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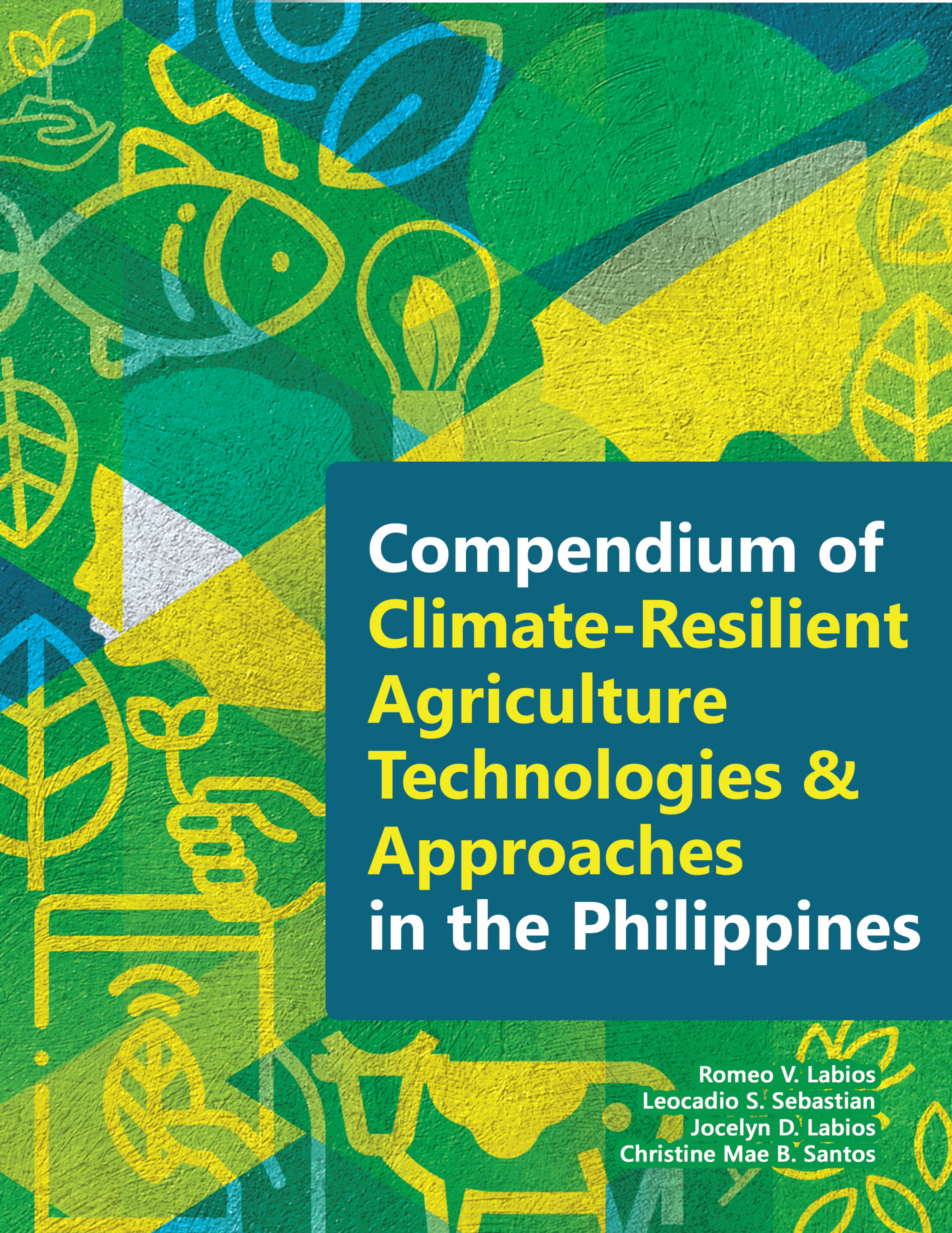

Compendium of Climate-Resilient Agriculture Technologies & Approaches in the Philippines

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The Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) is one of the 26 specialist institutions of the Southeast Asian Ministers of Education Organization (SEAMEO). Founded on 27 November 1966, SEARCA is mandated to strengthen institutional capacities in agricultural and rural development in Southeast Asia through graduate scholarship, research and development, and knowledge management. It serves the 11 SEAMEO member countries, namely, Brunei Darussalam, Cambodia, Indonesia, Lao People's Democratic Republic, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Vietnam, and Timor-Leste. For more information, please visit www.searca.org.

The CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS) is a strategic partnership of CGIAR and Future Earth, led by the International Center for Tropical Agriculture (CIAT). The Program is carried out with funding by CGIAR Fund Donors, Australia (ACIAR), Ireland (Irish Aid), Netherlands (Ministry of Foreign Affairs), New Zealand Ministry of Foreign Affairs and Trade; Switzerland (SDC); Thailand; The UK Government (UK Aid); USA (USAID); The European Union (EU); and with technical support from The International Fund for Agricultural Development (IFAD). For more information, please visit https://ccafs.cgiar.org/donors.

Suggested Citation:
Labios, R.V., L.S. Sebastian, J.D. Labios, and C.M.B. Santos. 2019. *Compendium of Climate-Resilient Agriculture Technologies and Approaches in the Philippines.* Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), College, Los Baños, Laguna, Philippines; and Wageningen, the Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). 253 p.

Published by SEARCA and CGIAR-CCAFS
Printed in the Republic of the Philippines
First Printing 2020

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e-ISBN: 978-971-560-274-7
p-ISBN (hard bound): 978-971-560-272-3
p-ISBN (sofbound): 978-971-560-273-0

This Compendium is dedicated to Dr. Arturo A. Gomez, fifth Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) Director (1988–1993), former Professor at the University of the Philippines Los Baños and one of the pioneers of Multiple Cropping Systems in the Philippines.

Foreword

The Filipino resilience, which is known to endure different forms of hardships, will be tested in the coming years by the worsening impacts of climate change. Rising sea levels, stronger and more frequent typhoons, longer and more severe droughts, and erratic climate variability are projected to deal with massive damages and losses to the Philippine economy, especially to the country's agriculture sector.

Filipino farmers, who lack access to basic services, knowledge, and skills necessary to adapt to and mitigate climate change impacts, are expected to bear the brunt of these impacts. Accessibility to these resources, however, is only one of the issues threatening Filipino farmers. Poverty in rural areas, various forms of inequalities between men and women farmers, stiff market competition, and country-level economic integration are other factors that compound the impacts of climate change on Philippine agriculture.

The Filipino resilience can only endure so much. It may not be broken yet, but cracks are already apparent.

Cognizant of these issues and the critical role of agriculture in ensuring food security in the country, the CGIAR Research Program on Climate Change, Agriculture and Food Security Southeast Asia (CCAFS SEA), together with the Department of Agriculture (DA), the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD), and the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), developed the *Compendium of Climate-Resilient Agriculture Technologies and Approaches in the Philippines*. CCAFS SEA worked with various agriculture experts in the Philippines to list climate-resilient agriculture (CRA) options that Filipino farmers can adopt on their farms.

The CRA options discussed in this Compendium are grouped based on their suitability for the different agroecological landscapes in the Philippines. They were discussed by agriculture experts during a stakeholder workshop conducted 31 January–1 February 2019 at SEARCA. The workshop involved a ranking and assessment exercise to identify options that can be prioritized in the country's agroecological landscapes.

The CRA options listed in the Compendium not only improve the agricultural productivity of farmers; they also enhance the farmers' adaptive capacity against climate change impacts and reduce the greenhouse gas emissions from their farming activities. The Compendium mentions different activities that can promote and disseminate these CRA options in the Philippines. Alongside the activities, it identifies various strategies to help the country overcome the challenges in applying and scaling these options. Strategies, though, must not be limited to promotion and dissemination. Another set of strategies must be crafted to transform the entire Philippine agriculture under a changing climate. The Compendium enumerates seven transformative strategies, each of which allows the farmers to participate in climate actions for agriculture.

The farmers' voices are crucial in crafting strategies for their context-specific situation and needs. The participation of women, youth, indigenous people groups, and other marginalized sectors is needed to ensure that such strategies are gender-sensitive and socially inclusive. Altogether, these strategies can strengthen the Filipino resilience amidst the unforgiving impacts of climate change.

We hope that the Compendium will be a valuable tool for the Philippine Government, as well as for research organizations, donor agencies, international partners, and other stakeholders working on the agriculture sector. We humbly offer this Compendium to our farmers, who ensure that all Filipinos will have food on their plates.

WILLIAM D. DAR
Secretary
Department of Agriculture

Messages

We cannot speak of agriculture without talking about climate.

Today, the combination of climate change and highly vulnerable agricultural production systems has threatened the livelihoods of farmers and fisherfolk and consequently, our food supply. Climate change undermines the agriculture sector's contribution to a world without hunger, economic development, and poverty reduction. Recent studies have shown how adverse impacts of climate change would push people further into poverty and be a major obstacle in achieving the UN Sustainable Development Goals (SDGs). The same could be said of the Filipino farmers who are in the frontline of climate change, but often lack the resources to build resilience and adaptive capacity. The irreversible nature of climate change demands each of us to move beyond climate talk to climate action.

The Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA), in its 11th Five-Year Plan (2020–2025), aligns its direction toward contributing to the achievement of the SDGs that address global challenges to achieve a better and more sustainable future for all. SEARCA commits to contribute and allocate resources for the achievement of SDG 13 (Take urgent action to combat climate change and its impacts), with emphasis on creating partnerships (SDG 17), that interrelate with the Center's thrust to contribute to SDG 2 (end hunger, achieve food security and improved nutrition, and promote sustainable agriculture) and indirectly, to SDG 1 (end poverty in all its forms everywhere). But what does it really mean to take "climate action," and what is required?

This *Compendium of Climate-Resilient Agriculture Technologies and Approaches in the Philippines* has been produced in response to the need to provide science-based and actionable knowledge on climate-resilient agricultural technologies and practices in different agroecological systems in the Philippines. The compendium aims to better guide policymakers, farmer organizations, researchers, extension workers, and the agribusiness sector, as well as climate-smart agriculture practitioners. It does not only present a menu of solutions but more importantly, it proposes that the business-as-usual attitude is no longer an option if we want to protect the future of our food supply and the well-being of the farmers and communities that produce it.

We, at SEARCA, believe that working with the Research Program on Climate Change, Agriculture and Food Security Southeast Asia (CCAFS SEA) of CGIAR, DA, and PCAARRD, is an important step toward the goal of helping millions of smallholder farmers become more resilient in the face of mounting climate impacts. We congratulate CCAFS and partners for embarking on this project, and the writers, editors, contributors, experts, scientists, researchers, and other stakeholders who volunteered their time, knowledge, and energy in identifying options that can be prioritized given the country's agroecological landscapes. Without them, this compendium would not have been possible.

To our readers for whom this compendium is dedicated, we hope that it will inspire you to contribute to the growing body of knowledge of climate resilient technologies and best practices or make improvements in your farming approaches, methods and tools. Let us do our part in driving home the message through this compendium that our farmers will always be part of the solution in creating climate-resilient agricultural landscapes.

GLENN B. GREGORIO, Ph.D.
Director
SEARCA

This *Compendium of Climate-Resilient Agriculture Technologies and Approaches in the Philippines* jointly developed by CGIAR Research Program on Climate Change, Agriculture and Food Security in Southeast Asia (CCAFS SEA), Department of Agriculture (DA), Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD), and the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) seeks to bring various CRA options that may guide our agriculture sector, specifically farmers, in enhancing their adaptive capacity against the changing weather patterns in different agroecological landscapes in the Philippines particularly in the lowland, upland, hilly land, mountainous, and coastal ecosystems. While the compendium is intended primarily for our farmers and fishermen, it is our hope that it will be of help to introduce CRA key concepts to agricultural service providers, extensions workers, policymakers, researchers, and students.

This compendium is a product of the contribution of various agriculture experts during a stakeholder workshop conducted on 31 January to 1 February 2019 at SEARCA that involved assessment exercises to prioritize CRA options best suited in the Philippine agroecology. It particularly enumerates seven CRA strategies that tackle basic information on how to apply CRA technologies in line with their relevance to various aspects of agricultural production and climate change mitigation. The first few chapters provide the basic information and prioritization systems of CRA technologies and approaches emerging in the Philippines, while the concluding parts discuss their promotion, dissemination, and transformation.

The uncertainty of changing weather patterns, their degree, timing, and impacts compel the need to capitalize mitigation strategies in the agriculture sector. As the future beckons with more challenging climatic events, we hope that the CRA technologies and approaches covered in this compendium will reach the hands of their intended users and will be put into practical use.

REYNALDO V. EBORA, Ph.D.
Executive Director
DOST-PCAARRD

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Acronyms

AMIA	Adaptation and Mitigation Initiative in Agriculture
ARMM	Autonomous Region of Muslim Mindanao
AWD	Alternate Wetting and Drying
AWS	Automatic weather station
ASEAN	Association of Southeast Asian Nations
BFAR	Bureau of Fisheries and Aquatic Resources
BSWM	Bureau of Soils and Water Management
CALABARZON	Cavite, Laguna, Batangas, Rizal, and Quezon
CAR	Cordillera Administrative Region
CCC	Climate Change Commission
CGIAR-CCAFS	CGIAR research program on Climate Change, Agriculture, and Food Security
CRA	Climate-resilient agriculture
CSA	Climate-smart agriculture
CSS	Climate smartness scores
CBFM	Community-based forest management
CFV	Conservation farming village
CSV	Climate-smart village
DA	Department of Agriculture
DENR	Department of Environment and Natural Resources
FAITH	Food Always in the Home
FAO	Food and Agriculture Organization of the United Nations
FBD	Flat-bed dryer
GHG	Greenhouse gas
GDP	Gross Domestic Product
GIS	Geographic Information System
ICRAF	International Center for Research in Agroforestry
IEC	Information, education, and communication
ICT	Information and Communications Technology
IPCC	Intergovernmental Panel on Climate Change
IIRR	International Institute of Rural Reconstruction
IPM	Integrated pest management
IPNI	International Plant Nutrition Institute
IRRI	International Rice Research Institute
K	Potassium
LCC	Leaf color chart
LGUs	Local government units
MBRLC	Mindanao Baptist Rural Life Center
MC	Moisture content
N	Nitrogen
NCCAP	National Climate Change Action Plan
NDRRMC	National Disaster Risk Reduction and Management Council

NSIC	National Seed Industry Council
NEDA	National Economic and Development Authority
NAMRIA	National Mapping and Resource Information Authority
NVS	Natural vegetative strips
NFTS	Nitrogen-fixing trees and shrubs
NGO	Non-government organization
OPV	Open-pollinated variety
P	Phosphorus
PaLA	Participatory Landscape Appraisal
PAGASA	Philippine Atmospheric, Geophysical and Astronomical Services Administration
PCAARRD	Philippine Council for Agriculture, Aquatic, and Natural Resources Research and Development
PhilCAT	Philippine Conservation Approaches and Technologies
PhilRice	Philippine Rice Research Institute
QTL	Quantitative Trait Loci
RICM	Rice integrated crop management
RKB	Rice Knowledge Bank
RS	Remote sensing
SALT	Sloping Agricultural Land Technology
SARAI	Smarter Approaches to Reinvigorate Agriculture as an Industry in the Philippines
SBD	Solar bubble dryer
SCGFS	Soil conservation guided farm system
SCoPSA	Sustainable Corn Production in Sloping Areas
SEAMS	SARAI-Enhanced Agricultural Monitoring System
SEARCA	Southeast Asian Regional Center for Graduate Study and Research in Agriculture
SFR	Small farm reservoir
SLM	Sustainable land management
SOCCSKSARGEN	South Cotabato, Cotabato City, Cotabato Province, Sultan Kudarat, Sarangani, and General Santos City
SPIdTech	Smarter Pest Identification Technology
SSNM	Site-Specific Nutrient Management
SWCCO	System Wide Climate Change Office
UAV	Unmanned aerial vehicle
WAISS	Water Advisory for Irrigation Scheduling System

CHAPTER 1

Introduction

The catastrophic impacts and unpredictable onsets of climate change are widely recognized. In the past decades, the composition of the earth's atmosphere has undergone major changes due to unregulated industrial operations, improper disposal of agricultural wastes, and mismanagement of land and aquatic resources. The Intergovernmental Panel on Climate Change (IPCC 2012) emphasized that the importance of coping with climate-related risks remains the main topic for global discussion and both mitigation and adaptation strategies should be prioritized.

Food security is likely aggravated by climatic changes. Thus, this exerts pressure on the agriculture sector. Because of climate threats, the global climate change agenda sees the need to incite agriculture as a catalyst for addressing climate change. Complex challenges posed by climate change can be alleviated if agriculture, including agroforestry and fisheries, adopts climate-smart measures. According to the Food and Agriculture Organization of the United Nations (FAO), the World Food Programme (WFP), and the International Fund For Agricultural Development (IFAD) (2012), climate-smart agriculture (CSA) increases agricultural productivity and income of communities by using less land, water, and other inputs while sustaining food security and building resilience against climate threats and shocks. CSA differs from other agriculture approaches in these three essential features: an exclusive focus on climate change, adaptation and mitigation strategies in pursuit of productivity, and funding opportunities for agricultural development (IFAD 2013). Since small-scale farmers in developing countries are more exposed to climate shocks and are unable to cope with disaster aftermaths, incorporating resilience in adaptation and mitigation strategies would be an effective approach to deal with climate shocks and stressors (CGIAR 2014). Thus, climate-resilient agriculture (CRA) is being mainstreamed, promoted, and adopted by various institutions.

