appropriate for the culture and context of the country where the survey is being conducted. Designing and finalizing the survey questionnaire took one to two weeks. Following this, the interviewers' training was conducted, typically taking two to three days. It was important that the team and interviewers had a clear understanding of each question. We spent one whole day discussing the details of the questionnaire to ensure all had the same understanding and definition of the questions. Furthermore, half a day was allocated to practice interviews. The training of interviewers allowed us to pre-test the questionnaire on-site and to make any necessary changes identified during the practice interviews.

Once interviewers were familiar with the questionnaire and any necessary adjustments had been made, the data were collected, which typically took 10–15 days. The first two to three days of data collection were the most critical as interviewers were still adjusting to the process. Therefore, data editing was conducted daily during the first days of the survey implementation to ensure that all interviewers understood the questions and that all issues that arose during this time were addressed.

The data collected included information on the farmer and their farm, agronomic and postharvest practices, production (yield), and related costs and income. Additionally, we collected information on farmers' knowledge, attitudes, and practices on irrigation and pest management. Data editing could take two rounds, including verifying values and translating open-ended questions. The questionnaire paper was collected and marked as edited once verified as complete and correct.

However, in some cases, the questionnaires needed to be returned to interviewers for verification and correction of extreme values or missed translation of answers into English. A second round of editing was conducted once all issues were resolved.

The entire process of data collection via PAPI, from data collection to questionnaire compilation, took 10 to 15 days. The questionnaires were then transported back to the IRRI headquarters for manual data entry, which took up to two months to complete. Historically, the entire data collection process via PAPI could take up to 90 days. The CORIGAP surveys were implemented by CORIGAP staff and local partners who served as coordinators and enumerators.

Advantages of PAPI. Pen-and-paper interviews are typically cheaper to design than computer-assisted interviews, as they do not require expensive computer equipment or software. Pen-and-paper interviews can be conducted in any location and do not require computer, tablet, phone, or internet access. This makes pen-and-paper interviews more accessible to participants who may not have access to technology or may be uncomfortable using it.

PAPIs are generally more straightforward to administer, as they do not require specialized training or technical expertise. They may yield more complete and detailed answers from participants, as they are not limited by the constraints of a computer interface. The interviewer can easily write down information on the paper questionnaire without restriction. Another advantage of PAPIs is that they can be modified or adapted on the fly, whereas computer-assisted interviews are more rigid and require advanced planning. This also allows flexibility whenever specific questions have to be added or revised. Lastly, PAPIs do not pose the same risk of data security breaches as computer-assisted interviews, which can be vulnerable to hacking or other cyber threats.

Disadvantages of PAPI. PAPI can be more time-consuming and labor-intensive than electronic methods, specifically in entering the data manually and interviewing the respondents. Entering data manually can take months, depending on the number of variables collected. Long questionnaires can cause survey fatigue to both respondents and interviewers. Another drawback of PAPI is the transport of forms from other countries, which can be expensive and risky as they could get lost or damaged. At times it was risky when we transported the questionnaires locally, especially in areas that used waterways. PAPI is more prone to human error, such as transcription (WorldBank 2022b; PaperSurvey 2019) and calculation which significantly affects the quality of the data collected. PAPI data collection is expensive as it includes supervising the interviewers, traveling, accommodation, printing questionnaires, and other related expenses in implementing the PAPI.

Issues, Impact, Solutions, and Lessons Learned. In the early part of the IRRC years (2005), we spent one to two days in each study site to discuss the activity with our local partners (who would help us train the interviewers) and to train interviewers by explaining the goals of the survey and the details of each question. This was done to ensure that the partners and interviewers had correct interpretations of the questions and a full grasp of why we were doing the surveys. We conducted simulation interviews among enumerators and then left the data collection to the local partners as part of our collaboration and capacity-building arrangements. Monitoring the progress of the data collection in the field and assisting interviewers and local partners with any issues encountered in the survey was difficult. Communication was only possible via email, and the internet connection in the partner country was relatively poor during those days.

Consequently, some erroneous data were collected. Data validation was only possible after the local partners entered the data and shared them with us via email. Poor internet connection caused communication delays with the partners whenever we needed to clarify data. In one instance, we learned that the local partners had another task of training the farmers to use a farmer diary to record their activities, related costs, and income on another project. This resulted in mixing up the two activities, and in one instance, farmer diaries were used instead of the household survey. All of the issues, as mentioned earlier, may have resulted from a lack of familiarity with the type of data we needed and different confusing scenarios that popped up during survey implementation. In one instance, we also lost hard copies, which were stored in the respective country, but due to office relocation, the hard copies were thrown away. This calls for more rigid data handling and storage practices that need to be unified across countries.

To avoid having similar problems in the following surveys, a decision was made that staff from IRRI headquarters would stay in the field throughout the entire survey duration to monitor and address survey issues such as misinterpreted questions and unexpected scenarios with farmer respondents. Data validation was conducted daily for the first three days of the survey and every two to three days after that to prevent delays in verifying extreme values via email and to allow verification and correction of wrong information while still in the survey sites. Staying in the field until survey completion also warrants proper and secure storage of filled questionnaires.

After several years of conducting PAPI in different countries, training interviewers remains an essential activity in data collection to minimize data problems. Although we allocated more time to training local interviewers, there were cases where we encountered erroneous data during the first few days of survey implementation. This was often due to incorrect conversion of units, collecting the total cost spent on inputs rather than the per unit cost, or adding extra zeroes. Therefore, it is crucial to ensure that the partners helping to train the interviewers clearly understand the purpose of the survey and the questions. Misinterpreted or questions that could be misinterpreted were explained, and each interviewer was closely monitored to avoid similar problems in the future.

Another area of improvement of the PAPI process was in the logistical aspect of data collection. Sometimes, more participants were sampled than needed, and in other instances, fewer participants were recruited due to misunderstandings in communicating with local partners organizing the surveys. When more farmers were invited, the interviewers had to work faster to ensure that all farmers on the site were interviewed, which may have affected the quality of their interviews. Similar logistical problems occurred when the number of survey days was shortened, forcing the interviewers to collect the same amount of data in less time.

7.2.2 *Case 2: Computer-Assisted Personal Interviewing (CAPI)*

Technological advancement brought us to computer-assisted personal interviewing (CAPI), which allows real-time data entry and embedded calculations while collecting data. Figure 7.3 illustrates the flow of data collection and quality control that was implemented using CAPI. Several CAPI software emerged. The SurveyBE (version 3.1.4918) was the first CAPI software we used in collecting baseline household data in Thailand, Indonesia, and Vietnam from 2012 to 2015. Afterward, we used CommCare (version 2.52.1) to collect midline and end-line household survey data from 2017 to 2022, as well as for the cross-sectional surveys. Questionnaire development could take up to 45 days in SurveyBE and CommCare, depending on the length of the questionnaire and the logical skip functions embedded. Both softwares allow multiple languages, which helps interviewers to record the correct information. It also saves time to have all questions translated into the local language before pre-testing. Back translation is equally crucial to ensure questions are translated correctly. App building requires internet access for both SurveyBE and CommCare. Embedding skip logic, validations (i.e., allowing only a reasonable range of values for specific variables), calculation, and hint messages are among the useful features for quicker and more accurate data collection. Once the app was built and translations were completed, pre-testing of the survey application took place to check for errors and fix bugs, ensuring a smooth data collection process. Once the app was running well, the training of interviewers followed. Training of enumerators allowed us to pre-test and revise the survey application if needed. During the training, we encouraged interviewers to discuss any issues they found during the pre-testing, so we could address them before starting the implementation.

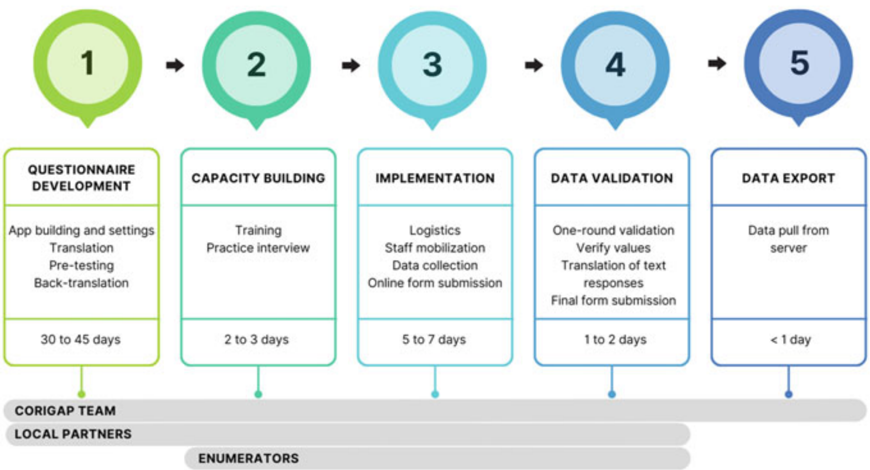

Fig. 7.3 Data collection and quality control using CAPI

To facilitate the training process, a training manual was created. This manual guided enumerators through the process of using the survey applications. This manual was also used to train the local enumerators remotely in 2021, and early 2022 for the end-line surveys in Indonesia and Vietnam when traveling was restricted due to COVID-19. As discussed before, the first two days of the survey implementation were the most crucial days to address errors and issues that may arise. Interviewers were always advised to review the filled-out survey questionnaires (called "forms" in CommCare) carefully before submitting the data. Data editing was conducted on the same day the data were collected to make sure that interviewers were fully able to use the survey application and that questions were interpreted correctly. Afterwards, data editing was conducted every two to three days to verify and discuss extreme values and translate open-ended answers to English. While data collection could be conducted without an internet connection, the submission of forms/questionnaires, on the other hand, required internet access. This means data can be collected in very remote areas, and forms could be uploaded as soon as the internet was available again. Data were exported to Excel to be reviewed by CORIGAP staff. Data were validated and subsequently updated on the validation days. The data of the validated survey questionnaires were exported and prepared for data formatting and analysis using statistical software such as SPSS and Stata.