Recent events and studies conclude that the Philippines is one of the most vulnerable countries to climate change. Upland and lowland regions in the country have been severely affected by typhoons, floods, and droughts. The emergence of CRA technologies and practices has aided organizations, farmers, and communities in responding to the adverse effects of climate change.

This manual aims to provide researchers, technicians, and agriculture practitioners with basic information on how to apply CRA technologies and practices in various agroecological systems in the Philippines.

CLIMATE CHANGE IN SOUTHEAST ASIA

Climatic effects are experienced differently in each region. In general, however, temperature is increasing, sea level is rising, and disasters are becoming more extreme. Southeast Asia is composed of countries that are identified as climate change "hotspots". Based on the vulnerability mapping of Yusuf and Francisco in 2009, the Philippines, Cambodia, Vietnam, Thailand, Indonesia, and Lao PDR will experience more climate change manifestations in the coming decades.

The region's annual temperature will increase by 0.4°C–1.3°C in 2030 and by 0.9°C–4.0°C in 2070, based on the global climate change trends and patterns (Yuen and Kong 2009). As temperature increases, sea level rise is estimated to be 16 cm–30 cm by 2030 and 7 cm–50 cm by 2070 (Yuen and Kong 2009). Sea level rise causes typhoons and tropical cyclones to intensify, which also increases flood incidence on arable lands in the region. High salinity in groundwater, on the other hand, will cause shortage in water supply for agricultural use. Long periods of drought and cold spell recorded in Southeast Asia contributed to a reduction in the region's productivity.

Changes in temperature and composition of coastal waters can affect the survival rate and alter the distribution of marine species, which destabilize the livelihood of most coastal communities in Southeast Asia. Asia holds 84 percent of the population engaged in fisheries and aquaculture (FAO, WFP, and IFAD 2014). Such demand of the growing population in the region results in overfishing. In the Philippines, for example, overfishing is observed in 10 of 13 designated fishing grounds. Overfishing and drastic changes brought about by climate change put coastal communities at high risk (Babson 2018).

Climate change will not only affect agricultural productivity, but also displace the rural population in vulnerable areas. This presents a direct threat to the livelihood and security of rural communities in Southeast Asia. As cited in "Climate Change and Urban Planning in Southeast Asia" (Yuen and Kong 2009), the Intergovernmental Panel on Climate Change (IPCC [2012]) states that the current socioeconomic and political disparities in Southeast Asian rural communities are exacerbated by climate change. Gearing for resiliency and building response capacity is critical in mitigating climate change impacts. Ultimately, capacity building is vital in managing these threats.

CLIMATE CHANGE IN THE PHILIPPINES AND AN OVERVIEW OF CLIMATE-RESILIENT AGRICULTURE IN THE PHILIPPINES

Climate change in the Philippines

Between 1997 and 2016, the Philippines ranked 5th among countries with the most weather-loss related events (Global Climate Risk Index 2018). With more than 7,600 islands and an estimated 36,298 km of coastline, it is considered as one of the countries that is most vulnerable to disasters and extreme weather conditions. The Philippine Department of Environment and Natural Resources (DENR) states that on the average, 20 tropical cyclones enter the Philippine waters each year, eight to nine make a landfall. Between 1947 and 2014, 10 deadly typhoons hit the Philippines; the five that occurred in 2006 resulted in massive damages on land and properties, as well as in the displacement of citizens. The most destructive typhoon to date is Haiyan, locally known as Yolanda, which hit the country in 2013, killing 6,300 people, displacing over 4 million, and causing damage worth USD 2 billion, as reported by the Climate Reality Project (2016). In September 2018, Typhoon Mangkhut affected 218,492 households in Luzon (Tomacruz 2018). Agricultural damages in the Ilocos Region, Cagayan Valley, Central Luzon, CALABARZON (Cavite, Laguna, Batangas, Rizal, and Quezon), and CAR (Cordillera Administrative Region) ballooned to about PHP 14 billion, as reported by the National Disaster Risk Reduction and Management Council (NDRRMC [2018]). Rice, corn, high-value commercial crops, livestock and poultry, and agricultural infrastructure were among the most affected by the disaster (Tomacruz 2018). Threats that are relative to the Philippines include food and freshwater scarcity, damage to infrastructures and properties, and, ultimately, sea level rise, which affects the population in coastal zones. The Philippine National Economic and Development Authority (NEDA) claims that the country is susceptible to climate change impact because its population is highly concentrated on disaster-prone areas (e.g., coastal communities).

The Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) projected climate change scenarios from 2020–2050. Based on the downscaling made by PAGASA using global climate model PRECIS[1], change in annual mean temperature is projected to increase by 0.9°C–1.2°C by 2020 and 1.7°C–3.0°C by 2050. By 2050, regions are expected to experience higher temperature, especially in Mindanao, the southern major island group of the Philippines. Annual precipitation is projected to increase from -0.5 percent to 17.4 percent by 2020, and from -2.4 percent to 16.4 percent by 2050. The country's northern major island group of Luzon and central major island group Visayas are expected to experience increase in rainfall, while Mindanao is projected to experience more dry spells. The National Mapping and Resource Information Authority (NAMRIA) states that a meter rise in sea level can translate to land loss of approximately 129,114 ha. Projected impacts of one-meter sea level rise in many areas of the country can affect coastal settlements and livelihood.

Challenges to Philippine agriculture in the context of climate change

The economic activity of the rural population in the Philippines relies on agriculture and fisheries (NEDA 2013). Agricultural production and postharvest are highly influenced by climate change since farmers base their activities on existing weather conditions

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1 PRECIS (Providing Regional Climates for Impact Studies) model is a computer-based regional climate model developed at the UK Met Office Hadley Centre for Climate Prediction and Research to facilitate impact, vulnerability and adaptation assessments in developing countries, as well as to help generate high-resolution climate change information.

(Labios and Malayang 2015). The rate of crop development and incidence of infestation of different insects and diseases are determined by the weather pattern (Zhao et al. 2005; Shapiro et al. 2007).

The agriculture sector experiences most of the climate-related damages each year. Recorded damages on agricultural production from 1990 to 2006 were caused by typhoons (70%), droughts (18%), and floods (5%). The top rice-producing provinces in the Philippines—Cagayan, Pangasinan, Isabela, Nueva Ecija, Camarines Sur, and Iloilo—are highly exposed to typhoons and floods. Meanwhile, North Cotabato and Maguindanao, which are the food baskets in Mindanao, are prone to El Niño events. In 2016, an El Niño phenomenon affected 181,687 farmers cultivating 224,843 ha of farmland. Of this group, 54 percent are rice farmers, 38 percent are corn farmers, and 8 percent are high-value crop farmers. Pests infested the regions of Central Luzon, SOCCSKSARGEN (South Cotabato, Cotabato City, Cotabato Province, Sultan Kudarat, Sarangani, and General Santos City), and the Autonomous Region of Muslim Mindanao (ARMM) when the El Niño event spread through the regions. Increased water and heat stress due to climate variability is expected to reduce crop yields, double insect and disease incidence, and cause shifts in agricultural production (Dikitanan et al. 2017).

Based on the study of climate change impact on economic welfare in agriculture, the net welfare loss to the agriculture sector caused by climate change is estimated at PHP 18.81 billion per year (Rosegrant et al. 2016). The gross domestic product (GDP) growth of the Philippines is also projected to decline by 0.9 percent in 2050 (Rosegrant et al. 2016). The Philippines may also become highly dependent on imported commodities, such as cocoa, coffee, corn, rice, vegetables, and even pork by 2050 (Dikitanan et al. 2017). Dependence on these commodities will be pronounced, although less on cocoa and corn.

With the changing climate, all agricultural production systems in the Philippines have undergone shifts and changes in productivity. This altering of production systems is actually a global phenomenon, and in the Philippines, it iscompromising the food security and nutrition of the Philippine population (FAO 2006). The Global Food Security Index indicates that in 2017, the Philippines dropped from 74th to 79th among 113 countries. It garnered a score of 47.3 out of 100, indicating that it lags behind other Southeast Asian countries, such as Indonesia and Thailand. The global index mainly measures the quality and affordability of food available in the country. The 2017 index also measured the country’s vulnerability to climate change impacts and its adaptation capacity.

Climate-resilient agriculture in the Philippines

CRA is a concept that aims to integrate climate responsiveness in developing agricultural technologies and approaches (Ts and As) to achieve food security and resiliency under a changing climate. CRA technology is a practice that resulted from the application of scientific knowledge in adapting to or mitigating changing climate. The aim is to enhance productivity and sustainability of the stakeholders' income while minimizing damage to the environment. On the other hand, a CRA approach defines the ways of dealing with the changing climate using CRA technologies, including stakeholders' involvement.

CRA is built on three pillars—productivity, adaptation, and mitigation. Under these three pillars, efficient and effective food systems should increase productivity among farmers and fishermen, enhance resiliency of every rural community, and most importantly, reduce greenhouse gases (GHGs) during production. CRA is designed to address the pressing challenges in environmental, social, and economic aspects of local production (Dikitanan et al. 2017).

CRA is a relatively new concept, which is gradually being mainstreamed by various institutions. However, many Ts and As under CRA have long been practiced by agricultural technicians and farmers to cope with threats brought about by climate change, which can affect their productivity. Indigenous practices are most notable since these methods have been used through time by the minority groups.

Adoption of CRA technologies and approaches may not only address challenges in mitigating climate change but also bring opportunities for economic growth and agricultural development. Ts and As can be identified as CRA if they are designed for productivity enhancement, adaptation, and/or mitigation.

Small-scale farms such as fruit and timber trees, around rice fields and vegetable plots found in some parts of Southern Luzon, Eastern Visayas, and Southern and Eastern Mindanao practice agroforestry. However, the insecurity of land tenure may discourage many farmers from investing in agroforestry despite its benefits (e.g., increased yields and resilience to climate threats). Adaptive calendars (adjusted schedule for planting and harvesting based on weather forecasts) and the use of stress-tolerant varieties are popular practices among vegetable farmers in CALABARZON and CAR since they require little investment.

To restore the soil to its natural form, some vegetable farmers promote organic farming. Due to the short shelf life of organic produce, technical support is still needed to prolong the freshness of vegetables, especially if they are intended for market distribution. It should be noted that technologies and practices under CRA benefit small-scale farmers. In terms of coastal resources, adoption of aquasilviculture activities (e.g., fish production in a mangrove reforestation areas), organic aquaculture (e.g., fish production based on the sustainability approach), and communal stocking and rehabilitation of fish (e.g., community-based fish stock enhancement) is evident among fishermen in the Central Luzon and ARMM. Not only do these practices promote climate risk management, but they also have a positive effect on the livelihood and sustainability of coastal communities. Selected CRA technologies and practices are ranked according to their climate smartness score (CSS), the average of a technology's scores on eight climate smartness dimensions related to the CRA pillars (productivity, adaptation, and mitigation) (Dikitanan et al. 2017). In the coastal communities, the degree of adoption of organic aquaculture (4.25 CSS), aquasilviculture (4 CSS), and communal stocking and rehabilitation (2.5 CSS) is low. For vegetables such as tomato, eggplant, and squash, the degree of adoption of organic farming is also low with 6.25 CSS. The degree of adoption of drought-resistant varieties (4.5 CSS) is medium and the adaptive-crop calendar method (4.25 CSS) has a high degree of adoption. In corn production, the degree of adoption of site-specific nutrient management and integrated pest management, use of early-maturing and stress-tolerant varieties, and water harvesting techniques are low, and their CSS range from 4 to 3.25. Agroforestry systems, soil and water conservation techniques, and organic farming have a low degree of adoption, with CSS that range from 4 to 3.25. In rice production, water harvesting technologies (e.g., small water impounding project), site-specific nutrient management and pest management, and use of drought- and salinity-tolerant varieties have a low degree of adoption, with CSS that range from 3.5 to 3.

Challenges in adopting CRA technologies persist because access to technology and information, as well as capacity-building activities, is limited. Local producers, especially farmers in the Philippines, have little to none of the needed financial resources; thus, investment costs can be a burden. This could slow down the promotion of CRA practices among farmers. The limited extension services in far-flung rural communities should also be addressed.

Summary of climate-resilient agriculture-related policies, strategies, programs, and plans in the Philippines

The Philippine government, together with various institutions and concerned organizations, is acting with urgency and commitment by passing legislation and promoting technology and practices that are geared toward achieving climate resiliency. The United Nations Framework Convention on Climate Change (UNFCCC) and the Global Alliance for Climate-Smart Agriculture encourage action at multiple levels and across multiple sectors through building capacity and raising awareness.

While global platforms have created momentum, CRA initiatives are also being done at the local level. In Southeast Asia, the Philippines has been a pioneer in passing national laws and policies in support of the agenda -on climate change. The creation of laws to increase productivity and adaptation to climate changes has started in the Philippines as early as 1991 (Dikitanan et al. 2017).

By virtue of the Philippine Climate Change Act (RA 9729) of 2009, an act mainstreaming climate change into government policy formulations and establishing the framework strategy and program on climate change, the Climate Change Commission (CCC) was created. CCC leads the policymaking body responsible for the oversight of climate change programs and action plans in the country. DENR, Department of Science and Technology, NEDA, local government units (LGUs), universities, and non-government organizations (NGOs) constitute the CCC advisory board. Through the CCC, the nationally-determined contributions of the Philippines has been submitted as part of the Paris Agreement.

CCC programs that are related to food security are handled by the DA, the System Wide Climate Change Office (SWCCO), in particular. SWCCO is responsible for mainstreaming climate change in the agriculture sector. Locally, the DA regional field offices are disseminating climate-related information and research and extension, including CRA, to farmers. Only a handful of agencies provide financial incentives for CRA, namely, the Agricultural Credit Policy Council and the Philippine Crop Insurance Corporation.

DA launched the Adaptation and Mitigation Initiative in Agriculture (AMIA) program in the Philippines in 2014 to comply with the national legislation on CRA. Some of the key legislations in favor of CRA are as follows: Agriculture and Fisheries Modernization Act of 1997 (RA 8435), Climate Change Act of 2009 (RA 9729), and Disaster Risk Reduction and Management Act of 2010 (RA 10121). RA 10121 focuses on adaptation measures, while RA 9729 addresses both the adaptation and mitigation pillars of CRA. The CRA strategic framework of AMIA aims to guide the decision-making and action of key stakeholders. The AMIA program enables rural communities in disaster-prone areas to pursue sustainable livelihood while mitigating climate change impacts. AMIA delivers support services through a science-driven knowledge platform. The AMIA program involves DA regional offices, state universities, international organizations, financial institutions, and NGOs to ensure inclusive partnerships.

For the initial phase of AMIA, climate risks and vulnerable areas in the country were identified. The current status of CRA in the Philippines, along with the costs and benefits of selected CRA technologies and practices, were also assessed. Some of the selected CRA technologies and practices include alternate wetting and drying (AWD), organic farming, and crop rotation. AMIA engaged climate-smart villages in the provinces of Quezon and Capiz to pilot and develop community action research, as well as guidelines for climate information services. AMIA has established community-level research and development (R&D) interventions in 17 pilot sites. Decision-support tools, such as crop and nutrient management application and Information and communications technology (ICT)-based farmer/fishermen advisory services and government services (e.g., training, insurance, and market linkage support) are being integrated into these pilot sites. By 2020, AMIA targets to build the capacity of nine million farmers and fishermen to utilize and practice climate information and services that would: (1) secure food, nutrition, and sustainable livelihood; (2) promote CRA technologies and practices; (3) develop adaptation and mitigation strategies to protect their income and livelihood from sudden and slow-onset of climate stresses and shocks; and (iv) support further development of CRA (Dikitanan et al. 2017).

The Philippine Rice Research Institute (PhilRice) has launched programs that aim to strengthen climate change resiliency and food security in rainfed and upland rice-farming communities in the provinces of Quezon and Romblon. These programs assess the knowledge and capacity of these farming communities on climate change; thus, participatory planning and field demonstrations have been conducted. Results and outputs from these activities will be used in developing design training modules (PhilRice 2017).

The National Climate Change Action Plan (NCCAP) was formulated in 2010 in accordance with the adoption of the National Framework Strategy on Climate Change. It outlines the country's agenda for adaptation and mitigation measures. Specifically, NCCAP aims to strengthen the country's adaptive capacity and overall resilience to climate change. NCCAP also addresses food security by ensuring the availability, sustainability, accessibility, and affordability of safe and nutritious food for the country.

These key policies define the government's commitment to harnessing the local communities in managing climate risks while pursuing a sustainable livelihood. It is recommended that the government should guarantee the harmonization of laws and policies and their full implementation to sustain ongoing CRA initiatives in the Philippines.

Roles of the community in adapting to climate change

The community is vital in implementing adaptive and mitigating strategies for coping with climate change. For the system to effectively work, communities must have the capacity and resources to manage production and reduce potential risks. At the local level, on-ground action in relation to adaptive responses is important since this is where climate impacts are experienced and managing behaviors are learned and applied (Smit and Wandel 2006; Thomsen et al. 2012).