Advantages of CAPI. CAPI allows efficient use of time and resources when collecting data. CAPI software systems facilitate data entry and checking of errors simultaneously, which saves time and costs and ensures that good quality data are collected. The calculation, validation, skip-loops, and multiple languages are built-in into the CAPI applications ensuring high data quality. It allows the collection and export of data in real time. Furthermore, CAPI provides flexibility in amending and updating the survey questionnaire while in the field. The use of portable gadgets such as phones and tablets provides easy facilitation in the field and obtaining data in real-time; it further minimizes the risk of losing data. The use of CAPI for our monitoring and research processes has provided high-quality data in a very short time. This has enabled us to run several questionnaires in very short periods of time and decreased time and resources significantly.

Disadvantages of CAPI. We would, however, also like to highlight some difficulties and disadvantages that we have encountered on our journey through the different survey applications. The need to invest in tablets, smartphones, and computer software is costly, but in the long term, this investment can be used for subsequent research. Intensive training of interviewers is needed in areas where people are not yet very familiar with the use of electronics, and it can be very challenging. For several surveys, we collaborated with local universities to overcome this problem. Another disadvantage is the size of screens on mobile phones and tablets; if a survey requires the use of pictures that will need to be shown to farmers, it can be challenging due to difficulties seeing. Therefore, it is advisable to have print-outs available as well.

Issues, Impact, Solutions, and Lessons Learned. When we started our monitoring activities, we encountered some issues with our translations, especially when they were provided by people unfamiliar with the agricultural context. We, therefore, made sure that all our questionnaires were always back-translated by an independent translator and checked by a local agricultural specialist.

Due to our limited knowledge when we started using CAPI tools, we encountered some issues while building the survey applications. For example, in one of our surveys, we used a complex loop question design that caused occasional difficulties for the tablets during interview sessions. Another example where we faced difficulties was embedding calculations that also caused tablets to freeze or shut down during interviews. These difficulties eased with time and further knowledge acquisition.

Data editing is much simpler with CAPI since the data collected can be viewed immediately. However, it becomes challenging when not all interviewers submit their collected data on the scheduled form submission. Data editing becomes more difficult when many open-ended questions need a translation. Lastly, an unstable internet connection poses difficulties when uploading and validating data. Therefore, we decided to have a back-up internet connection or conduct data validation on sites with a stable internet connection throughout the day.

7.2.3 Conclusion—Lessons Learned/Moving Forward

In conclusion, pen-and-paper personal interviews and computer-assisted personal interviews have advantages and disadvantages when collecting data. PAPI is typically cheaper to administer and can be conducted anywhere, but uses a lot of human resources. IT is prone to human error and can be more time-consuming and labor-intensive. PAPI is more applicable when collecting qualitative data as an alternative to recording interviews. On the other hand, CAPI is efficient in terms of time and cost, but it requires investment in equipment and software and is dependent on internet access.

The CORIGAP team experienced several challenges when collecting data via PAPI and CAPI. Still, we surpassed these challenges by implementing strict monitoring, conducting pre-testing, and regularly communicating with local partners.

Based on the issues and lessons learned from the CORIGAP surveys, it is recommended to consider the following when conducting future data collection:

- Allocate ample time for training local interviewers to minimize data problems. Proper training of interviewers is crucial in ensuring accurate and high-quality data.
- Ensure that the logistics should be well-planned and details of the surveys are well-communicated to the local partners to avoid issues such as having too few or too many respondents and last-minute changes in survey schedules.
- Back translation should be done independently to ensure the accuracy of translated questions.
- Invest in advanced features of CAPI software and allow reasonable time for testing survey applications, testing conducted by national partners is advisable.

- Strict monitoring of interviewers is needed to address any issues that may arise during the survey.
- Have interviewers note down any issue or relevant information every day to facilitate data validation.
- Data validation should be done regularly to ensure the accuracy and completeness of data.
- Be prepared for an unstable internet connection when using CAPI for data collection and have contingency plans in place.
- Have a contingency plan for unexpected application errors when using CAPI.
- Consider using PAPI and CAPI methods to balance the advantages and disadvantages of each method.
- Lastly, have a clear understanding of the goals and objectives of the survey to ensure questions are aligned with the goal of the survey.

7.3 Evaluating the Adoption and Contributions of CORIGAP-Promoted Technologies in Rice Production: Case of Vietnam, Thailand, Indonesia, and Myanmar

The CORIGAP project offered environmentally sustainable, climate-smart best management practices and technologies developed using new science-based tools combined with a participatory research approach. Specific management practices and technologies were provided to smallholder farmers in the irrigated rice systems to help increase rice production with fewer resources, materials, and costs, reduce negative environmental consequences, and to improve social, economic, and environmental sustainability. Increasing the profitability of rice farming due to the increase in yield and reduced cost of rice production is one of the expected outcomes of the CORIGAP interventions. The CORIGAP project has run for nine years with a target of 500,000 farmers across six Asian countries and has reached more than 758,196 farmers as of December 2020 (CORIGAP 2022). In this section, we will focus on four CORIGAP countries, namely Indonesia, Vietnam, Thailand, and Myanmar.

Every project and program has a life cycle of different stages, including planning, implementation, monitoring, and closure. These stages can be further defined depending on the content of the project or program. The CORIGAP project has undergone three funding phases. Each led to revisiting the Theory of Change (TOC), adjusting and redefining outcomes and outputs to assess and quantify the changes over time. Therefore, a monitoring and evaluation (M&E) component was crucial to the project. The CORIGAP project builds on the impact pathways of the Irrigated Rice Research Consortium, a long-term project that was implemented over 16 years. Rejesus's et al. (2013) impact assessment recommended investigating the heterogeneity of impacts across different groups of farmers accounting for several intersecting factors such as gender, age, and other rice stakeholders. Using different methodologies to assess changes and examine economic and sociocultural impacts is recommended, enhancing consistency in evaluations and monitoring the take-up and adoption numbers more carefully.

Different methods are described in the literature to monitor and evaluate changes and impacts. In general, methods can be categorized into qualitative and quantitative approaches. Project TOCs usually define key performance indicators. CORIGAP employed a combination of qualitative and quantitative approaches to assess changes due to technology and management adoption over time. A monitoring system was designed and implemented in four CORIGAP countries (Indonesia, Thailand, Myanmar, and Vietnam). The M&E system aims to determine the contribution of CORIGAP interventions to predefined outcomes. Furthermore, an effective M&E system is crucial to assess the progress of the implementation of project activities, identify bottlenecks affecting the project performance, and determine necessary steps to overcome problems. M&E systems provide a better understanding of what is happening on the ground, factors affecting the success of project implementation, or why things did not work.

The following paragraphs will describe a detailed description of CORIGAP's monitoring and evaluation activities. Furthermore, this section will also provide an evaluation of changes, quantitative and qualitative assessments, and lessons learned over time.

7.3.1 Monitoring of Farmers Reached in Each CORIGAP Country

As part of the CORIGAP M&E activities, each country was asked to monitor the number of farmers who reached the yield and profit increase in percent. Table 7.2 shows the target and achieved numbers. Overall, the project has reached and, in most countries, even exceeded the project targets. This would not have been possible without the country partners' engagement and additional sources of funding. In Vietnam, for example, the Vietnam Sustainable Agriculture Transformation Project (VnSAT) funded activities that supported 1M5R with US$150 million. The VnSAT project was implemented by the Ministry of Agriculture and Rural Development (MARD) and focused on institutional strengthening to support agricultural transformation and support for sustainable rice production. Therefore, the VnSAT project provided technical and financial support to farmers and millers/processors (Flor et al. 2021). Farmers were supported with training and field demonstrations. Furthermore, grants were provided to support the multiplication of certified seeds, investing in postharvest loss reductions and improving small-scale infrastructure such as roads, electricity, and water pumps which improved irrigation. The MARD incorporated its national strategies into the VnSAT project, which meant that 1M5R was embedded in the project and subsequently scaled through technology demonstrations and training of farmers' cooperatives across the Mekong River Delta. Farmers were encouraged to adopt 1M5R, and after targets were reached, the cooperatives would qualify for project investments and had to develop a business case to operate and benefit from the facilities and infrastructure to receive the funds (Flor et al. 2021). Therefore, the number of farmers in Vietnam reached in the provinces where CORIGAP was implemented exceeded the original target significantly.

Similarly, in China, a World Bank project, "Guangdong Agricultural Non-point Source Pollution Control Project," was implemented from 2014 to 2018 in the cities of Huizhou, Jiangmen, and Heyuan in Guangdong province. Three main strategies were determined and focused on (1) pesticide pollution, (2) chemical fertilizer pollution, and (3) farm waste pollution (livestock and poultry waste control). Regarding chemical fertilizer pollution, the 3CT was applied (Sect. 2.5). The technology aims to incentivize farmers to apply less nitrogen fertilizer, at specific times per season. Demonstration sites for pesticide and chemical fertilizer pollution control, as well as the implementation of pollution control measures, were performed (personal communication). The project started with 12,000 farmer households and reached 140,000 households in 2018, establishing a system of active participation. A complex incentive-based system has been developed mostly as part of the World Bank project. Farmers' involvement in the project was monitored electronically. Farmers were asked to sign a contract of participation outlining the conditions and received an electronic identity card that was used to monitor fertilizer and pesticide purchases in certified agricultural stores. Farmers were only allowed to buy certified products, which were complete mixtures of fertilizer and pesticides with low environmental toxicity. Farmers bought these products at reduced costs when using their personal

Table 7.2 The target and achieved number of households reached by country during CORIGAP up to December 2020

Country	Households reached		Yield and profit increase (target 10%)		Focal districts	
	Target	Achieved	Yield (%)	Profit (%)	Target	Achieved
China	100,000	320,000 *400,000*	11.0	21.3	8	6
Indonesia	90,000	172,000	Yogya 13 Sth Sum > 20 Nth Sum—low elev 9 high elev 90	Yogya 17 Sth Sum 30 Nth Sum—low 21 high 90	6	8
Myanmar	10,000	> 25,000	13.3	30	4	71
Sri Lanka	20,000	17,200	4 to 20		5	2
Thailand	30,000	18,000	1	15	4	8
Vietnam	250,000	231,329 *250,000*	7.8 *10*	28.3 *28.6*	8	8
Totals	**500,000**	**758,196**			**31**	**103**

Estimates of associated increases in yield and profit for smallholder farmers are shown. These figures were provided by each country

Note Yogya = Yogyakarta, Sth Sum = South Sumatra, Nth Sum = North Sumatra, elev = elevation

ID cards. Shopkeepers would get the difference in price between certified and non-certified products reimbursed through the World Bank project. Additionally, shopkeepers were obliged to provide information about the project to the farmers and actively disseminate information material. The education of farmers was provided through village technicians, often farmers themselves, who had already adopted the new technologies. Village technicians were paid to provide the training. There were incentives for the farmers and also for the whole village if they participated. This, in turn, helped the CORIGAP project to exceed its target in China.

7.3.2 *Quantitative Assessment of Changes Through Baseline and End-Line Surveys*

The following section will describe the monitoring processes at the household level to investigate how farmers' practices changed with adopting technologies and climate-smart management practices and how this behavior change affected the cost of producing rice, yield, and income of smallholder farmers and their communities. The changes in key indicators over time between adopter and non-adopter farmers will be measured and evaluated using descriptive statistical analyses and the difference-in-differences (DID) method. DID measures the differences in outcomes for the program participants before and after the program relative to non-participants. The study defines the program participants as adopters of CORIGAP interventions. It must be noted that in each CORIGAP country, multiple interventions took place simultaneously. For instance, the project introduced postharvest technologies, such as combine harvester, stripper harvester, multiple storage solutions, or straw management technologies. Another set of technologies includes water-saving technologies and nutrient and pest management practices. These instances resulted in a complex system with overlapping activities addressing multiple outcomes. The quantitative data analysis included only selected interventions with sufficient adopters suitable and valid for statistical analyses. Lessons from this section may be referred to for similar interventions and donors focusing on similar and multidimensional development projects.

7.3.2.1 Household Survey Design and Implementation

Household surveys were conducted in three periods to measure the changes in farm management practices, production costs, yield, and farmers' perceptions before, during, and at the end of the project. The data collection of the CORIGAP project was initially planned to be conducted at two points in time: baseline, before any interventions were introduced, and at end-line after four to five years of implementation. When CORIGAP was extended for a third phase, a third round of data collection was also initiated to understand more about the changes resulting from the

CORIGAP interventions in Vietnam and Indonesia. Therefore, the respective surveys were labeled baseline, midline (after four to five years), and end-line surveys (after eight years). For the other two countries, it was impossible to conduct a third survey due to Myanmar's political situation and Thailand's small sample size and ongoing COVID-19 restrictions.

The information collected from household surveys includes agronomic practices, labor and material inputs costs, rice yield, knowledge, attitudes, and practices on land preparation, rice cultivation, harvesting, and postharvest. Furthermore, newly developed measures were included in the end-line. These measures capture the impact of CORIGAP on the economic aspects and farmers' perceptions of social and environmental changes after adopting CORIGAP practices and technologies (see Sect. 7.4).

The baseline surveys in Myanmar were conducted using pen-and-paper assisted personal interviews. All other household survey data were collected using computer-assisted personal interviews. Baseline data in Thailand, Indonesia, and Vietnam were collected using the SurveyBe application (version 3.1.4918). Midline and end-line surveys were implemented using the CommCare application (version 2.52.1).

For all countries, purposive sampling was applied at the village level to examine the contribution of the CORIGAP interventions to its target beneficiaries. The treatment village selection was based on the needs assessment, cropping system, and location of the CORIGAP activities. The control villages were purposively selected for having similar geographical characteristics to the treatment sites. They were selected at a distance from the treatment sites to avoid diffusion effects of the intervention. Random sampling was applied at the farmer level in each country. Farmer lists were provided by the country partners.

Myanmar. The baseline household data in Myanmar were collected in eight villages of Daik-U Township, Bago Province, in August 2012. The treatment villages were Ka Doke Phayar Gyi, Oat Shit Kone, Pha Aung Weh, and Kyaik Sa Kaw. The control villages were Myo Ma, Mau Tan, Shwe Inn Done, and Doe Tan. The survey was stratified between rice-rice and rice-pulse cropping systems with 100 farmers per system (Table 7.3). For each cropping system, 50 farmers were interviewed from the treatment and control villages. Staff from the Department of Agriculture (DoA) collected the data. The data collected covered wet (June to October) and dry (December to April) seasons.

Indonesia. The baseline household surveys in Indonesia were conducted in the Special Region of Yogyakarta (two treatment villages and two control villages) in May 2014. The treatment villages were Jogotirto and Madurejo, while the control villages were Srimulyo and Bokoharjo. A total of 180 farmers were interviewed, 50 each from the two treatment villages and 40 each from the control villages (Table 7.3). The staff of BPTP provided the list of farmers and collected the data. Both wet (December–March) and dry (April–July) seasons were included.

Thailand. The baseline household surveys were conducted in the province of Nakhon Sawan in June 2013. A total of 84 farmers were interviewed in four villages; the treatment sites were in Nongjikree (n = 24) and Sapansong (n = 20), and Sakaengo (n = 21) villages. The control villages were in Pacluk (n = 19) and Sakengo

Table 7.3 Summary of household surveys conducted in CORIGAP countries from 2012 to 2022

	Country			
	Myanmar	Thailand	Indonesia	Vietnam
Baseline				
Province	Bago	Nakhon Sawan	Yogyakarta	Can Tho
Sample size	200	84	180	180
Treatment	100	44	100	100
Control	100	40	80	80
Data collection (Month/Year)	Aug/2012	June/2013	May/2014	June/2015
Midline (after 5 years)				
Province			Yogyakarta	Can Tho
Sample size			203	183
Treatment			98	105
Control			105	78
Data collection (Month/Year)			Sept/2018	Sept/2019
End-line (after 8 years)				
Province	Bago	Nakhon Sawan	Yogyakarta	Can Tho
Sample size	171	84	173	156
Treatment	82	44	94	86
Control	89	40	79	70
Data collection (Month/Year)	Aug/2017	March/2019	Nov/2021	March/2022

($n = 21$). The farmers interviewed belong to the Community Rice Center. The data collected covered wet (July–October) and dry (December–March) seasons.

Vietnam. Baseline household surveys were conducted in four communes of Can Tho in the Mekong River Delta, Southern Vietnam, in 2015. A total of 180 farmers were interviewed from Thanh An ($n = 50$) and Thanh Loi ($n = 50$) as the treatment sites and from Thanh An ($n = 40$) and Thanh Thang ($n = 40$) as the control sites. The survey covered two seasons, the winter-spring data, which starts in November and lasts until March, and the summer-autumn season which covers the months of July to October.

7.3.2.2 Midline Household Surveys

The midline household surveys were implemented to monitor the preliminary changes in farmers' practices in the midterms of the project intervention. Monitoring the changes in practices allows a better understanding of how the intervention affects smallholder farmers' production costs, yields, and incomes. The midline survey contains the same questions as the baseline survey and is implemented in Indonesia and Vietnam.

Indonesia. The midline household surveys in Indonesia were completed in September 2018 using the CommCare application. A total of 172 farmers were interviewed from the same list of farmers in the baseline (Table 7.3); 98 respondents were from Jogotirto and Madurejo, while 74 were from the villages of Srimulyo and Bokoharjo. The same local partners from AIAT who helped collect baseline data gathered the midline data. Farmers not interviewed were either too old, deceased, or not in the villages at the time of the survey.

Vietnam. Midline household surveys in Can Tho, Vietnam, were completed in September 2019. A total of 179 farmer respondents were interviewed from the original list of respondents in the baseline survey (Table 7.3); 127 were the same farmers interviewed in the baseline household surveys, while 52 were new farmers. The local partners decided to interview new farmers in communes where some farmers from the list of respondents in the baseline were not available at the time of the midline survey. Out of the total respondents in the midline, 105 were from Thanh An Town and Thanh Loi, while 78 were from Thanh An and Thanh Thang. Most of the local partners who collected the baseline data participated in the midline household survey.

7.3.2.3 End-Line Household Surveys

The end-line household surveys were conducted as a monitoring tool to assess the potential impact of adopting CORIGAP best management practices and technologies on the practices of farmers, which are reflected in the use of inputs, cost, yield, and income. The goal was to interview the same farmers. However, this was not possible in a few instances because they had moved, were too old, or were deceased. Therefore, in some instances, replacement farmers were interviewed. The survey was implemented using the household survey app built using the CommCare platform. The design enabled comparisons in yield and income before and after implementing best practices and new varieties, with and without the new practices.

Myanmar. The end-line household surveys in Myanmar were completed in August 2017. Kyak Sa Kaw village was replaced by Pyin Mah Lwin village as a treatment site. Pyin Mah Lwin replaced Kyak Sa Kaw due to changes in the local government structure, which affected the implementation of the CORIGAP activities. A total of 171 rice farmers were interviewed; 82 were from treatment and 89 from control villages. The data were collected with the help of the local DoA partners in Daik-U.

Indonesia. The end-line household survey was conducted in November 2021; a total of 173 respondents were interviewed, with 94 farmers from treatment and 79 farmers from control villages. The training of interviewers and the supervision of the surveys were all done virtually due to the COVID-19 pandemic. The same interviewers from the AIAT in Yogyakarta helped to collect the data.

Thailand. The end-line household survey was conducted in March 2019. A total of 72 farmers were interviewed; 41 were from treatment, while 31 were from control sites. Some of the farmers that were not interviewed have shifted cultivation to growing sugarcane. The data were collected in partnership with the Chainat Rice

Research Center. The interviewers were students of The Nakonsawan College of Agriculture and Technology.

Vietnam. The training of interviewers and end-line household surveys was conducted in March 2022. The activities were supervised virtually by an IRRI HQ staff because of COVID-19 and travel restrictions. A total of 156 farmers from the list of farmers in the baseline survey were interviewed; 86 were from treatment communes, while 70 were from control communes. The staff from DARD in Can Tho helped us collect the end-line data.