Community leaders have important roles in communicating adaptive measures. Information on community-based adaptive and mitigating strategies can be communicated through engagement with policymakers and concerned organizations (Keys et al. 2014). Involving the community in climate change initiatives helps in shaping policies, programs, and strategies intended for their needs. Furthermore, adaptation and mitigation projects for vulnerable areas can be sustained if there is community support (UNH 2019). Empowering the community toward adoption of technologies and practices for managing climate risks is essential in improving their livelihood adaptation and in building their resilience (Baas et al. 2008).

Ignoring cultural factors and weak linkages with the communities remain a barrier for formal institutions to effectively implement climate change initiatives (Islam and Nursery-Bray 2017). On the production aspect, social mobilization is effective for (a) organizing and motivating farmers' groups to work more systematically, (b) stirring the interest of farmers and their awareness of climate variability and its impact on agriculture, and (c) instilling self-initiative in identifying and implementing local adaptation measures. This process motivates community groups to build linkages with other stakeholders and serves as an opportunity to obtain technical assistance, administrative support, and other need-based support (Baas et al. 2008).

Climate-smart villages in the Philippines

The Consultative Group on International Agricultural Research (CGIAR) research program on Climate Change, Agriculture, and Food Security (CCAFS) established climate-smart villages (CSVs) in different parts of the world to provide practical adaptation options to improve food security and resilience. The project was launched in 2011, with 15 identified CSVs in West Africa, East Africa, and South Asia; it has now reached Latin America and Southeast Asia.

CGIAR-CCAFS selected potential sites that are climate- and disaster-prone, and project partners have established vital links with local communities that will become part of the CSVs. Researchers and community leaders have also come together to identify climate-smart options that may be adopted by the village. Various CRA technologies and practices, climate information services, and local development and adaptation plans have been tailored to the community's needs. Localized and site-based solutions for the villages have been the focal points of the project.

The community collectively decides on the climate-smart options that will be implemented. The process from pre-adoption to post-adoption is participatory and inclusive, as envisioned by CGIAR-CCAFS.

In the Philippines, the International Institute of Rural Reconstruction (IIRR), in partnership with CGIAR-CCAFS, has established CSVs in Guinayangan, Quezon province. IIRR is a rural development organization that works to achieve integrated and people-centered development in Asia, Africa, and Latin America. The pilot CSVs in Guinayangan demonstrate how a food-secure community can sustain the environment and, at the same time, mitigate the effects of climate change. The villages also serve as the centers of knowledge transfer on climate-resilient technologies and practices among farmers. CRA technologies and practices include agroforestry, soil nutrient management, pest management, and conservation tillage for improved land management. The CSVs test out climate-smart services, such as weather forecasts, to guide farmers in planning their activities (e.g., planting and harvesting). Advisories and forecasts are disseminated through mobile phones, while insurance programs and measures to conserve energy using biofuels are also provided.

Goat rearing and intensive feed garden nursery for fodder grasses are newly introduced by IIRR in partnership with the World Agroforestry Centre (ICRAF) in existing CSVs in Guinayangan (Cruz 2016). Goat rearing is a climate-smart practice that provides women farmers in Guinayangan with more income (Figure 1.1). Raising livestock can be a better livelihood option for women since it requires minimum production costs

Figure 1.1. An IIRR researcher demonstrates goat feeding

(Photo credit: A Cruz, CGIAR-CCAFS)

but brings high economic value. Aside from raising goats, raising native pigs is also practiced in the villages. Native pigs are known to be resilient to high temperature and diseases. They also feed on natural and locally available feeds like dried coconut meat and sweet potato tops. Communities within the CSVs hope that the LGUs and other communities will support and adopt these CRA initiatives.

After Typhoon Haiyan destroyed the coastal areas mainly by storm surge, the CSVs in the Philippines have focused on the mitigation of sea level rise.

CSV location Guinayangan is a municipality that spans a mountain and coastal ecosystem. Eight barangays that reside in coastal areas are involved in mangrove reforestation; the people use indigenous species of mangroves in covering frontlines and beach areas (Figure 1.2). Planting mangroves as bioshields improve the resilience of coastal communities against climate change and typhoons. The mangrove reforestation in Guinayangan is supported by IIRR and CGIAR-CCAFS (Cruz 2016).

According to CGIAR-CCAFS, the strength of the CSV approach is that it brings farmers, policymakers, scientists, and local organizations together in working toward climate-smart agriculture and food security.

Figure 1.2. A fisherman plants mangrove seedlings in Guinayangan after Typhoon Haiyan (using mangroves as bioshield improves the resilience of coastal communities against climate change and typhoons)

(Photo credit: A Cruz, CGIAR-CCAFS)

OVERVIEW OF THE NATURAL AND SOCIOECONOMIC CONDITIONS OF DIFFERENT AGROECOLOGICAL SYSTEMS IN THE PHILIPPINES

The Philippines is an archipelago that consists of approximately 30 million ha of land, which is subdivided into three major island groups: Luzon, Visayas, and Mindanao. It has more than 7,600 islands, 11 of which occupy 95 percent of the country's total land area. On the other hand, agricultural land covers 12.3 million ha, equivalent to 41 percent of the total land area (FAO 2017b). There are three main agroecological zones based on natural parameters such as rainfall, temperature, elevation, and landform—wet, moist, and dry (DA-BSWM 1993).

The mountainous regions in the Philippines are categorized as wet zone with annual precipitation of about 2,000 mm–2,500 mm. The semi-temperate climate in these regions is suitable for high-value crops such as strawberries and coffee. On the other hand, the moist zone covers most of the lowland and upland regions, with annual precipitation of 1,500 mm–2,500 mm. The moist zone extends over 5.7 million ha in Luzon, 2.8 million ha in Visayas, and 6.5 million ha in Mindanao (FAO 2006). The dry zone stretches over Ilocos Norte, Kalinga-Apayao, Batangas, Negros Occidental, Misamis Oriental, and Maguindanao. These regions have annual precipitation of less than 1,500 mm and have considerable moisture deficits from December to May (dry season). Rice and corn thrive in the moist and dry zones.

The use of stress-tolerant varieties (e.g., submergence, salinity, drought, and heat tolerance), and of water harvesting technologies (e.g., small water impounding and alternate wetting and drying), and integrated crop management (e.g., site-specific nutrient management and rice crop manager) are common among rice farmers in Western Visayas and Central Luzon, which are categorized as moist zones. Corn growers in moist zones such as SOCCSKARGEN and the Cagayan Valley also practice these technologies (Dikitanan et al. 2017).

The agroecological systems in the Philippines can be categorized as lowland, upland, hilly land, mountainous, and coastal. An agroecological system is devised to develop terrestrial land and coastal areas for farming, raising livestock, and fishing (FPE 2018). It is designed to manage sustainable farming systems that are highly productive, cost-efficient, and climate-resilient. This approach has the potential to reframe farming in a more sustainable way.

About one-third of 1,210 local agricultural plant species have food and socioeconomic value. The main crops produced in the Philippines are rice (4,656.2 ha), corn (2,561.9 ha), and coconut (3,517.7 ha), which occupy the largest share of land intended for crop production (PSA 2016). Other cash crops for feed, medicinal, ornamental, and industrial purposes are also produced in the country (FPE 2018). Variability of crops and livestock is necessary to sustain key functions and processes of the agroecological systems.

Lowland ecosystem

The lowland zones are characterized as landmass that have an estimated elevation of <100 m above sea level. Level to nearly-level (0%–3% slope) lowland can be safely cultivated and requires simple, yet good agricultural practices, and are either rainfed or irrigated and are suitable for field crop production. Nearly-level to gently sloping (3%–8% slope) lowland is good expansion land for rice and upland crop production (DA, DA-BSWM, DA-BAR 2017). Central Luzon and the Bicol Region have the widest lowland crop production in Luzon, while North Cotabato and Maguindanao are considered as food baskets of Mindanao. Agricultural production in the lowlands can be classified as irrigated or rainfed. These farming systems are prone to flooding, dry and cold spell, and insect and disease incidence, and must be managed properly. Raising livestock and aquaculture are also common in the lowland ecosystem.

Irrigated lowland. An irrigated lowland ecosystem usually exists in various topographies, such as floodplains, and valley bottoms. It is estimated that about 75 percent of the world's annual rice production is sourced from irrigated lowlands (RKB 2009). In the Philippines, 13 percent of the total agricultural area is equipped for irrigation. AWD is a common irrigation practice in the lowlands (Figure 1.3). However, the utilization rate for irrigation facilities varies across regions. For example, more than half of the farmlands in the Ilocos Region, CAR, and Central Luzon utilize irrigation facilities, but only 50 percent of farmlands in the other 15 regions utilize irrigation

Figure 1.3. Alternate wetting and drying is a common irrigation practice in the lowland ecosystem

(Photo credit: International Rice Research Institute Rice Knowledge Bank [IRRI-RKB])

facilities. Mindanao lacks irrigation facilities due to socioeconomic constraints. In Western and Central Visayas, irrigation development that requires water storage has been postponed due to prolonged dry season (Dikitanan et al. 2017).

Rice production in irrigated lowlands has abundant water supply and a controlled water system, which reduces the risk of crop failure. These and other factors make this type of ecosystem the most productive. Irrigation may be applied as a supplement during dry or wet season, depending on how much water is available in the area. Adequate irrigation enables two or even three croppings in a year (RKB 2009).

Rainfed lowland. Rainfed lowland areas are distributed across the three major island groups of the Philippines. This type of ecosystem is found in the following geographical regions: Ilocos; Cagayan Valley; MIMAROPA (Occidental Mindoro, Oriental Mindoro, Marinduque, Romblon, and Palawan); Bicol; Western, Eastern, and Central Visayas regions; Zamboanga Peninsula; ARMM; SOCCSKSARGEN; Caraga Region; Davao Region; and Misamis Oriental and Occidental (Fukai and Boonjung 1996).

Figure 1.4. An example of a typical rainfed lowland area

(Photo credit: IRRI-RKB).

Unlike irrigated lowland areas, rainfed lowlands experience insufficient water supply and lack of water control for irrigation (Figure 1.4). For these reasons, rainfed lowlands are more prone to intense drought and severe flooding. In coastal areas, where some land is allotted for rice production, salinity can be a problem because irigation water is unavailable to remove salt when rice production areas are submerged. To address these risks, rainfed lowland production uses more rice varieties and management systems than irrigated production (RKB 2009).

The success or improvement of any crop is determined through understanding the nature of crops and the environment in which they are grown. Moreover, the farmers determine the environment in rainfed lowlands in which a cultivar will thrive the best. They consider ecological factors, such as water depth, to determine the adaptation zones of the cultivar. Hydrologic conditions strongly influence the farmers in choosing cultivars and management practices. There are five environments for rainfed lowland rice production based on their hydrologic conditions: shallow favorable, shallow drought-prone, shallow drought- and submergence-prone, shallow submergence-prone, and medium-deep waterlogged (Mackill et al. 1996).

Most rainfed lowlands produce only rice each year and no other crops are planted before or after it. This cropping pattern is common in less favorable sub-ecosystems where long-duration, photoperiod-sensitive cultivars are abundant (Mackill et al. 1996).

In the socioeconomic condition of rainfed lowlands, lands intended for production are degrading as the population becomes denser and markets begin to shift. Farmers are pressured to utilize these lands intensively even in less favorable conditions (Mackill et al. 1996).

Upland ecosystem

Sixty percent of the total land area in the Philippines is classified as gently sloping to rolling (<18% slope) upland (DA, DA-BSWM, DA-BAR 2017). Most of these upland areas are in Northern Luzon (Ilocos Region, Mountain Province, Benguet, Ifugao, Kalinga, Batanes, and Nueva Vizcaya); Northern Mindanao (Bukidnon); Caraga Region (Agusan del Sur); and Central Mindanao (Cotabato). Uplands are defined by the Philippine Government as lands within identified mountain zones, which include tablelands and plateaus lying at high elevation. Upland areas have an elevation of <100 m to 500 m above sea level and are within the terrain classified as hilly to mountainous (Cruz et al. 1988). They are composed of grassland and forest ecosystem. Upland rivers and streams are fast-flowing and have high stream power. Uplands are important support systems for the lowland and coastal ecosystems. They contain a wide range of flora and fauna species, which provide food and livelihood to marginalized communities. However, upland areas are prone to soil erosion due to their rugged topography, infertile soil, dry land during summer, insufficient water supply, high temperature, complex farming systems, abundance of weeds and pests, and unpredictable field conditions (DENR-ERDB 2010).

Upland rice ecosystems can be found in low-lying valleys to undulating and steep sloping lands with high runoff and lateral movement. Texture, water holding capacity, and nutrient composition of soil vary depending on the geography. Low yields of upland rice ecosystems are attributed to insufficient and irregular moisture supply, weed infestation, nutritional imbalance, uncontrolled insect and disease incidence, limited suitable varieties, and inadequate cultural practices (Greenland 1997).

Sustainability issues and water scarcity are some concerns in the upland ecosystem since soil degradation and lack of water resources can have adverse consequences on the adjoining lowland ecosystem. Erosion is also more widespread, although it usually occurs under specific conditions of slope, rainfall, and land preparation. Research that tackles issues in nutrient cycling, pest ecology, and sustainable rotations for upland rice and other crops grown in the upland is limited (Arraudeau and Vergara 1988).

On the socioeconomic aspect, the uplands is considered as the ecological and social frontier for the sustainability of food production in decades to come (Sajise and Sajise 2017). Increasing food demands and the rate of agricultural land conversion for commercial use pressure farmers to till the uplands to make up for production loss (DENR-ERDB 2010). Consequently, upland areas are becoming more populated since people from the lowlands migrate to the uplands.

Although the sustainability of the agroecological system in the uplands is prioritized, marginal upland areas still exist. These areas are classified as cultivated open areas of forest and/or grassland, cultivated mixed grassland, eroded areas, and barren areas. The marginal upland areas resulted from overgrazing, indiscriminate mining, exploitation of forest resources, and other detrimental practices. There is less forest cover due to the depletion of forest resources. Soils in marginal upland areas are acidic and have low-nutrient content because of massive erosion, leaching, and degradation of agricultural land (DENR and IIRR 1992).

To counteract these adverse effects, various CRA technologies and practices are being implemented. Agroforestry is known to protect upland ecosystems and retain biodiversity (PCARRD 2003). It is an effective technology for rehabilitating and managing the marginal uplands (DENR-ERDB 2010). It is also used as a national strategy to promote sustainable development in the uplands. Agroforestry enhances upland ecosystems while conserving them and sustaining the productivity of the land and people (Landicho and Fernandez 2009). CGIAR-CCAFS, together with IIRR, has established an agroforestry initiative in a CSV in Guinayangan, Quezon that envisions trees-on-farms to achieve climate change adaptation and mitigation (Figure 1.5).

Figure 1.5. The agroforestry initiative of CGIAR-CCAFS and IIRR in Guinayangan, Quezon

(Photo credit: ICRAF, CGIAR-CCAFS, and IIRR)

Hilly land ecosystem

Rolling to moderately steep (18%–30% slope) hilly land and moderately steep to very steep (>30% slope) hilly lands have an estimated elevation of <100 m to 500 m above sea level (DA-BSWM-BAR 2017)(Figure 1.6). These are found mostly in Southern Luzon (Rizal, Mindoro, and Palawan); Bicol Region (Camarines Sur and Catanduanes); Central Visayas (Cebu, Bohol); Eastern Visayas (Samar, Leyte); Misamis Occidental; and Zamboanga Peninsula. The agroecological system in hilly lands consists of soil, water resources, crops, and livestock. The observed performance of such system in hilly land

Figure 1.6. A hilly land ecosystem with soil and water conservation measures

(Photo credit: DA-BSWM)

areas is characterized as productive, stable, sustainable, equitable, and autonomous. Environment focused management of the development in hilly land areas should aim for these interconnected characteristics (Alcantara 1991).

Hilly lands are often unproductive because of land degradation and poor resource management (Contreras 2012). Inadequate support services and infrastructure are also considered threats to productivity (Alcantara 1991). Unproductive hilly lands are also attributed to soil-related constraints such as shallow soils, high acidity, low nutrient, and low water retention capability (Contreras 2012). Severe soil erosion, floods, and low productivity will continue to worsen as hilly lands become denuded, degraded, and marginalized (Lawas and Calub 1991).

Alley and multistorey cropping systems for soil conservation are integral in sustaining hilly lands. Planting of shrubs, trees, or leguminous hedgerows along the contours, as well as planting agricultural crops in the alleys, has been adopted by hilly land farmers in some parts of Visayas and Mindanao (Paningbatan et al. 1994). Multistorey cropping is successfully done in the rolling areas of Luzon, particularly in Batangas and Cavite. Erosion rates on steep slopes can be lowered if soil conservation practices such as contouring, mulching, minimum tillage, and waterways are incorporated in the alley cropping systems (Paningbatan et al. 1994).

According to Cruz et al. (2012), soil improvement and slope stabilization methods such as contour strip planting, trenching, establishing contoured hedgerows and natural vegetative strips, applying brush dams and rainwater harvesting, planting leguminous or drought-resistant cover crops, improving road network, minimum tillage, and recycling organic matter and other nutrients to balance fertilization can improve hilly land productivity.

Lawas and Calub (1991) presented other options to enhance productivity in hilly lands: contract tree farming, fruit tree-based production systems, sloping agricultural land technology (SALT), and agroforestry. The degree of appropriateness of each of these options depends on location and time. Agroforestry enhances productivity and aids in soil conservation and soil improvement.

Highland ecosystem

The highland ecosystem in the Philippines is a hub for indigenous flora and fauna species and traditional ecological knowledge that influence the climate on a great scale. It has a landform of mountain slopes and occasional hill slopes with loamy soil. Its elevation is >500 m above sea level with moderately rolling to hilly slopes. It has a humid climate, with an annual rainfall of 1500 mm–2000 mm per year. Mountain ecosystems are intended for plantations and tree regeneration. Typically, mountain regions have a soil depth of about 20 cm–50 cm. The soil has low fertility and medium water storage capacity (WOCAT 2016; DA, DA-BSWM, DA-BAR 2017). Hence, watersheds play a big role in sustaining productivity in mountain ecosystems (Figure 1.7). Watershed management is notable and commonly practiced in mountainous provinces like Nueva Vizcaya, Quirino, Isabela, and Bukidnon. The Magat Watershed, which covers Nueva

Figure 1.7. A watershed with water impounding structure as source of irrigation for the lowland areas

(Photo credit: DA-BSWM)

Vizcaya, Quirino, and Isabela, is the biggest watershed in Northern Luzon. It supplies water for hydroelectric power generation, irrigation, and domestic water supply. It can irrigate 950 ha of farmland. On the other had, the Manupali Watershed in Bukidnon is composed of the upper Pulangi River Basin and Mt. Kitanglad Range. The municipality of Lantapan occupies the upland portion of the watershed, while Valencia occupies the low-lying part. The watershed supplies 40,000 ha of agricultural land in the province (Francisco and Rola 2004).

The highland ecosystem is a natural provider of vital resources and freshwater. However, it is also fragile to natural and anthropogenic changes. Natural occurrences such as volcanic and seismic events, as well as global climate change, can affect its structure. Industrial developments, vegetation loss, and soil degradation also cause disruptions in the highland ecosystem (IUCN 2018).

Communities within the highland ecosystem are exposed to several threats and physical hindrances. Fragile ecology is the most challenging threat for the communities, considering their capacity to withstand climate change. Climate change, combined with strenuous economic and social changes, affects the capability of the highland ecosystem to sustain itself, as well as the lowland community (IUCN 2018).

Fire breaks and green breaks are established in highland ecosystems to prevent wildfire and wildlings disturbances. Wildlings, seedlings that came from scattered seeds carried by birds, insects, and animals during pollination, grow naturally in the forest without human intervention. Fire breaks and green breaks are planted with cash crops to provide an immediate food source and extra income for smallhold land users (WOCAT 2016).

Coastal ecosystem

Based on the *Philippine Coastal Management Guidebook* (2001), the Philippines has a large coastal community of more than 70 million people. Seventy percent of the total municipalities in the Philippines are in coastal areas. The coastline stretches to an estimated 36,298 km, and the coastal waters cover an area of 266,000 km^2. It has an elevation of up to 10 m above sea level. Compared with Malaysia and Thailand, the Philippines is surrounded by 2,000 m–4,000 m of deep waters, while its shallow waters are relatively narrow and close to the shore. The country is supported by productive and diverse marine ecosystems, which also provide shore protection, nutrient cycling, and valuable economic goods.

The coastal zone of the Philippines is classified as a tropical coast with six major resource units on the coastlines. These resource units are coral reefs, mangroves, beaches, estuaries, lagoons, and seagrass beds (Figure 1.8). Upland and coastal ecosystems are tightly linked to one another. What occurs in one ecosystem can affect the other, so coastal resource management should also consider the upland ecosystem (One Ocean n.d.).

Figure 1.8. An example of a coastal zone in the Philippines with coral reefs, mangroves, beaches, estuaries, lagoons, and seagrass beds

(Photo credit: CM Santos)

Because the Philippines lies in the Indo-West Pacific region, it is part of the "coral triangle," which is dubbed as the most diverse habitat in the marine tropics. The Philippine waters are known as home to 400 species of corals and one-third of the 2,300 fish species in the world. Coral reef areas in the country are approximately 27,000 km^2, 60 percent of which is in Palawan.

The mangrove forests in the Philippines were estimated to be around 450,000 ha in 1920, but less than 150,000 ha a century later. The remaining areas are found in Mindanao (32%), Eastern Visayas and Bohol (23%), and Palawan (22%). Mangrove deforestation results from fishpond and saltbed conversion, mangrove deforestation for domestic use, and reclamation for industrial purposes. A depletion rate of 3,700 ha/year was recorded from 1980 to 1991. At present, Palawan and Zamboanga del Sur have old-growth mangrove areas. The mangroves found in the Philippines are members of the genera *Bruguiera, Ceriops,* and *Rhizophora (Rhizophoraceae)*, and of the families *Avicenniaceae* and *Sonneratiaceae.* Mangroves are important resource base for the Philippines because they provide shelter to several crustaceans and mollusks, and most importantly, they are the frontline and shore protection against disasters.

Small islands in the Philippines have beaches formed by coral reef growth and erosion. These coral sand beaches are integral part of the reef ecosystem because they provide life support for the crustaceans and mollusks dwelling in the reefs. Sea turtles also nest in undisturbed beaches. Unregulated development of Philippine beaches is a common threat to marine species. Brackish wetlands are usually found behind mangrove formations and among nipa palm plantations. In some places in the Philippines, these brackish wetlands are part of the mangrove ecosystem. Brackish wetlands serve as nursery feeding grounds for small water species. There are 16 seagrass species in the Philippines, the highest record in the Indo-Pacific region. Seagrass is essential to fish nursery areas and serve as foraging grounds for sea cows, turtles, and wading birds. However, the seagrass ecosystem in the country is under threat from natural disasters and man-made activities such as mining and blast fishing. Seagrass depletion also results from high water turbidity, unsustained production of seagrass, and threatened biodiversity.

The fisheries sector accounted for about 14.4 percent of the total GDP of agriculture, hunting, forestry, and fishing in the first quarter of 2018 (PSA 2018). It has employed more than a million Filipinos, more than half of which engaged in small-scale fishing (BFAR 2018). With the growth in Philippine tourism, coastal resources are predicted to become more valuable over time.

CHAPTER 2

Climate-Resilient Agriculture Technologies and Approaches in the Philippines

Climate-resilient agriculture (CRA) technology is a practice that results from the application of scientific knowledge used to adapt to or mitigate a changing climate. It aims to enhance the productivity and sustainability of the stakeholders' income while minimizing damage to the environment.

A CRA approach refers to the ways and means of dealing with the changing climate using CRA technologies, including the stakeholders' involvement.

IRRIGATED LOWLAND ECOSYSTEM

Technologies

Stress-Tolerant Rice Varieties. Stress-tolerant rice varieties are developed to withstand environmental stresses that adversely affect rice production in the country (Figure 2.1). Environmental stresses, which include drought, flooding, salinity, and sea level rise, are aggravated by the changing climate. The use of stress-tolerant varieties and associated crop management practices and proper application of technology are potential solutions to increase productivity.

Short-term flash floods (for up to 2 weeks), moderate or severe drought, or salinity can occur at any growth stage of the plant, sometimes more than once, resulting in severe yield losses. Modern rice varieties are not suitable for these conditions, and this is probably the reason why they are not widely adopted in areas often flooded or with levels of salinity. Thus, farmers continue to grow the local varieties even if yields are low (Mackill et al. 2012; Manzanilla et al. 2011).

Figure 2.1. Stress-tolerant rice varieties

(Photo credit: International Rice Research Institute-Rice Knowledge Bank [IRRI-RKB])

Stress-tolerant rice cultivars have greater tolerance for abiotic stresses such as flooding, drought, heat, cold, and saltwater intrusion, and biotic stresses such as insect and disease infestation. In the Philippines, the common environmental stress experienced by rice plants are drought, flood, heat, cold, and salinity. Appendix Table 2.1 lists rice varieties with abiotic-stress tolerance.

METHODOLOGY

To mitigate losses due to abiotic stress, the International Rice Research Institute (IRRI) in partnership with the Philippine Rice Research Institute (PhilRice) developed submergence-, saline-, drought-, and heat-tolerant rice breeding lines.

Submergence tolerance

Submergence affects rice crops at any growth stage through flash floods or stagnant flooding. Typically, the rice plant elongates to avoid complete submergence during floods. Deepwater rice varieties can do this quickly, but high-yielding modern varieties cannot elongate sufficiently. The recovery rate for rice plants is relatively low because they spend much energy to avoid submergence if floods last for many days. Fortunately, scientists have used SUB1A gene to develop submergence-tolerant rice variety. This is activated when the plant experiences submergence, making the plant dormant and conserve energy until flooding recedes. The SUB1A gene, derived from FR13A, a rice variety from Odisha, India, confers tolerance for up to two weeks of complete submergence (Figure 2.2). Varieties with the SUB1A gene give the same yield and other characteristics as the original varieties, and they can be used to replace these varieties in flood-prone areas (Singh et al. 2009; Mackill et al. 2012; Manzanilla et al. 2011). The SUB1A gene is incorporated in submergence-tolerant varieties such as IR64-SUB1 and NSIC RC194, which are now used in the Philippines. NSIC RC194 was developed by IRRI and PhilRice and is commercially available.

Salt tolerance

Rising sea levels greatly contribute to high salt content in the soil. Some lands become barren and unproductive land cannot be used due to its high salinity. To improve productivity in salt-affected areas, salt-tolerant rice varieties were developed and distributed to farmers for on-farm trials (Figure 2.3). Salt-tolerant rice, aided by the Saltol gene, can survive in saline-prone environments with salt of at least EC 4 dS/m (0.3% salt) (Gregorio et al. 2002; Islam et al. 2011; Gregorio 2010; Thomson et al. 2010; Ismail et al. 2010). Saltol is used to develop rice varieties that can cope with salt exposure during the plant’s seedling and reproductive stages. NSIC Rc296 (Salinas 9), NSIC Rc290 (Salinas 6), and NSIC Rc294 (Salinas 8) are examples of salt-tolerant rice varieties.

Rice varieties with SUB1A gene and Saltol are targeted for coastal areas where plants are prone to submergence and salinity. IRRI found out that SUB1 gene and Saltol can be incorporated in the same type of rice, increasing the tolerance of rice plant for submergence and salinity (Gregorio et al. 2002).

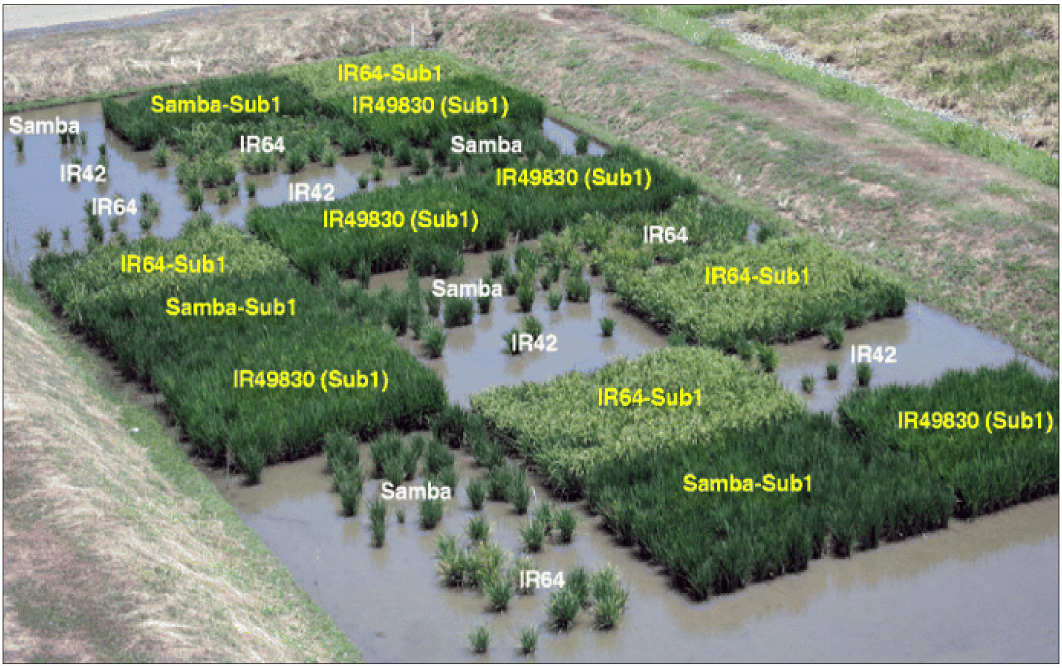
Drought tolerance

In the Philippines, IRRI developed and introduced *Sahod Ulan*, a variety that is drought-tolerant and widely planted by local farmers (Figure 2.4). Drought-tolerant varieties, compared with drought-susceptible ones, give higher average yields (0.8 t/ha–1.2 t/ha) under drought conditions. The rice genome called drought quantitative trait loci (QTL) makes the variety resistant to drought and able to yield under such conditions.

Heat tolerance

With climate change scenarios resulting from global warming, breeding for heat tolerance is one of the key research areas that could address problems related to temperature increase. Central Luzon, where >65 percent of rice is grown, will be most vulnerable to high-temperature stress in the next decade. Given the predicted increase in temperature by 2°C in the next 50 years or so, rice crop production will be affected if no mitigation or adaptation is done.

Figure 2.2. The Sub1A lines after 17 days submergence in field at IRRI



(Photo credit: IRRI-RKB)

Rice normally grows at temperature ranging from 20°C to 35°C, but at >35°C, it is increasingly sensitive, especially during the reproductive stage. Several studies have indicated that high temperature stress resulted in loss of pollen viability, poor anther dehiscence, and low pollen on stigma (Das et al. 2014); decreased seed setting (Cao et al. 2009); increased phytic acid (Su et al. 2014); high sterility and faster grain development (Satake and Yoshida 1978); decreased grain size and shape (Cao et al. 2008); decreased kernel weight and amylose content and increased chalkiness (Wu et al. 2016); and shrivelled seeds (Hasanuzzaman et al. 2013). All these can result in 10 percent–15 percent decrease in yield.

In the wet season, the temperature can exceed 35°C during the plant's flowering stage. This results in lower rice yields. Higher temperatures in the future could also affect population dynamics and structure of insects and diseases including beneficial microorganisms. A more active insect and disease vector can give rise to higher populations when exposed to high temperature. Minor insects and diseases could be more potent and active under changing climatic conditions. The migration of destructive insects from other countries can increase as a result of climatic changes in the region.

Popular rice varieties in the Philippines give high yields and have good grain quality and resistance to insects and diseases. However, they lack tolerance for high temperatures based on current yield performance. Climate change caused by global warming makes it necessary to prioritize breeding heat-tolerant varieties. New rice varieties should possess adaptability to rising temperatures, in addition to the other desirable traits that a variety should have (Manigbas et al. 2014).

Figure 2.3. Salt-tolerant rice variety on-farm screening

(Photo credit: IRRI-RKB)

Figure 2.4. *Sahod Ulan,* a variety developed and introduced by IRRI

(Photo credit: IRRI)

In 2016, a survey was conducted in high-temperature environments in farmers' field in Cagayan during the dry season. The temperature exceeded 35°C during the rice crop's flowering period, which is from April to May. Most of these varieties were planted in February due to irrigation schedule; therefore, the flowering coincided with high temperature. A high percentage of sterility (up to 80%) was observed. Other rice varieties were planted during the normal cropping season and the reproductive stage did not coincide with high-temperature months.

Few varieties can adapt to high-temperature stress, which could be due to early flowering or heat tolerance. More data are needed to confirm this initial observation.

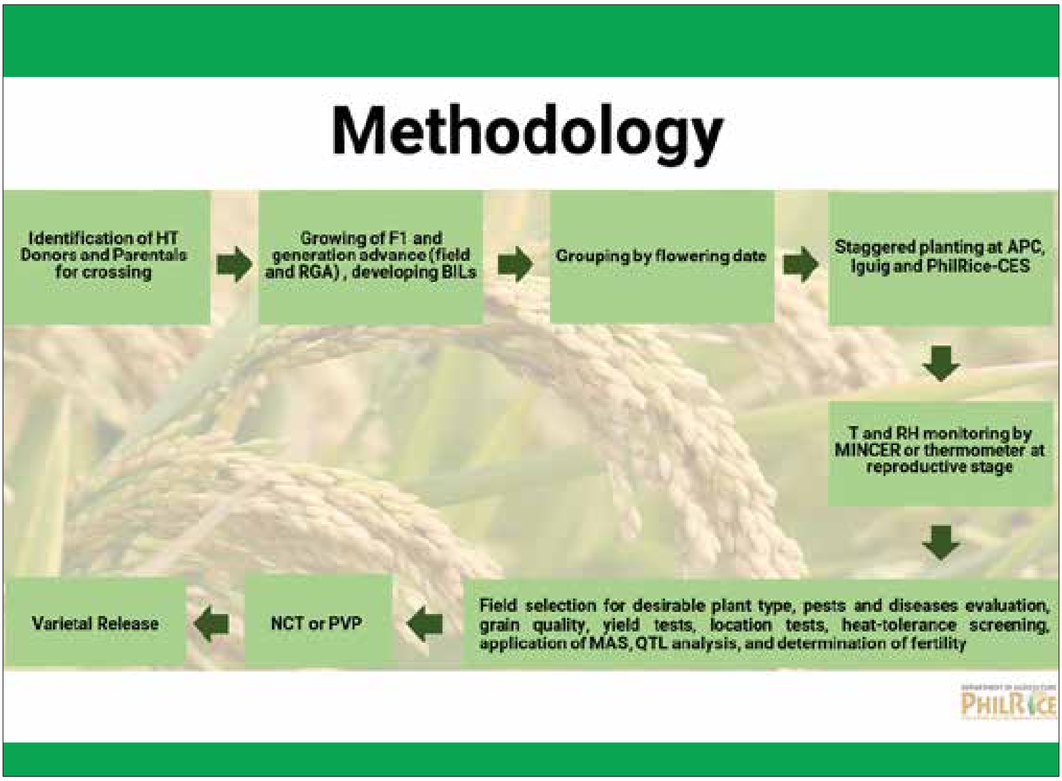
One of the most effective ways of mitigating the effect of climate change is the use of high temperature-tolerant cultivars (Manigbas and Sebastian 2007). Breeding for heat-tolerant rice started with the identification of donors for heat tolerance in 2010 at PhilRice, Science City of Munoz, Nueva Ecija. More than 200 varieties from IRRI and PhilRice germplasm were evaluated under high-temperature conditions during the hottest period in the dry season, which is April to May. Two outstanding *Indica* varieties from India, N22 and Dular, were chosen as donors and incorporated into the Philippine and other rice cultivars for improvement. Figure 2.5 shows the scheme of breeding strategy that the team developed. To monitor the temperature and relative humidity at the start of reproductive stage until maturity of the crop, a Micrometeorological Instrument for Near Canopy Environment in Rice (MINCER) was installed in the field to take data in the above and within canopy layer of rice. The data for crop duration were recorded every two minutes for 24 hours, and hand analyzed based on the onset of flowering to grain filling and maturity stage. The breeding scheme for heat tolerance was first introduced and developed at PhilRice, and this protocol was used in developing new breeding lines and future rice varieties with high-temperature tolerance.