7.3.3 Methodology Used to Assess Changes in Outcomes

To examine the changes in outcomes and farm management practices between the survey periods, we consider the DID method. The difference-in-differences method is a quasi-experimental approach that compares the changes in outcomes over time between a population enrolled in a program (the treatment group) and a population that is not (the comparison group). In this study, we focused on the adoption and non-adoption status of the respondent toward the CORIGAP interventions instead of the treatment and control grouping. The non-adopters of the proposed intervention represent the comparison group. The data collected for this study satisfies the requirement for applying the DID method, where there are available data on outcome indicators in the group that adopted the intervention and the group that did not receive the intervention, both before and after the introduction/dissemination of the CORIGAP intervention. Statistically, the DID is usually implemented as an interaction term between time and group dummy variables in the regression model below:

$$\mathrm{Y} = \beta_0 + \beta_1 * [\mathrm{Time}] + \beta_2 * \left[\mathrm{Group}\right] + \beta_3 * \left[\mathrm{Time} * \mathrm{Group}\right] + \varepsilon$$

In this regression model, Y represents the outcome of interest on which change is being measured. In the study, we considered farm management factors (inputs), yield and income. The βs are estimated coefficients and ε the error term. Figure 7.4 shows a graphical illustration of the DID method. The calculation and interpretation of the coefficients in the DID model are shown in Table 7.4. In our analysis, the coefficient of interest is β_3, which is the interaction of group and time or the difference in the changes over time between adopters and non-adopters.

As stated above, the treatment and control villages were assigned. However, prior to the midline and end-line surveys, some of these interventions were disseminated by other programs and institutions in parallel to CORIGAP, which resulted in the contamination of the initial grouping.[1] Some respondents in the control sites adopted at least one of the CORIGAP interventions, while others in the treatment sites did

[1] In Myanmar, MyRice, an ACIAR-funded project, has developed best practices for rice production and postharvest to improve the productivity of rice-rice and rice-pulse cropping systems. In Indonesia, Integrated Crop Management (PTT) and the Special Efforts Program (UPSUS) target to enhance rice productivity and achieve self-sufficiency. The efficient use of resources and increased

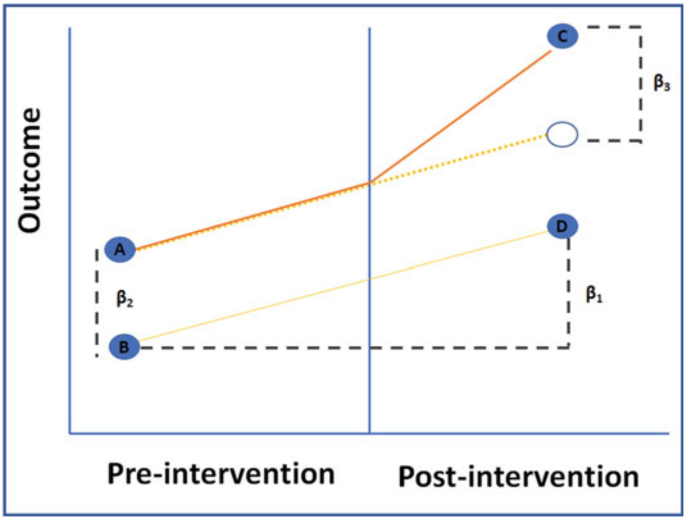

Fig. 7.4 Graphical illustration of the difference-in-differences method

Table 7.4 Calculation and interpretation of the regression coefficients

Coefficient	Calculation	Interpretation
β_0	B	Baseline average
β_1	D-B	Time trend in non-adopter group
β_2	A-B	Difference between two groups pre-intervention
β_3	(C-A)–(D-B)	Difference in changes over time

not adopt any of the interventions. Also, some respondents adopted one intervention, while other respondents adopted several. Table 7.5 shows the adoption rate of the interventions promoted by CORIGAP by season and by survey period. The adoption status of the respondents varied by season and by survey year. For instance, a respondent may adopt a specific technology during the wet season but not during the dry season and vice versa. In countries where three survey periods were implemented, a respondent may have adopted a specific technology during the midline period but not during the end-line period and vice versa.

Given the unbalanced number of adopters and non-adopters and the relatively small sample sizes for the midline and end-line periods for Thailand, Indonesia, and Myanmar, we decided to conduct an in-depth analysis of selected technologies in Vietnam only. Despite the contamination issues encountered during the surveys, the sample sizes for Vietnam in the baseline and midline periods have a more balanced

environmental quality are ways to accomplish this. In Thailand, the BMPs on has was promoted by the Thai Rice Department to increase farmers' income by reducing costs and ensuring yield is maintained or improved.

Table 7.5 Adoption rate (%) of CORIGAP interventions by country

Interventions	Midline		End-line	
	Wet season (%)	Dry season (%)	Wet season (%)	Dry season (%)
Vietnam				
	($n = 122$)	($n = 120$)	($n = 140$)	($n = 143$)
Improved Rice Varieties	67	63	32	29
AWD	75	79	67	51
Drum Seeder	20	17	1	0
Mechanical Transplanter	3	3	0	0
Ecologically-based rodent management	12	8	1	0
Laser Land Leveler	6	7	1	1
Combine harvester	98	100	89	73
Thailand				
			($n = 65$)	($n = 44$)
Improved Rice Varieties			15	16
Drum Seeder			18	18
Mechanical Transplanter			12	20
Solar bubble dryer			2	2
IRRI Superbag			2	2
Flatbed Dryer			2	2
Ecologically-based rodent management			2	2
Laser Land Leveler			2	2
Combine Harvester			29	23
Stripper Harvester			2	2
AWD			2	7
Indonesia				
	($n = 156$)	($n = 76$)	($n = 171$)	($n = 50$)
Improved Rice Varieties	83	92	91	90
Solar Bubble Dryer	30	37	27	36
Mechanical Transplanter	20	14	3	2
Combine Harvester	23	25	6	4
AWD	15	11	44	54
Drum Seeder	11	22	2	2
Ecologically-based rodent management	1	3	0	0
IRRI Superbag	8	17	1	0

(continued)

Table 7.5 (continued)

Interventions	Midline		End-line	
	Wet season (%)	Dry season (%)	Wet season (%)	Dry season (%)
Flatbed dryer	1	1	0	0
Stripper Harvester	5	4	0	0
Integrated Crop Management			3	4
Integrated Pest Management			13	8
Rice Crop Manager			1	0
Myanmar				
			(n = 148)	(n = 142)
Combine Harvester			32	37
Applying Balance Nutrients			16	15
Laser Land Leveler			8	10
Threshing (paddy immediately)			5	9
Drum Seeder			1	1
IRRI Superbag			1	0

distribution of adopters and non-adopters, particularly on improved rice varieties and AWD technology. Based on this, the DID method was applied to the improved rice varieties and the AWD technology using the panel data of baseline and midline surveys of Vietnam as a case study.

7.3.3.1 Case of Vietnam

We estimated the changes in key input factors and two outcome indicators (yield and income) between adopters and non-adopters by season. These input factors and outcome indicators are presented in Table 7.6.

Adoption rates of technologies are presented in Table 7.5 for all countries that benefited from the CORIGAP interventions. Vietnam showed high adoption rates for improved varieties and AWD technology, while Thailand had high adoption rates for improved varieties, drum seeders, mechanical transplanters, and combine harvesters. Indonesia had high adoption rates for improved varieties, combine harvesters, and mechanical transplanters, with a notable increase in AWD technology adoption during the midline period. The two most adopted technologies in Myanmar were combine harvesters and the application of balanced nutrients. Given the spill-over effects observed in all countries, we refrained from making comparisons on adoption rates between midline and end-line periods for Indonesia, Thailand, and Myanmar. However, we were able to examine changes between two survey periods for the top two technologies adopted in Vietnam. Tables 7.6–7.10 show the mean values of the

Table 7.6 List of indicators and their descriptions

Indicators	Description
1. Seed quantity (kg ha^{-1})	Quantity of seeds planted in kilogram per hectare
2. Frequency of irrigation (count)	No. of times irrigated the farm per hectare
3. Pesticide costs (US$ ha^{-1})	Total costs of pesticides applied in US$ per hectare
4. Nitrogen fertilizer (kg ha^{-1})	Quantity of nitrogen fertilizer applied in kilogram per hectare
5. Phosphorus fertilizer (kg ha^{-1})	Quantity of phosphorus fertilizer applied in kilogram per hectare
6. Potassium fertilizer (kg ha^{-1})	Quantity of potassium fertilizer applied in kilogram per hectare
7. Power and labor cost (US$ ha^{-1})	Total costs of machine and animal rental, fuel and labor costs in US$ per hectare
8. Yield (kg ha^{-1})	Total production over area planted in kilogram per hectare
9. Net income (US$ ha^{-1})	Total gross income minus the total production cost in US$ per hectare

key indicators by survey period and by adoption status of improved rice varieties and AWD during wet and dry seasons in Vietnam. The last column of each table contains the calculated values of the DID regression. Table 7.7 shows that there are significant differences in the power and labor cost (negative), yield (positive), and net income (positive) over the two survey periods between adopters and non-adopters of improved rice varieties. The negative value of the DID for the power and labor costs means that the adopters of improved rice varieties have fewer costs of power and labor over time compared to non-adopters. The positive DID results of yield and net income means that the adoption of improved rice varieties has a yield advantage of about 0.82 t ha^{-1} and a net income advantage of about US$327 over the non-adopters during the wet season. Results also show that there is no significant difference in the changes in seed rate, irrigation frequency, pesticide cost, and fertilizer quantity over time on whether they adopted or not adopted the improved rice varieties.

For the dry season, the change in the cost of pesticides applied over the two survey periods is significantly lower for the adopters of the improved rice varieties by about US$23 compared to the non-adopters (Table 7.8). For other indicators, the changes over time between adopters and non-adopters are not statistically significant.