Quantitative trait loci for heat tolerance

A combination of conventional and biotechnological approaches has been implemented in the breeding program for heat tolerance at PhilRice. Identification and mapping of genes, quantitative trait loci (QTL), and manifesting high-temperature tolerance will not only facilitate marker-assisted breeding (MAS) but also direct the way for cloning and characterization of underlying stakeholders, which could be useful for genetic engineering. This can be done by exploitation of new genes and alleles to predict gene function, isolate homologues, and conduct transgenic experiments in addressing high-temperature stress conditions.

QTLs were identified through inclusive composite interval mapping (ICIM) method using IciMapping 4.0 software version. Three major QTLs had a PVE (phenotypic variance explained) value of more than 30 percent. The others can be considered as minor QTLs. In the future, this can be used as decision guide for breeding using marker-assisted selection (MAS) and fine mapping of the novel genes for high-temperature tolerance (Grospe et al. 2016).

Figure 2.5. Breeding scheme in the development of new rice varieties for heat tolerance at PhilRice



Methodology

Identification of HT Donors and Parentals for crossing

Growing of F1 and generation advance (field and RGA), developing BILs

Grouping by flowering date

Staggered planting at APC, Iguig and PhilRice-CES

T and RH monitoring by MINCER or thermometer at reproductive stage

Field selection for desirable plant type, pests and diseases evaluation, grain quality, yield tests, location tests, heat-tolerance screening, application of MAS, QTL analysis, and determination of fertility

NCT or PVP

Varietal Release

(Photo credit: Manigbas, PhilRice)

For direct seeding, particularly where water is applied to suppress weeds, tolerance of anaerobic germination (AG) can improve early seedling establishment (Ismail et al. 2012). Materials with stronger tolerance for adverse soil conditions of excess Iron (Fe), deficient Phosphorus (P), and deficient Zinc (Zn) are also in the pipeline. The isolation of the Pstol1 gene (Phosphorus starvation tolerance 1) from variety Kasalath has shown its role in improving root growth and distribution in phosphorus-deficient soils and increasing yield by as much as 20 percent (Gamuyao et al. 2012). However, all these important traits can help farmers only through smart breeding by fast-tracking introgression into high-yielding rice and evaluation for their adaptation at target sites in the country.

Systematic and participatory strategies are used to identify and select appropriate and adopted rice varieties under local conditions (Paris et al. 2011; Mackill et al. 2012). The improvement of crop variety and dissemination of viable resource management options have contributed to yield stability, improved productivity, and diversified cropping patterns (ASEAN 2017).

Application

Adaptation

Stress-tolerant rice varieties give resilience to rice plants under any environmental stress. Production loss will be low, which can aid farmers to recover easily. Grain yield and quality will relatively improve because of gene improvements in these rice varieties.

Mitigation

Aside from reducing production costs, stress-tolerant rice varieties mitigate the impact of abiotic stresses on rice plants, especially if combined with the best management practices.

Site-specific nutrient management. Site-specific nutrient management (SSNM) is a technology that aims to optimize soil nutrients supply that match crop requirements according to a specific timeframe and inherent spatial variability. It consists of the fundamental steps or 4Rs of nutrient stewardship: right product, right rate, right time, and right place, which encompass the economic, social, and environmental dimensions of SSNM (Figure 2.6). Right product means that the crop needs and soil type should match the nutrient source or fertilizer product for a balanced supply of nutrients. Right rate means that the current supply of nutrients in the soil should be observed first before applying the right quantity of fertilizer, which is based on crop needs. Environmental losses such as runoff, leaching, and gaseous emissions can result from excessive application of fertilizer. Insufficient fertilizer on the other hand, leads to soil degradation. Right time means that a proper assessment of crop nutrient dynamics is done when nutrients are present at the time the crop needs them. Split applications of mineral fertilizers or combining organic and mineral nutrient sources can slowly release nutrients. Right place means to minimize nutrient losses; nutrients should be placed and kept at an optimal distance from the crop and soil depth so that crops can absorb them. It is recommended that nutrients be incorporated into the soil rather than just applied on the surface.

SSNM is an alternative to blanket guidance, a type of fertilizer application that leads to improper balance of nutrients in soils due to over-or under-fertilizing. Fertilizers are applied timely at optimal rates to address nutrient deficits in high- yielding crops and other natural indigenous inputs such as soil, crop residues, manures, and irrigation water. This technology monitors pathways of nutrient flow and expedient nutrient supply by combining fertilizers, organic manures, crop residues, and nutrient-efficient genotypes in increasing productivity. It benefits farmers by providing greater return on investment in fertilizers (Ortiz-Monasterio and Raun 2007). Aside from its cost-efficient benefit, SSNM times the application of nitrogen to crop needs, which reduces nitrous oxide emissions. By timely application, nitrogen losses due to volatilization, leaching, and runoff is avoided.

In the Philippines, several national programs on rice production are anchored on SSNM technology (Buresh 2015; Buresh et al. 2019). There are programs initiated by the International Plant Nutrition Institute (IPNI), which use SSNM in promoting increased and sustainable corn production in the Philippines (Ocampo et al. 2015; Pasuquin et al. 2014, 2012, 2010).

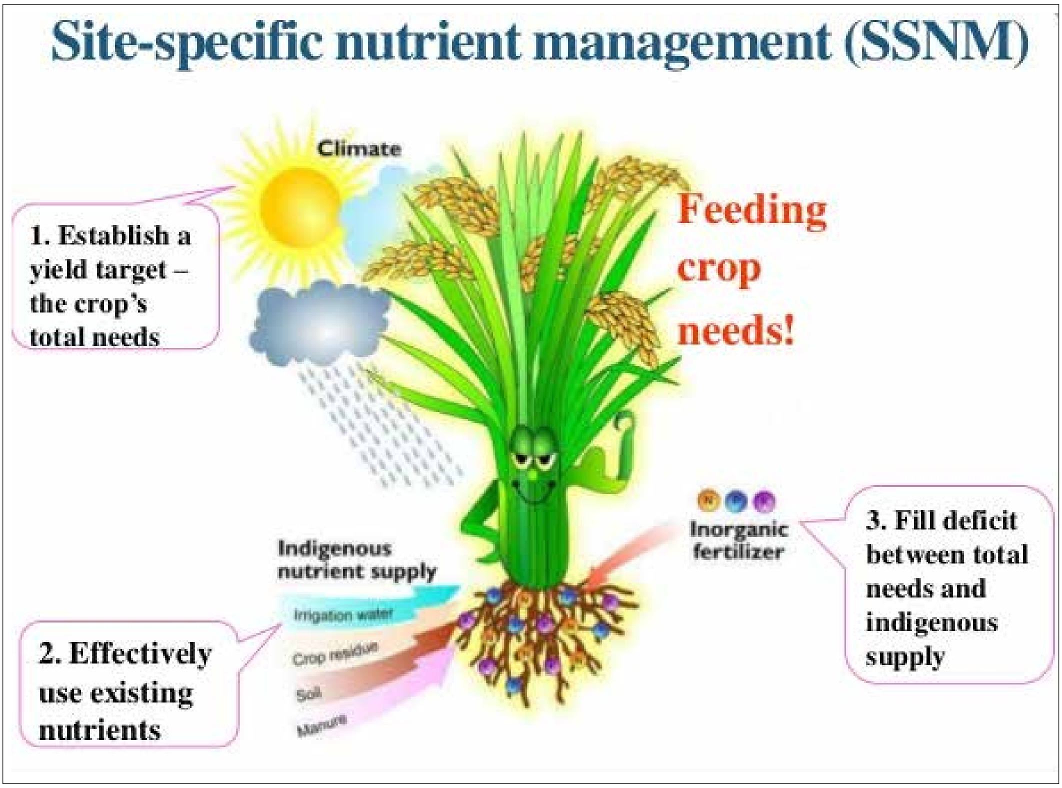
METHODOLOGY

Application of Site-Specific Nutrient Management on Irrigated Lowland Rice

The SSNM technology involves three steps: (1) Establish attainable yield; (2) Use existing nutrients effectively; and (3) Apply fertilizer to fill the deficit (IRRI-RKB) (Figure 2.6).

Establish an attainable target yield.
Rice yields are location- and season-specific, depending on climate, rice cultivar, and

Figure 2.6. Fundamental steps in implementing site-specific nutrient management



(Photo credit: IRRI-RKB)

crop management. The yield target for a given location and season is the estimated grain yield attainable with farmer's crop management when Nitrogen (N), P, and Potassium (K) constraints are overcome for a given rice variety. It is usually set as 80 percent of the potential yield obtained through simulation modeling. Alternatively, this can be obtained by asking the farmers about the approximate yield they have attained over the years with their management practices and under normal climate. The amount of nutrients taken up by a rice crop is directly related to its yield. The yield target, therefore, indicates the total amount of nutrients that must be taken up by the crop.

Use existing nutrients effectively.

The SSNM technology promotes the optimal use of existing (indigenous) nutrients coming from the soil, organic amendments, crop residue, manure, and irrigation water. The uptake of a nutrient from indigenous sources can be estimated from the nutrient-limited yield, which is the grain yield for a crop not fertilized with the nutrient of interest but fertilized with other nutrients to ensure that yield is not limited.

For N, the indigenous N supply can be assessed through nutrient-omission plot trials as the grain yield obtained without the application of N fertilizer, but with the other nutrients supplied. The same method is also used for P and K. N supply can also be estimated based on soil properties such as texture and organic matter content. Sandy soils with no appreciable input of nutrient-rich organic materials are generally considered low N supply soils. Medium N supply soils are loamy or clayey soils with intermediate organic matter content and no appreciable input of nutrient-rich organic materials. High N supply soils, on the other hand, are usually clayey or loamy soils with high soil organic matter content or appreciable input of nutrient-rich organic materials.

Apply fertilizer to fill the deficit between crop needs and indigenous supply.

Fertilizers N, P, and K are applied to supplement the nutrients from indigenous sources and obtain the yield target. The quantity of required fertilizer is estimated by the deficit between the crop's total needs for nutrients as determined by the yield target, and the supply of these nutrients from indigenous sources as determined by the nutrient-limited yield.

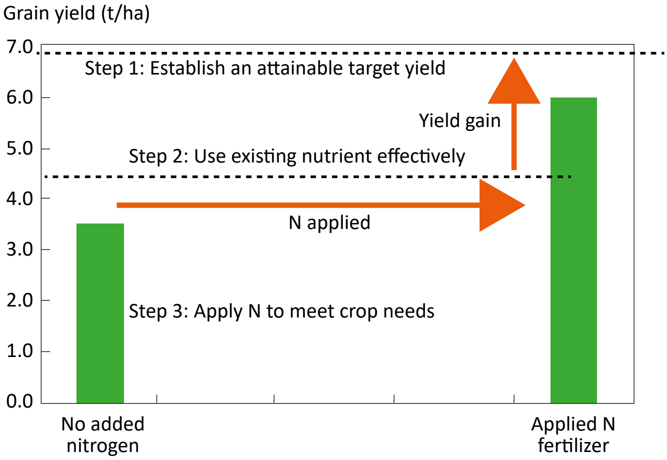
The required fertilizer N is distributed in several applications during the crop growing season to best feed the crops need for supplemental N. Fertilizers P and K are applied in sufficient amounts to overcome deficiencies and maintain soil fertility. The three steps can be summarized in Figure 2.7, with N as an example.

Nutrient management in site-specific nutrient management

NITROGEN MANAGEMENT

Nitrogen is an essential element for plant growth. Rice plants can obtain much of their required N from the soil and organic amendments, but the supply of N from these naturally occurring indigenous sources is seldom sufficient for high rice yield. Supplemental N from fertilizers is often essential for higher yields and profit from irrigated and favorable rainfed rice fields.

Figure 2.7. Steps in determining fertilizer N required for rice



Source: IRRI-RKB

The demand of rice for N is strongly related to growth stage. Rice plants require N at early and mid-tillering (branching) stages to ensure a sufficient number of panicles (grain bunches). Nitrogen absorbed at panicle initiation stage increases spikelet (flower) number per panicle. Nitrogen absorbed during the ripening phase, with adequate solar radiation, enhances the grain filling process. For best effect, farmers should apply fertilizer N several times during the growing season to ensure that the N supply matches the crop need for N at the critical growth stages of tillering, panicle initiation, and grain filling.

The SSNM approach for managing fertilizer N aims to increase profit for farmers by achieving high rice yield, and high efficiency of N use by the crop.

With this approach, the recommended use of fertilizer N could be higher or lower than the farmers' current practice. Managing N by the SSNM approach typically involves a change in the farmers' current practices on distributing fertilizer N during a crop growing season.

Using the formula $FN = (GY–GY0N) \times 1000/AEN$, a 130 kg N/ha is needed to achieve 5 t/ha (AEN =15).

In the SSNM approach, fertilizers are applied using the following principles to achieve high yield and high efficiency of plant use:

- Apply only a moderate amount of fertilizer N (about 30%) to young rice within 14 days after transplanting (DAT) or 21 days after sowing (DAS), when the need of the crop for supplemental N is small.
- The remaining 70 percent fertilizer N can be applied in two splits: 35 percent at active tillering and 35 percent at panicle initiation. If the target yield is high, e.g., with hybrids, then another split application is required at heading.

Table 2.1. Estimated fertilizer N rate based on yield gain and target efficiency for fertilizer N (AEN)

Yield Gain from N (t/ha)	Fertilizer N Rate (kg/ha)			
	15 AEN	17 AEN	20 AEN	25 AEN
1	65	60	50	40
2	130	120	100	80
3	195	175	150	120
4			200	160

- Alternatively, apply fertilizer N after 14 DAT or 21 DAS based on the crop's need for supplemental N, as determined by the leaf N status. The leaf color chart (LCC) is a tool that can be used to assess leaf N status and the crop's need for N (Figure 2.8).
- Apply all fertilizer P near transplanting or sowing. Apply fertilizer K twice, 50 percent near transplanting or sowing and 50 percent at early panicle initiation. When fertilizer K rates are relatively low (for example, 30 kg K_2O ha^{-1}), all fertilizer K can be applied near transplanting or sowing.

PHOSPHORUS AND POTASSIUM MANAGEMENT

P and K are essential elements for plant growth. It is particularly important in the early growth stages. It promotes root development, tillering, and early flowering. K strengthens plant cell walls and contributes to greater canopy, photosynthesis, and crop growth. It does not have a pronounced effect on tillering, but it can increase the number of spikelets per panicle (flowers per grain bunch) and percentage of filled grain.

Rice plants obtain much of their required P and K from the soil, crop residues, organic amendments, and irrigation water; but the supply of P and K from these naturally occurring indigenous sources are often insufficient to sustain high rice yields. Supplemental P and K from fertilizers are thus essential for sustaining high and profitable yields of rice without depleting soil fertility.

APPLYING P BASED ON OMISSION PLOT YIELDS AND YIELD TARGET

General Rule: Where the soil P supply is small, apply 20 kg fertilizer P_2O_5 per ha for each ton of target grain yield increase (difference between yield target and yield in 0 P plot).

The maintenance fertilizer P rates given in Table 2.2 are designed to replenish the P removed with grain and straw, assuming a low to moderate return of crop residues. Look up the fertilizer P_2O_5 rate based on the yield target (Step 1 of implementing SSNM) and an estimate of soil P supply measured as yield in a 0 P omission plot (Step 2 of implementing SSNM).

Figure 2.8. The LCC used in adjusting the amount of fertilizer N to be applied at key growth stages and in determining the right timing of fertilizer N application

(Photo credit: IRRI-RKB)

Table 2.2. Maintenance fertilizer P_2O_5 rates according to yield target and P- limited yield in 0 P plots

Yield in 0 P plot (t/ha)	Fertilizer P_2O_5 Rate (kg/ha)[a] for Yield Target				
	4 t/ha	5 t/ha	6 t/ha	7 t/ha	8 t/ha
3	20	40	60	[a]	[a]
4	15	25	40	60	[a]
5	0	20	30	40	60
6	0	0	25	35	45
7	0	0	0	30	40
8	0	0	0	0	35

Notes:
[a] indicates unrealistic targets

Theoretically, fertilizer P application would not be required if a yield response were not expected for the selected yield target (i.e., yield target=yield in nutrient omission plot). This zero-fertilizer P strategy results in mining the soil of P reserves and may affect yields in the medium to long term, especially if other nutrient sources such as straw or manure are not applied.

NOTES:

1. To avoid excessive fertilizer P use arising from overly optimistic yield targets, the maximum yield increase over yield in the 0 P plot is 3 t/ha (Table 2.2). A reduction in the yield target is suggested for cases where a yield increase of more than 3 t/ha over the yield in the 0 P plot is required.
2. To prevent mining of soil P reserves, the following rules of thumb can be applied:
   - If most of the straw is retained in the field (e.g., after combine harvest or harvest of panicles only) and the nutrient input from manure is small, apply at least 4 kg P_2O_5 per ha for every ton of grain harvested (e.g., 20 kg P_2O_5 for a yield of 5 t/ha) to replenish P removed in grain.
   - If most of the straw is removed from the field and nutrient input from other sources (manure, water, sediment) is small, apply at least 6 kg P_2O_5 per ha for every ton of grain harvested (e.g., 30 kg P_2O_5 for a yield of 5 t/ha) to replenish P removed in grain and straw.

Maintenance fertilizer P rates can be reduced if:

- soils receive organic amendments such as farmyard manure. Organic material can contribute substantially to the buildup and maintenance of soil P reserves, depending on nutrient concentration and amount applied. Apply organic amendments in nutrient omission plots to assess the combined nutrient-supplying capacity of soil and applied organic materials.
- soils are periodically flooded with substantial nutrient inputs from sedimentation.

P applied to rice has a residual effect on the succeeding crop, but direct application to each crop is more efficient. Fertilizer P should be incorporated in the soil before seeding or transplanting.

Fertilizer P application is not recommended if yield in a 0 P plot with favorable conditions is greater than the yield target.

It may be necessary to reassess the soil P supply after 8–10 cropping cycles.

APPLYING K

General rule: Where the soil K supply is small, apply 30 kg fertilizer K_2O per ha for each ton of target grain yield increase (difference between yield target and yield in 0 K plot).

The maintenance fertilizer K rates given in Table 2.3 are designed to replenish the K removed in grain and straw by considering the amount of straw returned to the field from the previous crop.

Table 2.3. Maintenance fertilizer K_2O rates according to yield target and K-limited yield in 0 K plots

Rice Straw Inputs	Yield in 0 K Plot (t/ha)	Fertilizer K_2O Rate (kg/ha)[a] for Yield Target				
		4 t/ha	5 t/ha	6 t/ha	7 t/ha	8 t/ha
Low (<1t/ha)	3	45	75	105	[a]	[a]
	4	30	60	90	120	[a]
	5		45	76	105	135
	6			60	90	120
	7				75	105
	8					90
Medium (2-3 t/ha)	3	30	60	90	[a]	[a]
	4	0	35	65	95	[a]
	5		20	50	80	110
	6			35	65	95
	7				30	80
	8					65
High (4-5 t/ha)	3	30	60	90	[a]	[a]
	4	0	30	60	90	[a]
	5		0	30	60	90
					35	70
					25	55
						40

Notes: a indicates unrealistic targets

Look up the required fertilizer K_2O rate in Table 2.4 based on:

- the yield target (Step 1 of implementing SSNM),
- the estimate of soil K supply measured as yield in a 0 K omission plot (Step 2 of implementing SSNM), and
- the amount of K recycled with straw yield and the straw management level in the previous season (Table 2.4).
- Substantial mining of soil K reserves may affect yields in the medium to long term, especially if most of the straw is removed.

NOTES:

1. To avoid excessive fertilizer K use arising from overly optimistic yield targets, the maximum estimated increase over yield in the 0 K plot is 3 t/ha (Table 2.3). A reduction in the target yield is suggested for cases where a yield increase of >3 t/ha over the yield in the 0 K plot is required.

2. In the short term, fertilizer K application would not theoretically be required if a yield response is not expected for the selected yield target (i.e., if yield target=yield in 0 K plot). This strategy results in mining of soil K reserves and may affect yields in the medium to long term, especially if other nutrient sources such as straw or manure are not applied.

Table 2.4. Input of K with recycled straw according to yield and straw management practices in the previous season

Straw Management	Previous Season	
	Low-Yielding Season 4–5 t/ha	High-Yielding Season 6–8 t/ha
Surface cut and full straw removal <10% straw remaining as stubble: India, Nepal, Bangladesh, Vietnam	Straw K input: Low (0–1 t straw recycled)	Straw K input: Low (0–1 t straw recycled)
Low cut Short stubble (25 cm–30 cm) in the field, no burning of the whole field: Philippines	Straw K input: Medium (2–3 t straw recycled)	Straw K input: Medium to High (3–5 t straw recycled)
High cut Long stubble (>30 cm) in the field, no burning of the whole field: Philippines, Indonesia	Straw K input: Medium (3–4 t straw recycled)	Straw K input: Medium to High (5–7 t straw recycled)
Combine harvest with high cut Long stubble in the field, burning of the whole field: Thailand, S. Vietnam, Northern India	Straw K input: High (4–5 t straw recycled but 20%–25% P and K losses because of burning [P] and leaching of K)	Straw K input: High (6–8 t straw recycled but 20%-25% P and K losses because of burning [P] and leaching of K)

Notes:

- To avoid excessive K fertilizer use arising from overly optimistic yield targets, the maximum estimated increase over yield in the 0 K plot is 3 t/ha (Table 4). A reduction in the target yield is suggested for cases where a yield increase of >3 t/ha over the yield in the 0 K plot is required.
- In the short term, fertilizer K application would not theoretically be required if a yield response is not expected for the selected yield target (i.e., if yield target=yield in 0 K plot). This strategy results in mining of soil K reserves and may affect yields in the medium to long term, especially if other nutrient sources such as straw or manure are not applied.
- To prevent mining of soil K reserves, the following general rules can be applied:
  - — If most of the straw is retained in the field (e.g., after combined harvest or harvest of panicles only) and the nutrient input from manure is small, apply at least 3.5 kg K_2O per ha for every ton of grain harvested (e.g., 17.5 kg K_2O for a yield of 5 t/ha) to replenish K removed in grain.
  - — If most of the straw is removed from the field and nutrient input from other sources (manure, water, sediment) is small, apply at least 12 kg K_2O per ha for every ton of grain harvested (e.g., 60 kg K_2O for a yield of 5 t/ha) to replenish K removed in grain and straw.
- The maintenance fertilizer K rates given in Table 4 can be reduced if
  - — Soils receive organic amendments such as farmyard manure. Organic material can contribute substantially to the buildup and maintenance of soil K reserves, depending on nutrient concentration and amount applied. Apply organic amendments in nutrient omission plots to assess the combined nutrient-supplying capacity of soil and applied organic materials; or
  - — Soils are periodically flooded with substantial nutrient inputs from sedimentation.
- When the total amount of K fertilizer to be applied is small, it can all be applied at seeding or transplanting. For larger applications (40–120 kg K_2O per ha), apply in two splits: 50 percent as basal application before crop establishment or within the first two weeks after crop establishment and 50 percent at panicle initiation (PI). For large applications (>120 kg K_2O per ha), apply in three splits (1/3 basal, 1/3 at PI, and 1/3 at heading to first flowering).

3. To prevent mining of soil K reserves, the following general rules can be applied:
   - If most of the straw is retained in the field (e.g., after combined harvest or harvest of panicles only) and the nutrient input from manure is small, apply at least 3.5 kg K_2O per ha for every ton of grain harvested (e.g., 17.5 kg K_2O for a yield of 5 t/ha) to replenish K removed in grain.
   - If most of the straw is removed from the field and nutrient input from other sources (manure, water, sediment) is small, apply at least 12 kg K_2O per ha for every ton of grain harvested (e.g., 60 kg K_2O for a yield of 5 t/ha) to replenish K removed in grain and straw.

The maintenance fertilizer K rates given in Table 2.3 can be reduced if:

- Soils receive organic amendments such as farmyard manure. Organic material can contribute substantially to the buildup and maintenance of soil K reserves, depending on nutrient concentration and amount applied. Apply organic amendments in nutrient omission plots to assess the combined nutrient-supplying capacity of soil and applied organic materials; or
- Soils are periodically flooded with substantial nutrient inputs from sedimentation.

When the total amount of fertilizer K to be applied is small, it can all be applied at seeding or transplanting. For larger applications (40–120 kg K_2O per ha), apply in two splits: 50 percent as basal application before crop establishment or within the first two weeks after crop establishment and 50 percent at panicle initiation (PI). For large applications (>120 kg K_2O per ha), apply in three splits (1/3 basal, 1/3 at PI, and 1/3 at heading to first flowering).

APPLICATION

Adaptation

In general, good nutrient management should primarily increase resilience of crops aside from increasing productivity and farmers' income (Richards et al. 2016 Thornton and Herrero 2014). Improved resistance of crops to diseases is a result of balanced soil nutrients, particularly N, P, and K, which can be managed through SSNM (Pasuquin et al. 2014). It is important to note the attainable yield of the current year to know how to optimize fertilizer inputs. This can save farmers from wasting money on fertilizers during bad-weather years (Richards et al. 2016). In rice production, the growth and crop needs for supplemental nutrients vary among fields, seasons, and years because of the different environmental conditions, crop and soil management, and climate. Adjustments in applying N, P, and K to satisfy site-specific needs of a rice crop are essential in managing supplemental nutrients for rice.

Mitigation

SSNM is seen as a greenhouse gas mitigation strategy because it reduces nitrogen oxide (N_2O) emission. It is most applicable to farming systems where fertilizer N is overused. Principles in SSNM lessen the quantity of N application, which, in return, prevents leaching and volatilization. Slow or controlled release of fertilizers also reduces N2O emissions because of balance in crop nutrient demand and nutrient release during application. Another potential strategy in reducing reactive N losses is fertilizer deep placement (Shreeja n.d.; Gaihre et al. 2015). Integrating mitigation methods with SSNM can further reduce N_2O emissions and reactive N losses (Wassmann et al. 2009a, 2009b).

Controlled irrigation (alternate wetting and drying). Alternate Wetting and Drying (AWD) is a water-saving technology that farmers operating irrigated rice lands can use to reduce irrigation cost and water input so that water can be used for other purposes. With AWD, the field is alternately flooded and non-flooded. The number of days of non-flooded soil in AWD between irrigations can vary from one day to more than 10 days (Figure 2.9).

AWD also offers mitigation co-benefits through its capacity to reduce greenhouse gas (GHG) emissions, specifically methane, relative to traditional lowland rice cultivation.

The practice requires access to reliable irrigation supply. Control of water inputs and drainage schedule of the rice fields should be managed properly.

The level of adoption of AWD is moderate towards spontaneous adoption (FAO and WOCAT 2016). Farmers who use *Palayamanan*[2] system in Ilocos Norte province are adopting AWD (Corales et al. 2004).

AWD has many advantages: (1) It reduces water use for irrigation so that water can be used for other purposes; (2) It reduces the use of irrigation water because there is less of it; and (3) It reduces the use of irrigation water, thereby reducing the cost. It reduces emission of GHG specifically of methane, since GHG emission is caused by flooding of rice fields.

Methodology

Practical implementation of AWD is facilitated using a simple tool called "field water tube" as observation well, which monitors the water level in the field. It is made of a 30-cm-long PVC pipe with a 10 cm to 15 cm diameter. In some instances, bamboo can be used instead of the PVC pipe. The 20 cm of the pipe is perforated on all sides (with about 2 cm between holes) to allow lateral movement of water in the root zone. It is installed into the soil with 10 cm with no holes protruding above the soil surface. Soil must be removed inside the tube so that the bottom is visible.

After transplanting the rice seedlings, implementation of AWD can run for about one to two weeks. If weeds are present in the field, AWD implementation should be postponed for two to three weeks.

During the first 21 to 30 days after direct seeding or transplanting, 2 cm–3 cm of water is maintained to control weeds and to ensure that the crop has already recovered from transplanting shock. AWD is imposed after 21 to 30 days, during which the water in the

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[2] *Palayamanan* system is a synergy of farming practices implemented and managed by a farming family to contribute in food security, income stability, and environmental sustainability.

Figure 2.9. An AWD field with a 'field water tube' as an observation well used in monitoring the water level in the field

(Photo credit: IRRI-RKB)

tube is monitored. Once the water inside the tube disappears, irrigation is applied to a water depth of 5 cm above soil surface.

During fertilizer application and flowering stage, sufficient water should be maintained to avoid spikelet sterility. Terminal drainage from one to two weeks before the expected time of harvest is also done to promote uniform maturity of the crop and to facilitate postharvest operations in the field.

When the water level has dropped to about 15 cm below the surface of the soil (also called as "safe AWD"), irrigation should be applied to re-flood the field to a depth of about 5 cm. Safe AWD has been shown to reduce water use by 15 percent without decreasing yield. From one week before to a week after flowering, the field should be kept flooded to a depth of 5 cm as needed. After flowering, during grain filling and ripening, the water level can be allowed to drop again to 15 cm below the soil surface before re-irrigation.

APPLICATION

Adaptation

AWD system involves alternate flooding and draining of rice fields during the production cycle, which makes it viable as a climate change adaptation technology (ASEAN 2015). In contrast, the traditional practice of rice growing consumes a disproportional amount of water compared to other crops in flooded fields (ASEAN 2015). The proper use of

AWD system can reduce water usage by up to 38 percent in rice cultivation (ASEAN 2015; Lampayan et al. 2015). Since projected drought occurrence will increase in many areas in Southeast Asia as a result of climate change, using less water in rice production enhances the resilience of farmers while sustaining their productivity (ASEAN 2015).

Mitigation

AWD's capacity to reduce GHG, particularly methane, is seen as a mitigation strategy. In AWD implementation, farmers are required to drain rice fields until the soil becomes oxygenated while maintaining sufficient soil moisture to support crop growth. During the decomposition process, partial draining is enough to inhibit anaerobic bacteria from producing methane. With AWD, an average reduction of methane emission is observed by the Intergovernmental Panel on Climate Change (IPCC) (2006) compared with traditional, continuous flooding (ASEAN 2017).

System of Rice Intensification. The System of Rice Intensification (SRI) is an innovation in rice production system developed to increase land and water productivity, labor, and capital with less external inputs (Verzola n.d.; BIND 2004). It can be adopted for different rice varieties. SRI, a set of modified approaches in rice, soil, water, and nutrient management (Figure 2.10), can be categorized as basic, organic, and partial. In the basic SRI, single young seedlings are transplanted at wider spacing and intermittent irrigation is applied. Chemical fertilizer is used, but organic matter is encouraged to improve soil structure. Organic SRI follows the same procedure as basic SRI, but no chemical fertilizer is applied. Application of organic materials, such as compost or manure, to fertilize soil and enhance biological activity is recommended. Partial SRI, on the other hand, can apply components from the other types of SRI, according to farmer's preference and present local conditions. However, this type of SRI may not be as beneficial as Basic and Organic SRI (CIIFAD n.d.).

To ensure farmers' acceptability, it is suggested that implementation be gradual, beginning with Basic SRI to Partial SRI, then to Organic SRI. Each component can be adjusted according to farmers' preferences, site conditions, and availability of local resources.

The SRI method is based on four main principles:

- Early, quick, and healthy plant establishment;
- Reduced plant density;
- Improved soil conditions through enrichment with organic matter; and
- Reduced and controlled water application.

Farmers can use these principles to address and respond to their agroecological and socioeconomic conditions. It is important to consider the changing weather patterns, soil conditions, labor availability, water control, and access to organic inputs before using SRI.

Figure 2.10. The System of Rice Intensification, known as SRI, is a set of modified approaches to rice, soil, water, and nutrient management

(Photo credit: Pasali Phil Foundation)

METHODOLOGY

The following are guidelines in transplanting rice plant seedlings as part of the recommended SRI management practices for irrigated condition:

1. Transplant seedlings during the two leaf-stage, which is usually between eight and 12 days old.
2. Carefully and quickly transplant the seedling to protect the roots and minimize transplanting shock.
3. Transplant at one plant per hill instead of three or four together to avoid root competition.
4. When transplanting, observe spacing (25 cm x 25 cm or wider) to encourage greater root and canopy growth.
5. Transplant in good quality soil in a square grid pattern.
6. The soil should be enriched with organic matter to improve its structure and nutrient and water holding capacity, and to foster microbial development.
7. Minimum amount of water is applied during the plant's vegetative growth followed by plot drying until cracks become visible, at which time, another thin layer of water is introduced. This method is called AWD. Farmers can have varying irrigation schedules depending on soil and climate conditions. During flowering, a thin layer of water is maintained, followed by alternate wetting and drying in the grain filling stage, before draining the paddy two to three weeks before harvest.
8. The composition of soil structure is improved by adding nutrient requirements. In return, the soil can hold more nutrients in the rooting zone and release them once the plants require them. Farmers have different preferences when fertilizing. Some farmers strictly follow exclusive organic fertilization. However, most farmers improve the soil by complementing the organic matter with chemical fertilizers to balance fertilization of the crop.
9. Weeds should be kept under control at an early stage. Different weeder types are used in weed control and maintenance. Weeders have multiple functions and benefits. Some weeders incorporate weeds into the soil for decomposition and nutrient recycling; some provide light tillage. Root pruning stimulates root growth. Organic matter is mixed with water to enrich the topsoil. Weeders redistribute water across the plot to level the soil and eliminate water patches that create anaerobic conditions for the plants. Weeders achieve homogenous field conditions, create uniformed crop stand, and increase productivity.