Tables 7.9 and 7.10 show that the adopters of AWD have no significant difference in the DID values for all indicators for both the wet and dry seasons. In theory, it was expected that the farmers who adopted the AWD would use less water for irrigation compared to the non-adopters. However, the total amount of water used for irrigation during the whole cropping season was not monitored. As a proxy variable, we used the number of times a farmer irrigated the field during the wet and dry seasons. Results show that there is no significant difference in the frequency of irrigation between adopters and non-adopters of AWD. This could mean that farmers still continue to follow their normal frequency of irrigation, but the amount of water

Table 7.7 Mean values of the key indicators by survey period and by adoption status of the respondents on improved rice varieties and their difference-in-differences, wet season, 2018

Indicators	Baseline		Midline		DID
	Adopter ($n = 82$)	Non-adopter ($n = 40$)	Adopter ($n = 82$)	Non-adopter ($n = 40$)	
Seed quantity (kg ha^{-1})	106	95	165	171	–18
Frequency of irrigation (count)	6	6	6	6	0
Pesticide cost (US$[a] ha^{-1})	119	120	133	133	0
Fertilizer quantity					
N (kg ha^{-1})	98	106	88	83	13
P (kg ha^{-1})	27	27	25	24	1
K (kg ha^{-1})	39	47	42	43	7
Power and labor cost (US$[a] ha^{-1})	250	233	182	189	−23 *
Yield (kg ha^{-1})	8,761	9,367	7,387	7,173	821 **
Net income (US$[a] ha^{-1})	1,647	1,953	949	928	327 **

[a]Values are in 2021 US$
*Significant at 10%, ** significant at 5%, *** significant at 1%
DID—Difference-in-differences

Table 7.8 Mean values of the key indicators by survey period and by adoption status of the respondents on improved rice varieties and their difference-in-differences, dry season, 2018

Indicators	Baseline		Midline		DID
	Adopter ($n = 76$)	Non-adopter ($n = 44$)	Adopter ($n = 76$)	Non-adopter ($n = 44$)	
Seed quantity (kg ha^{-1})	102	113	171	177	5
Frequency of irrigation (count)	6	6	6	6	0
Pesticide cost (US$[a] ha^{-1})	109	100	115	130	−24 *
Fertilizer quantity					
N (kg ha^{-1})	98	103	84	84	5
P (kg ha^{-1})	26	28	23	25	−1
K (kg ha^{-1})	39	44	41	43	2
Power and labor cost (US$[a] ha^{-1})	227	236	174	206	−23
Yield (kg ha^{-1})	5,814	6,082	6,020	5,906	383
Net income (US$[a] ha^{-1})	827	984	577	557	177

[a]Values are in 2021 US$
*Significant at 10%, ** significant at 5%, *** significant at 1%
DID—Difference-in-differences

Table 7.9 Mean values of the key indicators by survey period and by adoption status of the respondents on alternate wetting and drying (AWD) and their difference-in-differences, wet season, 2018

Indicators	Baseline		Midline		DID
	Adopter ($n = 92$)	Non-adopter ($n = 30$)	Adopter ($n = 92$)	Non-adopter ($n = 30$)	
Seed quantity (kg ha^{-1})	99	111	163	177	−1
Frequency of irrigation (count)	6	6	6	6	0
Pesticide cost (US$[a] ha^{-1})	120	116	133	133	−4
Fertilizer quantity					
N (kg ha^{-1})	100	102	90	77	16
P (kg ha^{-1})	27	27	25	23	3
K (kg ha^{-1})	41	44	44	36	10
Power and labor cost (US$[a] ha^{-1})	243	246	179	193	−11
Yield (kg ha^{-1})	8,910	9,111	7,351	7,211	341
Net income (US$[a] ha^{-1})	1,695	1,909	952	911	256

[a]Values are in 2021 US$
*Significant at 10%, ** significant at 5%, *** significant at 1%
DID—Difference-in-differences

used by AWD adopters might be lower compared to the non-adopters. It has been shown that farmers in the Mekong Delta reported having reduced their water use. However, when specifically asked if they applied AWD as presented in the AWD manual, farmers were struggling to apply this technology correctly (Connor et al. 2021a). Furthermore, the geographical location of the fields and access to water were the main barriers to apply AWD in the recommended way (Tuan et al. 2022). The obtained results during the household survey may represent farmers' willingness to adopt AWD but do not represent the correct application thereof and, therefore, the expected reductions could not be observed.

7.3.4 Conclusions

This study focuses on three survey periods and examines the changes in farm management practices and resulting outcomes from the CORIGAP interventions using data collected in four countries, Vietnam, Thailand, Myanmar, and Indonesia. Some technologies stood out with high adoption rates during the midline and end-line periods, for example, the improved varieties, AWD technology, mechanical transplanter, and combine harvester. Many of these technologies have also spilt over to the non-intervention sites, which indicates the potential scalability of the promoted technologies. Given the unforeseen changes in the survey design, the econometric analysis to examine the contribution of CORIGAP intervention on production inputs,

Table 7.10 Mean values of the key indicators by survey period and by adoption status of the respondents on alternate wetting and drying (AWD) and their difference-in-differences, dry season, 2018

Indicators	Baseline		Midline		DID
	Adopter ($n = 95$)	Non-adopter ($n = 25$)	Adopter ($n = 95$)	Non-adopter ($n = 25$)	
Seed quantity (kg ha^{-1})	101	124	172	177	19
Frequency of irrigation (count)	6	6	6	6	0
Pesticide cost (US$[a] ha^{-1})	110	91	121	119	−16
Fertilizer quantity					
N (kg ha^{-1})	101	95	83	85	−8
P (kg ha^{-1})	27	28	23	25	0
K (kg ha^{-1})	41	42	41	44	−1
Power and labor cost (US$[a] ha^{-1})	228	237	185	193	1
Yield (kg ha^{-1})	5,877	6,046	6,028	5,790	407
Net income (US$[a] ha^{-1})	874	923	587	506	129

[a]Values are in 2021 US$
*Significant at 10%, ** significant at 5%, *** significant at 1%
DID—Difference-in-differences

yield and income, was only implemented for Vietnam. The results showed that the adoption of improved rice varieties has a yield advantage of about 0.82 t ha^{-1} and a net income advantage of about US$327 over the non-adopters based on the level of changes from baseline to midline survey during the wet season. An analysis of the Myanmar data published by Wehmeyer et al. (2022) found that all farmers experience substantial positive changes. These changes were in line with national development efforts. In general, differences between adopters and non-adopters were not significant. There were, however, differences between the rice-rice and rice-pulse cropping patterns, indicating that rice-pulse farmers had higher yields than rice-rice farmers even though rice-rice farmers had larger cultivation areas received higher agricultural credits, and had superior income levels. The study further found that education was an important predictor of yield, indicating its importance for accelerating agricultural development in Myanmar. Therefore, one recommendation for Myanmar is to improve extension services and knowledge transfer to expand the dissemination of sustainable BMPs and make farmers more resilient against the negative impacts of climate change (Wehmeyer et al. 2022).

There were several challenges and limitations related to the survey design, data analysis, and econometric method. Intervention programs that promote a bundle of technologies often pose the challenge of defining adoption for econometric analysis. A respondent can adopt multiple and different combinations of interventions, which makes it difficult to determine the contribution of each intervention to the key indicators. One possible solution is to segregate the analysis into different bundles of interventions; however, it requires large sample sizes. Before the midline and endline surveys, other organizations and institutions also promoted some interventions similar to the ones disseminated by the CORIGAP program, which resulted in the contamination of the initial grouping in our survey design. Since development does not happen in isolation, outcome and impact assessments need to take these facts into account and opt for different methodologies, such as contribution analysis (Apgar et al. 2020; Mayne 2012) or process tracing (Ton 2012) which have been shown to be effective methods to account for project contributions on development issues. Nevertheless, based on the analysis, the study indicated that the CORIGAP interventions contributed to the observed changes in farm management practices and related outcomes in the focus countries.

7.4 Perception of Economic and Social Changes

A lot of studies exist that investigate the uptake of agricultural technologies and practices covering a plethora of crops, ecosystems, and sociocultural contexts. Such studies often distinguish between external and internal factors that can influence the adoption of new technologies and practices. External factors generally concern the biotic environment in which crops are grown, such as field conditions (Connor et al. 2021a), soil composition (Dai et al. 2015), or irrigation (Connor et al. 2021a). Furthermore, farmers' personalities and knowledge have been classified as internal factors affecting technology adoption (Bopp et al. 2019; Connor et al. 2021a; Dang et al. 2014).

As described in Sect. 2.5, farmers in Guangdong province, China, were introduced to the 3CT aiming to reduce the use of inorganic fertilizer while decreasing the number of unproductive tillers and controlling pests and diseases (Wehmeyer et al. 2020). For this cross-sectional study, 142 farmers from six villages were interviewed to evaluate perceived changes in their farming and livelihood. We found that all farmers in the sample adopted 3CT. Furthermore, the results showed that the farmers were highly satisfied with 3CT and perceived positive livelihood changes and increased agronomic performance while reducing fertilizer use. Farmers who had adopted 3CT for the longest perceived significantly higher levels of change, more benefits, and improved agricultural efficiency (Wehmeyer et al. 2020). These results show that 3CT has great potential to be implemented in other regions of China (Wehmeyer et al. 2020).

In Indonesia, we investigated 153 farmers in three sub-districts of Yogyakarta. Especially in Indonesia, an archipelago in the Pacific Ocean, the adoption of sustainable technologies is crucial for climate change adaptation and mitigation. We investigated the adoption of sustainable rice farming technologies and practices with a special focus on additional revenue allocation and perception of social, economic, and environmental change (Connor et al. 2021b). Farmers adopted two technologies or practices, which, as presented above, were high-yielding rice varieties. Farmers increased their revenue from US$105 to US$122 per hectare per season. The main barriers to adoption included time constraints, unsuitability for field conditions, and incompatibility with cropping systems. This study also provided insights into where farmers will invest the additional income. We found that farmers invested the extra income in their farming businesses and also improved their diets. Farmers reported having experienced several changes due to the adoption of technologies and practices that were introduced through the CORIGAP project. These changes were observed in social and human capital as well as perceived poverty reduction in the area (Connor et al. 2021b).

In Vietnam, we placed a special focus on the adoption of the 1M5R recommendations (Chap. 4). 1M5R is a complex technology package that has been rolled out widely across the Mekong River Delta. Here, we were specifically interested in also investigating the adoption constraints. We investigated a total of 465 farmers in An Giang and Can Tho Province (Connor et al. 2021a). We found that farmers generally followed the requirements of pesticide reduction, postharvest loss reduction, and the use of certified seeds. However, farmers had problems reducing their fertilizer use, water use, and seed rate (Connor et al. 2021a). Reasons farmers mentioned included that practices were difficult to follow and to apply in the correct and prescribed way. A regression analysis results in several factors predicting the adoption of the whole package of the 1M5R requirements. However, the adoption of the individual requirements was mainly driven by the ease of implementation and non-rice income, especially for practices with lower adoption rates (Connor et al. 2021a).