APPLICATION

Adaptation

As demonstrated in more than 50 countries (SRI-Rice 2015), SRI increases yield 20 percent to 100 percent with 90 percent reduction in required seed and up to 50 percent water saving. This also translates to economic benefits for farmers. SRI principles and practices have been adopted in rainfed rice ecosystem, as well as for other crops such as sugarcane.

Mitigation

SRI contributes to the reduction of GHG emissions, particularly methane and nitrous oxide, through management methods such as creating aerobic soil conditions using shallow and intermittent irrigation or AWD. Simple changes in water management (e.g., intermittent irrigation, which is an intrinsic part of SRI) lead to significant GHG reduction (CIIFAD n.d.)

Ecological engineering for biological pest control. Ecological engineering in lowland rice agro-ecosystems is done by planting flower strips in rice fields. These strips serve as habitats for beneficial arthropods that control pests (Figure 2.11) (DA, DA-BSWM, DA-BAR 2017; Wiemers et al. 2016).

More sustainable management for cropland and surrounding habitats are required to counteract the negative impact of agricultural intensification, such as loss of biodiversity and ecosystem. Ecological engineering, through the provision of habitats for beneficial arthropods, has recently gained considerable attention as a method of reducing pesticide input through stimulating biological pest control by natural enemies.

Ecological engineering primarily aims to regulate pest species through the provision of habitats for their natural enemies. Moreover, other ecosystem services like pollination and cultural services may simultaneously be enhanced by using the same measures. One popular and effective measure in temperate countries where agro-environmental schemes are implemented is the planting of flower strips as habitats.

In intensively managed tropical rice production systems, biological pest control, pollination services, and landscape aesthetics could also benefit from the establishment of flower strips on the bunds within irrigated fields. Ecological engineering is done to increase biodiversity in rice fields and provide habitats for beneficial organisms such as predators of rice pests (e.g., spiders) or parasitoids (e.g., hymenopteran parasites), which, in turn, will help lessen or totally diminish the use of pesticides. An additional benefit is landscape beautification.

Methodology

Establishment and maintenance of flower strips

In establishing flower strips, seeds of flowering plants (e.g., flowering annuals such as *Melampodium divaricatum*) are collected and planted in a nursery (Wiemers et al. 2016). After a month or so, they are transplanted into rice fields on bunds with a strip size of 0.25 m x 5 m and 5 m between strips (this serves as access for other farm operations such as fertilizer application). Farmers are instructed not to spray insecticides when they test this system. The flowering plants should be pruned during the fallow period in the wet season and will require watering during the dry season when rice is cropped.

Figure 2.11. Planted flower strips in rice fields serve as habitats for beneficial arthropods as pest control

(Photo credit: IRRI-RKB, PhilRice)

The flower strips are composed of annual species that will need to be replanted after the rice crop is harvested.

Adoption of technology

Ecological engineering is a widely adopted sustainable land management (SLM) technology in Luzon, Philippines, as well as in rice-producing areas in Vietnam. With some adaptations, it should also be applicable to irrigated lowland rice production systems throughout Southeast Asia.

Application

Adaptation

This method increases biodiversity in bunds within irrigated rice fields. Aside from its aesthetic benefits, ecological engineering also increases resilience of crops to damages and yield through the regulation of pest species.

Mitigation

Ecological engineering mitigates the production of GHG by reducing usage of pesticide inputs. By creating habitats for beneficial arthropods, natural pest control is carried out without damaging the ecosystem.

Floating garden. Floating gardens are rafts of aquatic weeds on which vegetables and other edible crops can be grown (Figure 2.12). These are a pragmatic agricultural alternative in areas affected annually by flooding where aquatic weeds like water hyacinth are abundant. Monsoon season has always left agricultural fields and land submerged during certain periods of the year, which is intensified by climate change. Often, fields are submerged for more than two months and, even when the waters recede, are left too waterlogged to yield crops.

METHODOLOGY

According to Brown (2013), these are the steps in making a floating garden:

1. Decide on an appropriate size for the floating garden. Generally, rafts are about 8 m long and 2 m wide and 0.6 m–1 m deep. The size depends on the space and resources available.
2. Collect water hyacinth. Aquatic weed, such as water hyacinth, will serve as the base or raft for the floating garden.
3. Lay bamboo poles over the water hyacinths. The poles should be proportioned to the overall size of the raft.
4. Collect additional water hyacinth and place it on top of the bamboo layer to build thickness. Weave the water hyacinth into a raft.
5. Once the plants have been woven and the general structure of the raft has been established, remove the bamboo poles.
6. Wait seven to 10 days, then add more water hyacinth to the existing raft.
7. Add a mulch of soil, compost, and cow dung to cover the raft. This layer should total about 25 cm deep. Usually, the compost is composed of azolla and other easily accessible organic matter.
8. Pick an appropriate place for the raft. Floating gardens should not be placed in waters with tides or currents because the water movement damages the water hyacinth and risks total disintegration of the raft.
9. Plant seeds. The most effective technique is to place a couple of seeds into a ball of compost and *tema*, an organic fertilizer. Place these balls in a shaded, protected area while the seeds germinate. Once seedlings sprout, plant them on the raft.
10. Tend the floating garden. In Bangladesh, the most common crops are leafy vegetables, okra, gourds, eggplant, pumpkin, and onions. Animals like ducks and rodents might be attracted to the rafts. Using improvised materials like fishing nets for fencing can effectively protect the gardens.
11. Harvest the crops. Rafts can be reused or, if no longer usable, can be used as compost for a new raft.

Figure 2.12. A floating garden grown with vegetables

(Photo credit: IRRI-RKB, PhilRice)

APPLICATION

Adaptation

Floating gardens are adaptation measures for areas affected annually by flooding that last for more than two months and where aquatic weeds like water hyacinth are abundant. Floating gardens enable farmers to grow crops even when their fields are inundated. Vegetables are commonly planted, which will provide nutritious food to the households while the farms are not productive due to flooding. Much of the appeal of this method is the relative ease of constructing and cultivating a floating garden.

Mitigation

Aquatic weeds such as the water hyacinth are used as rafts, and where plants are grown, contain carbon stock. When the floodwater recedes, they are incorporated into the soil to decompose and contribute to the organic matter content of the soil, where carbon is being stored.

Sorjan system. The Sorjan system is a land modification technique that constructs a series of alternating deep sinks and raised beds as adaptation in flood-prone or swampy areas (Figure 2.13). This system, which was developed by Indonesian farmers, allows the growing of upland crops on raised beds and wetland crops on the sinks, thereby ensuring crop production and regular income of farming households during flood season or dry season. The Sorjan system can serve as both a flood control measure during the rainy season, and as irrigation water supply during the dry season. During flood season, the sink impounds water and slows down water velocity. The water can be used in the production of rice and other water-tolerant crops like *gabi* and *kangkong*, or even in fish production. Meanwhile, the raised beds or bunds will allow the growing of upland crops such as vegetables and other cash crops. During the dry season, water stored in the sinks will serve as a source of irrigation for the upland crops on the raised beds.

PhilRice experts suggest that the ideal dimension of the raised bed is around 3 m wide and 30 cm above water level. The bund around the area, on the other hand, is about 70 cm–100 cm wide and 30 cm high. The sink for rice and *gabi* production is from 3 m–5 m wide and 30 cm deep, while a deeper sink of about 1 m wide and 1 m–1.5 m deep can be constructed around the area for fish production.

PhilRice highly encourages the integration of rice, vegetables, and fish (Corales et al. 2004). Depending on the season, the vegetables that can be grown in the Sorjan method are eggplant, pepper, tomato, upland *kangkong*, bush beans, cowpea, *pechay,* mustard, kale, lettuce, spinach, okra, corn, and herbs. On the other hand, the fish component may include catfish, gourami, or tilapia. Meanwhile, the bunds can be planted with okra and bush or pole beans.

Sorjan also offers flexibility. Farmers may opt to plant vine vegetables such as winged bean, bottle gourd, bitter gourd, ridge gourd, or squash, on trellises as an overhead feature on top of the sink.

METHODOLOGY

Bed construction

The raised beds can be constructed in several ways, including the following:

- Plowing with mold board plow and shoveling the soil to form the raised beds.
- Plowing a flooded field, harrowing to move the soil into a rough raised bed and then shoveling to straighten the edges.

The construction method will depend greatly on labor availability. An area of about 1,000 m^2 will require about 300 to 600 labor hours, depending on the number of beds to be constructed, and their width and height.

Figure 2.13. Alternating deep sinks and raised beds planted with crops

(Photo credit: PhilRice)

Determining bed height and width

In deciding on the bed height and width, the following factors should be considered:

Height

- Slope. For sloping field, a lower height is needed because there are fewer problems with drainage (for the upland crop planted on the beds).
- Chance of flooding/height of floodwater. The bed must be high enough so that the upland crops will not be flooded.
- Rate of soil erosion from bed to sink. Raised beds should be higher for highly erodible soils.
- Soil fertility/depth of topsoil. Sink should not be dug too deep. Take care not to expose the subsoil.

Width (and/or number of beds):

- Water requirement. For rainfed areas, the width will depend on the amount of runoff from the bed that is needed for the rice in the sink.
- Land preparation method. If you plan to plow the beds, beds should be wide enough to allow plowing. On the other hand, constructing several narrow beds is faster than making fewer but wider beds.

Increasing fertility of sink

Removing the topsoil from the sink area reduces soil fertility, which will affect lowland crop production. Efforts should be made to increase soil fertility by applying high amounts of organic matter. This can be achieved by:

- planting green manure or grain leguminous crops on the sink after removing the topsoil
- mulching the crops with rice straw during the dry season
- applying livestock manure
- growing azolla on the sink

If moisture is available, leguminous crops, such as soybean, cowpea, or mung bean, can be planted. Mung bean does very well in newly constructed beds. Mulch the crop as well. Upland crops that can be planted on the raised beds include sweet pepper, cucumber, squash, *ampalaya*, and grain and vegetable legumes.

Crops for planting

Crops that can be planted on the raised beds include eggplant, pepper, tomato, upland *kangkong*, bush beans, cowpea, *pechay*, mustard, kale, lettuce, spinach, okra, corn, and herbs. Vine vegetables such as winged bean, bottle gourd, bitter gourd, ridge gourd, or squash on trellises can also be planted. Fish that can be raised in the sink include catfish, gourami, or tilapia. The bunds, on the other hand, can be planted with okra and bush or pole beans.

APPLICATION

Adaptation

The Sorjan system is an adaptation measure in both flood-prone and drought-prone areas. There is an opportunity to grow crops even during the flood season, and a chance to increase irrigation water supply during the dry season. Diversification of crops involving upland and wetland crops can reduce the risk of crop failure during extreme weather events.

Mitigation

The Sorjan system contributes to mitigation of climate change by reducing the use of pesticides. Growing fish in the sink area will discourage farmers from using pesticides. In addition, fish stocks will naturally feed on pests and weeds on the farm.

Rice-fish system. The rice-fish system is an integrated crop management where fish is raised concurrently or in rotation with rice crop in a symbiotic relationship (Figure 2.14). It is an ancient practice used by many farmers in Asia. In the concurrent culture of rice and fish, rice is considered as the primary crop, and fish as the second crop. Fish culture must conform to the rice crop requirements, but essential modifications can be made (Eusebio and Labios 2001). Rotational cropping of rice and fish is a system in which rice and fish are cultured alternately or separately using the same field and at different times. Below are the three types of rice-fish system:

- One rice crop and one fish crop annually
- Two rice crops and one fish crop annually
- Five harvests in two years (e.g., rice-fish-rice-fish-rice)

Fish may be cultured or may migrate from surrounding waterways into the rice fields when flooding occurs. The types of culture systems for fish were pointed out by Coche (1967). The types of culture systems are classified according to the source or origin of the fish and the relation of fish culture to rice crop. The four categories of fish origin are as follows:

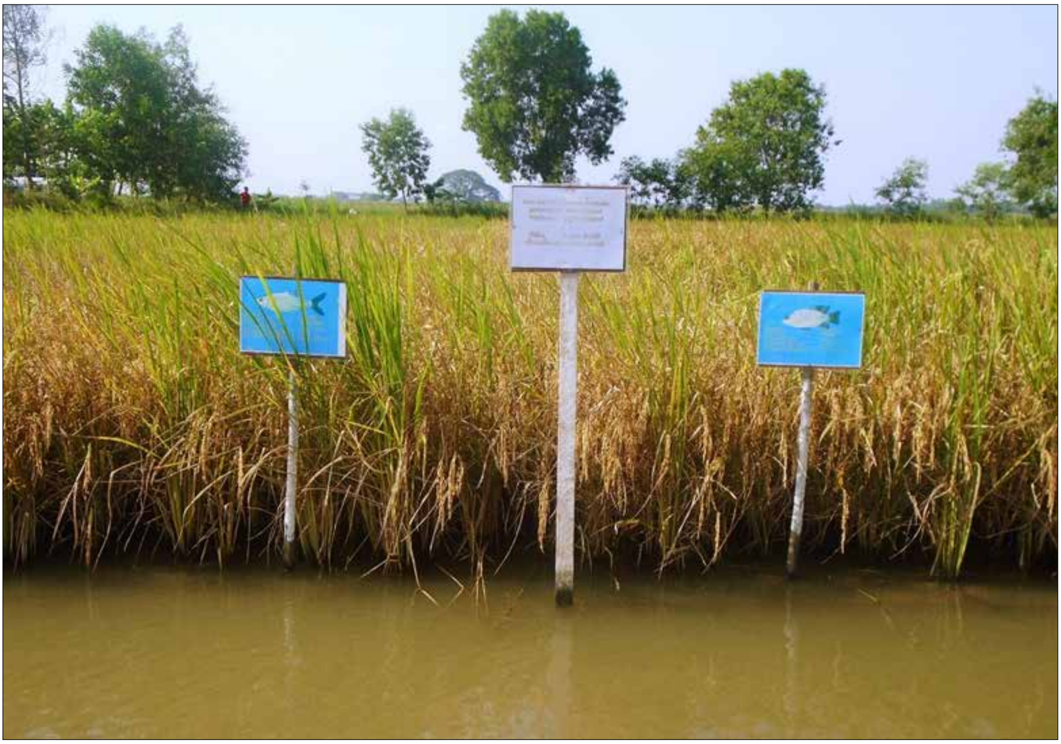
- Harvesting wild fish that have entered from surrounding water courses
- Introducing new fish species directly into the field or indirectly in connected ponds to increase fish crop
- Trapping wild fish into the field with tidal water
- Trapping fish and allowing them to grow before harvest

The rice-fish system lessens the impact of agricultural chemicals on the environment. Fish feeds on pests and weeds promote damage control in pest and weed management. Fish feed requirements are met while making it unnecessary to use pesticides, thus improving rice productivity. Fish manure is used as a natural fertilizer. The movement of fish helps loosen the soil and initiates fertilizer and root development. Depending on the type of rice-fish system, the species available, and the management used, fish yield can range from 1.5 to 174 kg/ha per season, which makes rice farming more profitable. Production of fish and other aquatic animals in the same rice field does not decrease rice yields. In fact, the practice is proven to double harvest yield. It yields 6.7–7.5 rice t/ha and a total of 0.75–2.25 fish t/ha on the average. The rice-fish system also provides additional source of animal protein for household consumption and farm income.

Various factors influence fish culture in rice fields (Coche 1967; Huet 1972; Vincke 1979). These are altitude and latitude, rainfall and water supply, water temperature and dissolved oxygen, water turbidity, salinity and tidal flux (in coastal waters), fertility and richness of plankton and other fish organisms, and polluting effects of chemicals.

The common indigenous fishes found in Asian rice fields are species of white fish that eat small plants or planktons such as danios (*Rasbora*), barbs (*Puntius*), snakeskin gourami (*Trichogaster*), and halfbeaks (*Xenentodon*). The species of blackfish that are carnivorous and can survive at low or no oxygen level are snakehead (*Channa*), catfish

Figure 2.14. A rice-fish system where fish is raised concurrently with rice crop



(Photo credit: RV Labios)

(*Clarias*), climbing perch (*Anabas*), spiny eels (*Mastacembelus*), and sheatfish (*Ompok*). There are introduced exotic fish species in Asia as well, which are common carp (*Cyprinus*), tilapia (*Oreochromis*), and silver carp (*Hypophthalmichthys*). Other aquatic animals may also be harvested, such as crabs, shrimps, snails, and insects.