The adoption of best management practices was investigated with 129 farmers in two regions in Myanmar, the Ayeyarwady Delta and the Bago region. Reasons for adoption included higher yields, reduced costs, and labor savings. Reasons for non-adoption included unsuitable or expensive practices (Connor et al. 2021c). There was an estimated increase in income (>0) of 113 US$ ha^{-1} (SD = 90.64 US$ ha^{-1}), due to an increase in yield and reduced costs. Farmers were further asked what they did with their additional income. A considerable number of farmers stated that they use that income for religious and social activities, food, health care, and education. Some farmers were able to expand their farm business, and by adopting the new technologies and practices, these farmers produced rice more sustainably (Connor et al. 2021c).

7.5 Meta-Analysis of CORIGAP's Knowledge Management System and Research Outputs

This sub-chapter describes the project's knowledge management system, from knowledge product development to outreach mechanisms. Specifically, for scientific and adaptive research publications, a bibliometric mapping of terms and citations describes the level of alignment with the existing research thrusts. Lastly, this section will also provide how far out the products and mechanisms reached its stakeholders, the general public, and evaluates their contribution to the body of knowledge.

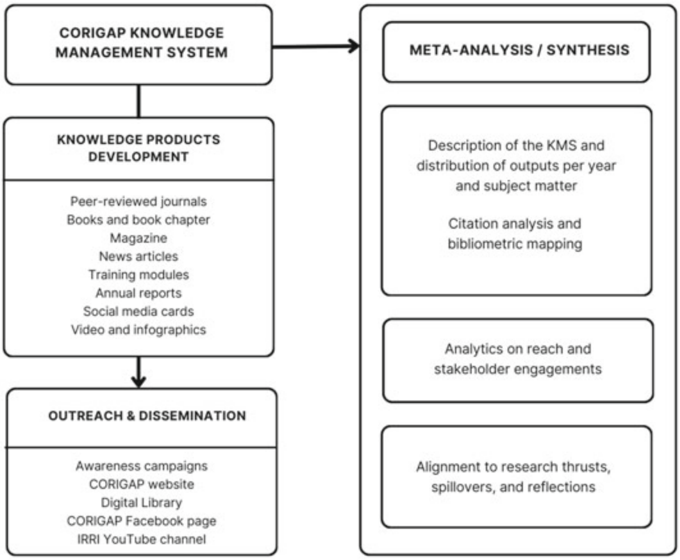

Fig. 7.5 Framework for synthesizing CORIGAP knowledge management system

Figure 7.5 illustrates the thought process of synthesizing CORIGAP's knowledge management system.

7.5.1 CORIGAP Knowledge Management System

A suite of knowledge products was developed over the years to scale the project outputs further and transfer the learnings to stakeholders and the general public. Outreach and dissemination strategies for reaching different audiences were segmented into various tools and media. CORIGAP has invested in digital repositories and online information campaigns to expand the outreach of every knowledge product developed.

7.5.1.1 Knowledge Products Developed Between 2013 and 2023

The inventory of CORIGAP knowledge products in ten years is listed in Table 7.9. The intended audiences of the materials encompass stakeholders from within and outside the organization, from project researchers and scientists to national partners in the country sites. It also went as far out as the extension workers and the general public. CORIGAP has published a total of 104 peer-reviewed articles in scientific journals and eight book chapters. A bibliometric mapping of these materials is provided in the next section to provide in-depth insight into the metadata.

About 144 information cards published on CORIGAP's online platforms have translated scientific outputs into general knowledge for the public. These information cards, usually pictured in high-resolution images and captions, are a valuable tool to simplify science communication for non-scientific audiences. In Phase III, information cards were frequently used to launch themed awareness campaigns and to feature old and new publications.

Additionally, 58 news articles were traced from local news outlets in Southeast Asia featuring the works and outreach activities of CORIGAP in the region. The IRRI editorial unit published news features about the project to further disseminate the outputs to its stakeholders globally. CORIGAP was also featured in 11 issues of IRRI's Rice Today online magazines.

In 2022, selected scientific publications and project milestones were rehashed into five outcome story videos capturing the local partners in Vietnam, Thailand, Myanmar, Indonesia, and Sri Lanka. Video products cover various topics, from stories of success in the field to informative videos on selected mechanization and postharvest technologies translated into local languages and English. Instructional videos on sustainable pest management are also available. Currently, there are 53 video materials accessible on YouTube and the CORIGAP digital library (https://corigap.irri.org/digital-library/publications).

The CORIGAP team has made available PDF copies of training modules on technology use and training event facilitation which can also be found in the CORIGAP repository. In 2022, the team published a 35-page toolkit for facilitating Learning Alliance (Chap. 6) and other multi-stakeholder platforms under the Creative Commons license. Learning Alliance consists of networks focused on learning the changes and involved in the complex process of capturing the learnings. The rationale is that technological change in the food system is a dynamic process that, in return, requires change across its networks of stakeholders. As behaviors change, so are the tools and approaches (Flor et al. 2022). The toolkit was published to provide facilitators and members of a multi-stakeholder platform the guidance and techniques to support learnings within their network (Table 7.11).

7.5.2 Outreach and Dissemination Strategies for Knowledge Products

7.5.2.1 Repository Building Through a Digital Library

The CORIGAP digital library is an online repository of published and verified materials created during the project's lifespan. It was developed in 2021 to store all CORIGAP knowledge products under the IRRI domain. It now holds peer-reviewed journal articles, books, book chapters, magazines, news articles and features, proceedings, training modules, and video resources. In 2022, materials

Table 7.11 Inventory of CORIGAP knowledge resources between 2013 and 2022

Knowledge Product	Intended audience	Count produced (2013–2022)
Peer-reviewed journal	Scientists, researchers, academe, extension workers	104
Social media info cards	Local partners, general public	144
News article	Scientists, researchers, extension workers, general public	58
Videos	Local partners, extension workers, general public	49
Reports	Donors, scientists, researchers	12
Magazine	General public	11
Book and book chapters	Scientists, researchers, academe, extension workers, local partners	8
Training module	Local partners, extension workers, researchers	3
Total products		**389**

from the Irrigated Rice Research Consortium (IRRC) were included in the repository. For ease of access and retrieval, search and filter functions are based on the publication year, country of focus, type of material, CORIGAP author, and title. To date, more than 300 materials are stored in the digital library.

7.5.2.2 Information and Awareness Campaigns

Despite the mounting number of knowledge resources produced over the years, there remained a gap for the general public to access information and materials. Themed information and awareness campaigns on social media (i.e., Facebook, Twitter, LinkedIn) were conceptualized to raise CORIGAP's visibility and amplify its collaboration with its national partners. One strategy that the CORIGAP team applied to cope with the limited attention span of social media users was the use of creative information cards with digested science information and visual cues. The online campaigns also served as a channel to direct interested users to the website and digital library, where downloadable publications and products are available for free.

Some of the notable online campaigns of CORIGAP include the following:

1. "Frogs of IRRI," an information campaign on the functional roles of frogs in the rice ecosystem
2. Launch and month-long promotional campaign for the CORIGAP Digital Library featuring selected works of CORIGAP scientists
3. International Women's Day featuring CORIGAP's women scientists and female NARES partners and their contributions to shaping CORIGAP's work in Southeast Asia

4. Promoting a partnership event with DLG (German Agricultural Society) and Agritechnica Asia in Bangkok, Thailand
5. Livestreaming of the CORIGAP Science and Lessons Learned Seminars in Can Tho, Vietnam
6. Pre-promotion campaign and snippets of the CORIGAP book and legacy site.

7.5.2.3 Website and Social Media Networks

Traditionally, project updates only happen internally and are arranged in physical venues. With social media and online browsers' rising popularity, stakeholders have become closer to accessing information with mobile devices, such as cell phones, laptops, and tablets. Syntheses from project activities and training events can be shared online as they happen. In this manner, there is the assurance that the intended audience receives relevant and up-to-date information. Using the CORIGAP online accounts (i.e., Facebook, YouTube, website), the team featured events on the field, country meetings, and training events. They were especially used to feature scientific findings, training modules, and science seminars' live streams that further enable stakeholder engagements. Google Analytics platform was used to track the online reach and engagement of social media campaigns.

Sponsoring online campaigns also expanded the reach and public engagement of the project. In a social media campaign between November and December 2021, an information card about the regional demand for packaged and labeled rice in Vietnam reached 295,683 users, of which 42,022 moved on to the CORIGAP page to access the related publication. Another material on factors leading to the adoption of CORIGAP technologies reached 483,819 users, of which 174,487 moved on to the CORIGAP digital library. Visitors came from CORIGAP countries, but outreach was global, including India, Bangladesh, Nepal, Ethiopia, Nigeria, and Pakistan (Google Analytics). In December 2022, an online campaign released a total of ten information cards and reached over 2.9 million users globally, and routed more than 132,000 unique accessions to the digital library. In 2022, the CORIGAP website's unique visits and traffic increased by 88%, and it now has 21,742 users.

7.5.2.4 Bibliometric Mapping of CORIGAP's Contribution to the Body of Knowledge

Bibliometric data were collected from the CORIGAP digital library and cross-referenced with the Web of Science bibliographic database. The final dataset contains the metadata of 104 CORIGAP peer-reviewed journal publications from 2013 to 2022. Search filters based on topic, funding agency, publishing years, and authors were used to locating all the CORIGAP journal publications.

Table 7.12 rounds up CORIGAP's share in SDC-funded publications as sectors get more specific. CORIGAP has a share of 36.2% of the 287 food-sector publications funded by SDC between 2013 and 2022 globally, 52.5% for agriculture ($n = 198$), and 89.7% for rice ($n = 116$) sectors.

Table 7.13 lists the distribution of CORIGAP peer-reviewed publications per research area. More than half (52%) of the publications are in the agriculture research area, while 36% are in engineering, food, and science technology. About a third (34%) of the publications are under environmental sciences, particularly ecology, water resources, and biodiversity conservation. Categorically, 22% of the research focuses on the biological sciences, mainly in entomology, zoology, plant sciences, and toxicology. Eight publications were produced for economics and development studies toward the later phase of the project.

The publications have combined citations of 1,915, garnering an average of 18.41 citations per material and an H-index of 23.0. An H-index above 20 is within the good range index of productivity (Hirsch 2005). Figure 7.6 illustrates the citation map of CORIGAP peer-reviewed publications. Each circle represents a journal, and the size of the circle depicts the number of citations in that journal. The journal citation clusters concentrated on field crops research, agriculture ecosystems, and social sciences. Table 7.14 lists the five CORIGAP publications with the most citations,

Table 7.12 Publications funded by the Swiss Agency for Development and Cooperation (SDC) between 2013 and 2022

Sector	Count	% share of CORIGAP ($n = 104$)
Global	1,797	5.8
Food	287	36.2
Agriculture	198	52.5
Rice	116	89.7

Source Web of science

Table 7.13 Distribution of CORIGAP peer-reviewed publications per research area

Research area	Record count	% of 104
Agriculture	54	52
Engineering, Food, and Science Technology	37	36
Environmental Sciences (34%)		
Environmental Ecology	26	25
Water resources	6	6
Biodiversity Conservation	3	3
Biological Sciences (22%)		
Entomology	10	10
Zoology	6	6
Plant Sciences	5	5
Toxicology	2	2
Economics and Development Studies	8	8

Source Web of science

Fig. 7.6 Citation network map of CORIGAP peer-reviewed publications

topped by Lampayan et al. (2015) on the topic of adoption and economics of alternate wetting and drying for irrigated lowland rice and followed by Akter et al. (2017) about Women's empowerment and gender equity in agriculture: A different perspective in Southeast Asia.

For the co-occurrence network of CORIGAP publications, terms with a minimum of ten co-occurrences were preserved and computed for relevance rates and link strength. This way, only the terms with the most robust relevance and linkages were mapped.

Figure 7.7 illustrates the network of terms and co-occurrence relations using the text-mining functionality of the VOSviewer platform (https://www.vosviewer.com). Each circle represents a term, and the circle's size represents the number of publications regarding that term. A total of 3,672 terms were processed using a network language processing technique where a linguistic filter was applied to tag the parts of speech. The words that were not relevant were excluded from the processing. Clusters are formed to represent the concentration of terms according to topics. Three clusters (blue, red, and green) were identified in the network map using the dataset's keywords, titles, and abstracts.

Terms of topics on "productivity," "efficiency," "performance," "difference," and "comparison" frequently occurred in the blue cluster, showing that a proportion of the CORIGAP publications touch on change indicators and quantifiable measures. The subject matters of "water productivity" and "grain yield" also co-occurred with the abovementioned measures. The red cluster illustrates the co-occurrences of the terms "farmers," "rice field," "smallholder," "rodent pest," "species," and "weed," indicating that a proportion of the publications touch on grassroots studies and challenges on the field level. It also linked the "Philippines" and "Cambodia" countries with serious pest concerns. In the green cluster, co-occurrence was observed among the terms "climate change," "greenhouse gas emission," "sustainability," and "energy efficiency" and linked heavily to "Vietnam" and "Thailand." Lastly, terms in the green cluster touch on environmental indicators, such as greenhouse gas emission, energy efficiency, sustainability, and climate change. The terms also have associations with the words "data," "evidence," and "gap."

Some terms transect multiple clusters. The terms located in the central region of the network map similarly have the most linkages to other words and clusters. Figure 7.8 shows the most cross-cutting terms, namely "data," "efficiency," and "problem," respectively. The term "data" has strong linkages in the environmental indicators in the green cluster but spanned as far out as the red and blue clusters

Table 7.14 Five CORIGAP publications with the most citations

Title	Author	Source	Publication year	Total citation
Adoption and economics of alternate wetting and drying water management for irrigated lowland rice	Lampayan, Rubenito M.; Rejesus, Roderick M.; Singleton, Grant R.; Bouman, Bas A. M	Field Crops Research	2015	245
Women's empowerment and gender equity in agriculture: A different perspective from Southeast Asia	Akter, Sonia; Rutsaert, Pieter; Luis, Joyce; Htwe, Nyo Me; San, Su Su; Raharjo, Budi; Pustika, Arlyna	Food Policy	2017	105
Grain yield, water productivity, and nitrogen use efficiency of rice under different water management and fertilizer-N inputs in South China	Pan, Junfeng; Liu, Yanzhuo; Zhong, Xuhua; Lampayan, Rubenito M.; Singleton, Grant R.; Huang, Nongrong; Liang, Kaiming; Peng, Bilin; Tian, Ka	Agricultural Water Management	2017	90
Grain yield, water productivity, and CH4 emission of irrigated rice in response to water management in South China	Liang, Kaiming; Zhong, Xuhua; Huang, Nongrong; Lampayan, Rubenito M.; Pan, Junfeng; Tian, Ka; Liu, Yanzhuo	Agricultural Water Management	2016	75
Yield gaps in rice-based farming systems: Insights from local studies and prospects for future analysis	Stuart, Alexander M.; Pame, Anny Ruth P.; Silva, Joao Vasco; Dikitanan, Rowell C.; Rutsaert, Pieter; Malabayabas, Arelene Julia B.; Lampayan, Rubenito M.; Radanielson, Ando M.; Singleton, Grant R	Field Crops Research	2016	72

Source Web of science

having co-occurrences mostly on quantitative terms (efficiency, comparison, difference, experiment) and descriptive terms in the field (rodent, rice field, species, pest, context, contrast).

Similarly, the term "efficiency" in the blue cluster traced strong internal links to "water productivity" and "grain yield" but are as associated with "yield gap," "sustainability," and "data" in the green cluster as well as "problem," and "rice field" in the red cluster. The term "problem" has demonstrated strong internal relevance to the terms "weed," "pest," "rodent," and "farmers" Interestingly, the term also stretches

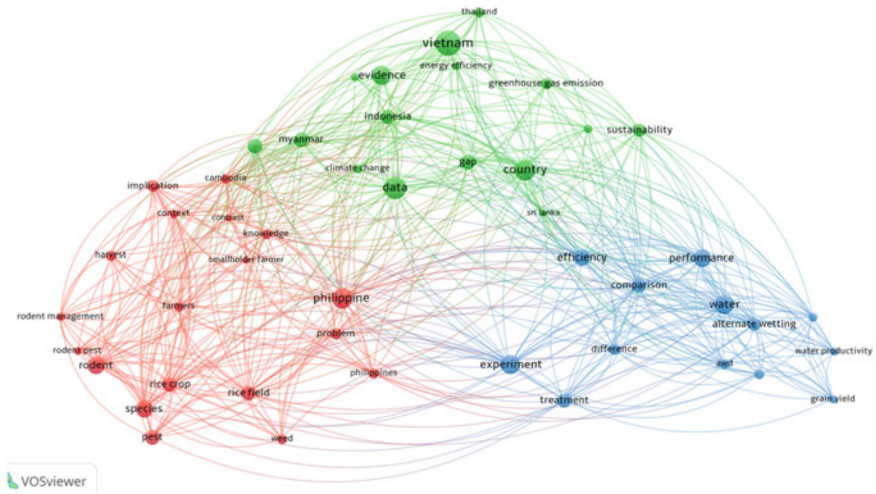

Fig. 7.7 Network of terms and co-occurrence relations of CORIGAP peer-reviewed publications

as far out as "Indonesia" and "Sri Lanka" in the green cluster and "experiment," and "water management" in the blue cluster.

7.5.2.5 Alignment with IRRI's Research Thrusts, Spillovers, and Reflections

CORIGAP's contribution to the body of knowledge is substantially reflected in its scientific publications. CORIGAP's adaptive and scientific research, in terms of subject matter, is data-driven and aligned with generating evidence to improve rice productivity and is well integrated into sustainable models context-specific in Southeast Asia. CORIGAP's scholarly impact is notably well based on the bibliometric indexing of the Web of Science.

While more than half of the scientific outputs categorically contribute to agronomic research, almost half transect multiple disciplines such as engineering and food science technology, environmental and biological sciences, and development studies. Multi- and transdisciplinarity are vital toward a holistic approach that involves a range of stakeholders, particularly those from the grassroots and extension sectors.

Another way to adapt to science communication's changing landscape is to optimize the use of enabling technologies and social media networks. Readers have shifted to electronic devices and internet connectivity in the past decade. This has been the impetus to create a basic digital library to access resources with download and hyperlink functions. Many of the population are subscribed to at least one social media network to access information from local and international sources. Inevitably, due to the massive amount of online data, social media consumption created an audience that demands easily digestible information with strong visual

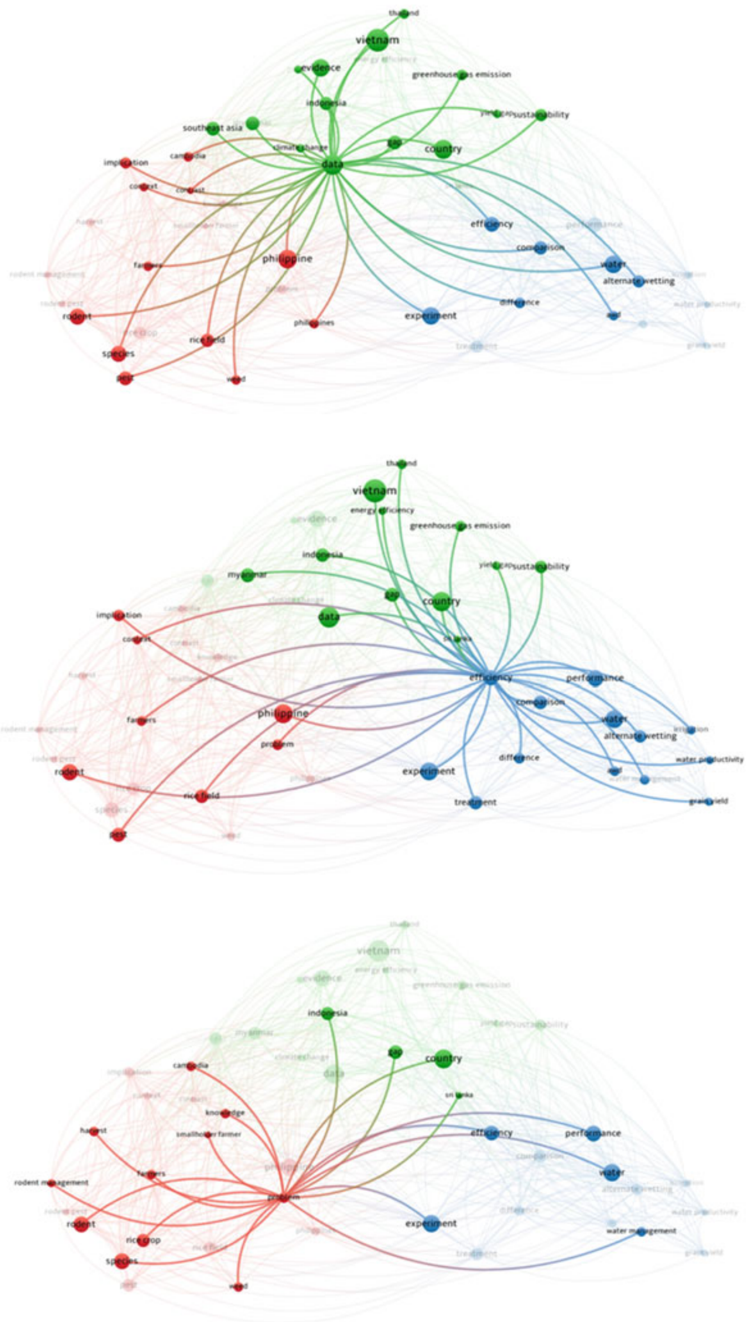

Fig. 7.8 Sub-network of cross-cutting terms “data,” “efficiency,” and “problem”

cues that can be conveyed quickly. In the case of CORIGAP, a social media post gains more public engagement when the scientific knowledge is in layperson's terms and with associated visual material.

The functionalities of social media expanded the audience base of CORIGAP and transformed the science jargon into general knowledge. It not only provides scientific information but is also integrated into other products making CORIGAP more accessible. Each post on social media included a call-to-action for the viewers linking them to the repositories (i.e., website, digital library). Information and awareness campaigns through social media networks are another form of reaching the general public more effectively. An effective knowledge management system does not only revolve around knowledge generation and collation to a central repository. It is imperative to translate each knowledge product in a manner that can be understood and accessible by any member of the public in any medium available to them.

One of the positive spillovers of communicating through social media is the expansion of reach to demographics that were not even part of the initial targeting. Integrating into the transforming information system creates platforms that enhance the capacity to transfer learning and engage stakeholders down to the grassroots level, including the unintended audiences. Online presence of CORIGAP spread as far out as South Asia and Africa, evident from the number of inquiries and web analytics coming from these regions. Such action could branch to different opportunities, including scaling out to other areas and further uptake of the best practices.

In conclusion, investing in a forward-looking knowledge management system is essential, especially for repository-building and knowledge-sharing platforms. CORIGAP Phase III captures the impact and mutual benefits realized during Phases I and II, so stakeholders and the general public can access information beyond project closure. The tools developed for outreach and dissemination are knowledge repositories that will continue to exist for as long as they are relevant.

7.6 Anecdotal Evidence of CORIGAP's Influence on Policy

One of the main reasons for the success in the out-scaling of CORIGAP research outputs was the inclusion thereof in national programs. This required influencing policy decisions so that the CORIGAP technologies and management practices would be incorporated into national programs. There were several pathways that the project pursued.

1. **Collaboration with national scientists** and research institutions as part of the CORIGAP activities. Every year throughout the project cycle, the national partners developed work plans based on the activities and findings of the previous year in the annual review and planning meetings. These were then implemented, and awareness and results were disseminated to the national policymakers through their reporting channels.

2. **Visits to policymakers during travel of CORIGAP scientists** in the partner countries. Both IRRC and CORIGAP scientists influenced policy informally by making sure that they visited national policymakers during their travel and updated them on project progress, and lobbied for linkages to national programs.
3. Senior research managers connected to policy as members of the **CORIGAP advisory committee (AC)**. The AC met annually during or after the annual review and planning meeting. AC's direct involvement in the project review and planning ensured that the national policy level was informed. They also provided valuable input about national policy to ensure that CORIGAP was in line with national priorities.
4. Participation of policy influencers in **Participatory Impact Pathway Analyses (PIPA)** and **Learning Alliances (LA)**. After the introduction of the PIPA and LA approaches to IRRI by the CORIGAP Postharvest Team, many postharvest activities started with a PIPA and led to the creation of a LA. The PIPAs usually had some policymaker or policy influencers as participants. They not only learned about what the project aimed to achieve but also actively participated in the design of activities and then often supported activities, e.g., in An Giang, where CORIGAP postharvest activities were funded by 1/3 by CORIGAP, 1/3 by the private sector, and 1/3 by the national extension system, after the PIPA.
5. **Seminars for policymakers** were not explicitly planned except for the last phase for 2021, during which they could not be implemented due to the COVID-19 lockdowns and travel restrictions. However, the postharvest team implemented one seminar on hermetic storage in Indonesia (2007) and one in Vietnam, each on laser leveling (2013) and hermetic storage (2017), targeting policymakers exclusively. During field days, demonstrations on laser leveling or during the AGRITECHNICA ASIA Live events in Myanmar (2019) and Vietnam (2022), many policymakers participated and learned about CORIGAP outputs and outcomes.
6. The **Council for Partnership on Rice Research in Asia (CORRA)** is composed of the leaders of the national agricultural research and extension systems (NARES) of 16 rice-growing countries in Asia and IRRI. Before COVID-19, CORRA members met annually. CORIGAP scientists were often invited to present their research, which in turn resulted in requests from CORIGAP members to start activities in their countries.
7. **Conferences and Seminars**. Scientific conferences and seminars are sometimes attended by policymakers. This was, in particular, the case for the International Rice Congress (IRC), which was organized by IRRI every four years in a different country (New Delhi (2006), Hanoi (2010), Bangkok (2014), and Singapore (2018). Each IRC drew a lot of attention, also from policymakers. During the IRC in Vietnam and in Thailand, ministerial round tables were held as side events of the scientific congress, which exposed the ministers to IRRI's outputs, including CORIGAPs.
8. Through **CORIGAP publications** like RIPPLE and web-based information channels and also non-scientific publications that were read by policy influencers/makers like Rural 21.

Table 7.15 Government decrees/resolutions in Vietnam that were directly or indirectly influenced by the project

Degree/ resolution	Title	Issuer, date of issue
63/ 2010-QĐ-TTg	On "Policy of supports to reduce post-harvest losses of agricultural products and aqua-cultural products."	Vietnamese Prime Minister, 15th Oct. 2010
109/2010/ NĐ-CP	"Exportation of Vietnamese rice" or called "Obligatory conditions for food companies/traders exporting of rice."	Vietnamese Prime Minister, 04th Nov. 2010
560/ QĐ-BNN-CB	Temporary regulations of technical requirements for paddy storage and rice milling plants servicing for rice export	Minister of Agriculture and Rural Development (MARD), 24th Mar. 2011
65/ 2011-QĐ-TTg	An amendment and addition to some articles of Decision No. 63/2010-QĐ-TTg on "Policy of supports to reduce post-harvest losses of agricultural products and aqua-cultural products" issued on 15th Oct. 2010'	Vietnamese Prime Minister, 02nd Dec. 2011

9. Inclusion of CORIGAP outputs in **national rice strategies**. In Myanmar, for example, CORIGAP scientists were working very closely with their partners, who were also contributing to the national rice strategy. In other countries, the impact pathway was less direct, but usually, the national scientists were asked for inputs to rice strategies, and thus CORIGAP outputs were also included.
10. A major impact on policy, although not measured and documented scientifically, came through the participation of CORIGAP scientists with their COPRIGAP products in **national programs.** Examples from Vietnam are the World Bank-funded Agricultural Competitiveness Project (ACP) and Vietnam Agricultural Transformation (VNSat), and the ADB-funded Strategic Research for Sustainable Food and Nutrition Security in Asia project. The latter was an IRRI-coordinated project with activities on postharvest in Vietnam, Cambodia, and the Philippines. It used CORIGAP outputs as interventions.

Table 7.15 provided an overview of government decrees/resolutions in Vietnam that were directly or indirectly influenced by the project. It needs to be noted that the influence on policies was not an explicit outcome of the project and was, therefore, not systematically monitored. However, in future projects, this should be included in the Theory of Change and monitored with the respective indicators.

7.6.1 Lessons Learned

Engaging with the policy level, initially informally during visits of CORIGAP scientists to policymakers, led to CORIGAP outputs being incorporated into national programs. This led to successful scaling out through national programs. In fact, after Phase II, CORIGAP exceeded the target of reaching 500,000 households and had reached more than 883,000[2] by March 2023. Having high-level national research managers with good input to national policy formulation also helped in that process. Targeted policy dialogue activities through CORIGAP were only conducted in limited numbers. Evidence of the impact of the project on the policy level is, therefore, anecdotal. In the future, similar projects that target scaling, activities, and resources for policy discourse should be included at the early stages of the project.

In the following, we propose some ways to have effective impacts on postharvest policies for the Vietnamese government:

- Provision of consultation directly to policymakers of MARD or indirectly to policymakers of the government;
- Written reports related to postharvest of rice directly to MARD;
- Awareness of postharvest losses, causes, and solutions to the public, particularly stakeholders of the rice supply chains and the local authorities, and the government via interviews by media means, such as central or local televisions, newspapers;.
- Lectures on postharvest of rice and training courses for provincial extension centers, rice farmers, rice cooperatives, food companies, etc.;
- Study tours showing good models of postharvest for all value chain stakeholders;
- Published papers/presentations at conferences/seminars/workshops organized by MARD, Ministry of Industry and Trade, Ministry of Science and Technology, other organizations under MARD, provincial authorities, various projects in the Mekong Delta, the South Western Steering Committee (belonging to the government), or the government.

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[2] 883,000 is the latest number computed. However, some data are still reviewed by the national partners to be included.

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