Coche (1967) and Vincke (1979) specify that fish species suitable for rice-fish systems should have the following characteristics:

- Can live and grow in shallow water
- Can tolerate high temperature and low oxygen, which are the conditions in rice fields during hot days
- Have the capacity to grow fast and reach the standard market size
- Can tolerate high turbidity
- Can be confined in an enclosed field

Methodology

Constructing and preparing the rice field

Strong and impenetrable bunds with height of 25 cm–60 cm and slope of 30–45 degrees (Coche 1967) should be provided for fish culture in rice fields. The bunds help in retaining water and keeping fish inside the rice field.

Trenches, sumps, or ditches are useful in plots since they will serve as fish confinements. Trenches can be dug on one side of the plot, as a peripheral that adjoins the bunds, or diagonal across each plot. The number, contour, and size of the trenches depend on the size of the plot, soil, and fish stock. However, the deeper the trenches, the more the fish are secured from extreme water temperature. The width of the trench should consider the size of fish ready for harvest. Usually, trenches have a width of 50 cm–180 cm and a depth of 30 cm–90 cm while side trenches have a slope of 30–45 degrees depending on the soil type.

Sumps or ditches are provided in the plot since these will serve as a fish refuge during the dry season. Sumps are usually located near the water inlet and outlet connected to the trenches. Sumps can be found at the junction of several trenches in some cases. It is recommended that the sump is several square meters big and the depth is lower compared to the trenches. The design of water inlet and outlet, which are responsible for supplying and draining water, vary in every region. To aid in reducing fish losses caused by accidental bund over flooding, a spillway should be properly placed in the plot.

Planting and stocking

As discussed earlier, a proper rice field for fish culture should have strong bunds, deep trenches, sumps, water inlet and outlet, and a spillway. The rice field should also be stripped of weeds. Water outlets should be provided with fitting screens and nets so that waste will not enter the field and fish stock will not escape. Rice is planted in the plot that is about 35 cm apart and the trenches filled with 50 percent water, just enough for the roots of seedlings to properly develop. When rice seedlings start to develop roots, water level across the field should be raised to 10 cm–20 cm so that the fingerlings can be released in the sumps. As soon as the fingerlings adapt to the rice field water, they should be released in the field. The water level should be gradually increased to promote growth of both rice and fish.

Predatory fish, particularly snakehead, should not be present when fish seed is introduced into the system. Even with the presence of pests and weeds, feed supplements such as duckweed, termites, earthworms, and rice bran can be supplied to fish stocks if economically available.

Harvesting

After about 4 to 5 months, rice and fish are ready to harvest. It is best to harvest the fish before keeping the field dry for a week. This process will make paddy seeds mature well before the actual paddy harvest. The water in the field can be drained out and fishes can be collected in the sumps or netted out. Fish harvests usually include a percentage of caught wild fish that may have naturally entered the field.

Other considerations

Rice fields should not be dried up while fish stocks are present; hence, water control and management are crucial. Flood control can be difficult in rainfed rice systems since fish stocks can escape during field flooding.

Application

Adaptation

The ecological soundness of rice-fish system and the beautification of landscape can boost ecotourism as part of diversified local livelihood. Rice-fish system provides economic opportunities for farmers because of high harvest yields. The system supports the selection and utilization of suitable rice varieties for local climate and soil conditions.

Mitigation

Fish presence in the rice fields may discourage farmers from using pesticides since these can poison the fish stocks, as well as the consumers. Fish stocks naturally feed on pests and weeds. Consequently, the rice-fish system can reduce the use of pesticides and GHG.

Rice-duck system. The rice-duck system is an integrated farming method commonly practiced in the Philippines and other Asian countries (Figure 2.15).

Figure 2.15. Releasing of ducks in the early growth stages of rice in controlling weeds, insect pests, and golden apple snails

(Photo credit: IRRI-RKB, PhilRice)

The symbiotic relationship between rice and duck benefits farmers the most. Ducks feed on fallen grains, snail, and succulent weeds, duck manure is used as organic fertilizer for rice crops. Duck manure can be solely incorporated in the soil or composted with other organic materials. Ducks can freely graze in the rice fields. They can source feeds (e.g., rice bran) from discarded *palay* and rice milling by-products. Ducks are also used as biological control for golden snail (*kuhol*), insects, and weeds. The continuous movement of ducks in the rice fields stimulates the availability of macronutrients N, P, and K to rice crops.

Compared with traditional rice farming systems, rice-duck system minimizes production cost because duck feeds and rice crop fertilizers are naturally available. Likewise, environmental benefits such as the reduction of GHG emission is supported by the system. Aside from rice, farmers can increase their income by culturing duck meat. The rice-duck system can increase productivity of rice by 20 percent and net profit to farmers by 50 percent. Duck meat consumption significantly increases food security rate because it has high protein content and other nutritional benefits.

Based on the experience of more than 1000 rice-duck farms in the Philippines, integrated rice-duck farming system (IRDFS) increases rice productivity up to 9t/ha (average is only 4.2 t) and reduces the production cost by 30 percent (Equator Initiative 2013).

METHODOLOGY

Site selection and rice field preparation

The selected farm lot should have at least one hectare for the allotted rice-duck system. The 1-ha area can accommodate 100 ducks. The farm lot should have an elevated area allotted for the construction of a duck shed to avoid muddy conditions. Ducks perform well in clean and dry sheds.

Land preparation should consist of one plowing, two harrowing, and one leveling. Seedlings are prepared using the *dapog* method, a kind of nursery for rice seedlings grown in concrete floor or raised soil bed covered with polyethylene sheet. Rice seedlings should be transplanted 12 days after sowing. Crops should have a spacing of 20 cm x 20 cm or wider, enough for the ducks to freely graze between rows and hills. Snails can be controlled using the *pulot* system (manually picking the snails) since ducks can be allowed to graze only 20 days after transplanting. However, gathered snails can be given to the ducks as feed materials. Two-thirds of fertilizer N and all of fertilizers P and K should be applied basally at transplanting. The fertilization rate of N, P, and K depends on soil fertility. The rest of fertilizer N will be top dressed at panicle initiation.

Duck culture management

The most adaptive duck type in the Philippines is the mallard duck (*Anas borchas*). The mallard type is commonly used in the rice-duck system because it is commercially available and easy to manage. Before purchasing ducks, a duck shed must already be constructed. The duck shed can be constructed using cheap materials such as *nipa*, *sawali*, or bamboo. Litter materials such as rice hulls are spread on the floor to keep it dry.

In the first month, ducks should be carefully handled because they are vulnerable to unfavorable weather conditions (e.g., low temperature and continuous rains) and field predators (e.g., rats, cats, and snakes). The duck shed must have an extra source of heat (e.g., a brooder) and should be kept dry.

Ducks should be fed with commercial feeds (e.g., chick starter mash and boiled rice for ducklings) when in confinement; they can be released in the field a month after. During this stage, the ducks can feed on materials found in the field. If feed materials in the field are insufficient, ducks may need supplemental feeding.

Golden snail, weed, and insect control using rice-duck system

The best time to let the ducks freely graze in the rice fields is after the harvesting period. Ducks feed on fallen grains. In this situation, golden snails tend to burrow in the soil and come out when there is water. To address this problem, the following can be done:

- Continue duck grazing. Allow the ducks to continuously graze in the rice fields. The ducks will feed on available and visible small snails in the area. Snails bigger than 2 cm can be harvested for human consumption or crushed and fed to the ducks.
- Use attractants. Snails will come out when there is water and vegetation. Scatter leaves and weeds in the rice fields and wait for the snails to come out in groups.
- Use a snail trap. Place the attractants or baits inside the snail trap (snail traps are designed and developed by Farming Systems and Soil Resources Institute, University of the Philippines, Los Baños [FSSRI-UPLB]). Snails can easily accumulate in the snail trap because of the attractant. Set the snail traps in the morning and collect snails the next day.

Using these three methods will reduce snail infestation.

Transplanting guidelines

The ducks should not be allowed to graze in the rice fields during transplanting as they tend to destroy the rice seedlings. Flooding should be delayed from the usual 4 DAT to 10 DAT. This inhibits snail infestation on young rice. If irrigation water is present, the remaining snails can destroy the transplanted seedlings. Allow the ducks to graze again at 20 DAT until panicle initiation to minimize damage caused by snail infestation. At this stage, rice crops are sturdy and cannot be trampled by ducks.

Panicle Initiation

Grazing of ducks should be stopped during panicle initiation to prevent the ducks from feeding on the grains. The ducks should be confined until after harvest, during which they can be allowed to graze again but only in fallowed fields. Bigger snails should be picked, crushed, and fed to the ducks throughout the growing stage.

APPLICATION:

Adaptation

The rice-duck system provides resilience to farmers in terms of pest management, less production cost, and diversified livelihood. Ducks are useful as biological control for golden snails, weeds, and insects. The farmers do not need to use or invest in harmful pesticides, thereby reducing production cost. The value chain of by-products from the rice-duck system provides other livelihood options for the farmers. Duck meat, eggs, and manure can be sold separately, aside from milled rice. The replicability of the system can increase resilience rate for farmers who are willing to adopt it. Food security and climate change adaptation are achievable using the rice-duck system.

Mitigation

GHG emission, particularly of methane gas, is caused primarily by flooded rice fields. Flooding cuts off the oxygen supply in the soil, which accelerates decomposition of organic matter. Thus, methane is released into the atmosphere. A study by Huang et al. (2005) suggests that ducks in rice fields mitigate methane emission. The study found that methane emission is proportional to the number of methanogens in the soil. Methanogens found in rice fields highly affect methane emission, which can be suppressed by using the rice-duck system. The more ducks released in the rice fields, the higher the dissolved oxygen content.

Laser-controlled land leveling. Land leveling is a precursor to good management practices in soil and crop. Unleveled soil causes irregular water distribution and soil moisture, which can greatly affect germination and crop yield. Laser-controlled leveling can also be used in terracing, improve subsurface drainage, and leveling construction sites. Laser-controlled land leveling is a proven technology, which is highly useful for conserving irrigation water (Figure 2.16).

Laser-controlled land leveling is an advanced method for precisely leveling the field. It uses equipment, which is controlled in height with reference to a horizontal laser plane created by a rotating laser beam.

There are five major components of a laser-guided land leveling system:

1. The laser transmitter is placed on a tripod on the side of the field. A rotating laser beam creates a horizontal laser plane that serves as a reference for the height. A small slope can be set to control water flow during irrigation and drainage.
2. The drag bucket is pulled by a tractor. It is connected to the tractor’s hydraulic system and adjustable in height through a hydraulic ram that allows vehicles to move vertically.
3. The laser receiver placed on the drag bucket detects the height of the drag bucket with reference to the laser plane and transmits the signal to the control box.
4. The control box receives and processes the signals from the laser receiver and sends electric signals for adjusting the height of the bucket relative to the laser plane to the hydraulic valve.
5. An electrically controlled hydraulic valve located on the drag bucket is connected to the control box. It regulates the flow of the oil of the tractor’s hydraulic system for adjusting the height of the drag bucket.

For surveying the field before and after leveling, a handheld laser receiver and a levelling staff for measuring height are useful accessories.

The advantages of laser-controlled land leveling over conventional land leveling are reduced time and water usage for irrigation; more uniform water distribution; reduced

Figure 2.16. A laser-controlled land leveling set-up in the field

(Photo credit: IRRI)

water consumption during land preparation; precisely leveled and smooth soil surface; and even moisture distribution for crops. This leads to better weed control in the field; a better seedbed resulting in good crop germination and growth; invariant crop maturity; and allows saving seed, fertilizer, chemicals, and fuel.

Laser controlled land leveling can also be used for land consolidation when smaller fields are combined into larger ones. Larger fields, which are more suitable for mechanization and operational efficiency, also increase the farming area. If the field size is increased from 0.1 ha to 0.5 ha, the farming area will also increase by 5 percent–7 percent when the field borders or bunds are removed. When combining fields, which are often terraced, laser-controlled land leveling will give the farmers an option to reshape the farming area efficiently. Mechanized operations in rice production in the consolidated fields will also be reduced by 10 percent–15 percent.

METHODOLOGY

Preparations

Laser leveling includes five operations:

- Surveying the field to determine time required and cost;
- Plowing the field;
- The actual leveling operation;
- Surveying the field to check for accuracy; and
- Maintenance and repair of levees. Check if all equipment is in order before leveling operation.

1. Make sure the laser transmitter and manual receiver are fully charged and with back-up batteries before taking them to the field.
2. Check all electrical connections at the receiver, the control box on the tractor and at the hydraulic valve.
3. Check the hydraulic hoses for secure connection and leakages.
4. Mount the laser transmitter on the tripod and choose a location at the sided of the field where there are no obstructions (e.g., trees, buildings) that could block the laser plane at any position of the tractor in the field. Make sure the laser receiver on the drag bucket will always be exposed to the plane. For example, if the tractor has a cabin, the receiver needs to be mounted higher than the cabin.
5. Check the system in manual mode using the Up and Down buttons. Check in automatic mode.
6. For surveying the land, bring the handheld receiver mounted on the leveling rod and bring pegs, which will serve as markers for the points during land survey. Bring either a tape measure or calibrate your step.

Plowing the field

Before the leveling operation, the field should be plowed from the center of the field going outwards. Plow when the soil is moist. Drier soil requires higher tractor power. Remove surface residues before leveling to assist soil flow from the bucket (Lohan et al. 2014; Chandiramani, Kosina, and Jones 2007).

1. Determine a spot in the field that is on average height.
2. Place the tractor at this spot for starting the leveling operation.

Land survey

To calculate or estimate the amount of soil to be shifted, and to determine the time of the laser leveling operation and thus calculate the cost, the field should be surveyed before the operation. Use the laser transmitter on the tripod and the handheld receiver with levelling staff. It can be done as a separate operation or before the tractor is used. Draw a map of the field and outline the topographic profile by placing height readings in a grid. To determine the mean height, take the sum of all the readings and divide it by the number of readings. The mean height of the field is the starting point of the laser leveling operation. The tractor needs to be set there, and height of the transmitter adjusted that the drag bucket just sits on the ground here. Estimate how to effectively move the soil from high to low points, using a field diagram and the mean height of the field.

Leveling operation

The following are guidelines for field leveling evaluation:

1. Position the tractor with the laser-controlled bucket at a point that represents the mean height of the field.
2. Calibrate the laser plane by either adjusting the height of the transmitter on the tripod or the height of the receiver on the drag bucket, set the cutting blade's height slightly above ground level (1 cm–2 cm).
3. Drive the tractor in a circular direction from the high points to the lower points in the field.
4. When driving to the higher point observe the drag bucket. As soon as it is almost filled with soil, turn and drive toward the lower area to drop the soil there. Work out a feeling for optimal turning point to maximize working efficiency. Note that the drag bucket still collects some soil directly after turning.
5. When the whole field is leveled, you might need to re-calibrate the laser plane height and use the tractor and bucket to do a final leveling from the high end to the lower end of the field.
6. Re-survey the field to make sure the desired level of precision is achieved.

Remember that provided proper land preparation practices, the fields usually don't need to undergo major leveling works for four to eight years, depending on soil type and land field cultivation practices. Advise the customer to do land preparation with ploughs that don't shift the soil sideways.

Maintenance and repair of levee

It is equally important to maintain and repair levees or bunds after land leveling. Levees can be constructed manually or through a bund builder (Figure 2.17). A simple bund builder can be constructed using two discs mounted on a three-point linkage toolbar of a tractor.

Application

Adaptation

Laser-controlled land leveling is considered a resource-conservation technology. It can change the way crops are produced through efficient use of critical inputs without harmful effects on the productivity and resilience of the ecosystem. Laser-controlled land leveling reduces irrigation time by 47 to 69 hours/ha per season and improves yield by about 7 percent, compared with traditional land leveling. In terms of accessibility, small-scale farmers can afford to rent the equipment. Farmers who are members of cooperatives owning the equipment can share the costs. The process duration depends on the amount of soil that needs to be shifted; very unleveled soil takes longer time. Minor leveling can be done once every three years, while major leveling is done once every eight years.

Mitigation

Laser-controlled land leveling may be a simple method, but it can reap massive returns such as increased productivity, conserved water supply, and reduced GHG emission. When the land is evenly leveled, irrigation water reaches every part of the area, with less waste from runoff or waterlogging. Essentially, it is a water-saving technology as it optimizes the use of groundwater to ensure even coverage.

Figure 2.17. Maintenance and repair of levees or bunds is important in land leveling

(Photo credit: IRRI)

Grain drying, grain storage, and grain cooling for postharvest

GRAIN DRYING

Grain drying is a method to remove moisture in the grain for safe storage. The shelf life of dry grain is longer, compared with that of wet grain. Rice is harvested at 20 percent–25 percent moisture content (MC), while it is considered safe for storage at 14 percent MC. High MC is problematic for grain storage because it causes fast deterioration, induces insect and mold infestation, and lowers germination rate. Grain drying is vital in producing high-quality grains and seeds.

Grain drying should be done right after harvesting the grains (within 12 hours to 24 hours after harvest). The duration of viable grain storage depends on the MC. If grains are to be stored longer, the MC should be lower (e.g., 12 percent for several months of storage).

The purpose of storage is to protect the grains from insects, rodents, birds, and molds, as well as to prevent moisture from entering the grains. Improper grain drying and storage leads to high postharvest losses in quality and quantity.

There are two methods of grain drying: the traditional methods and the mechanical drying method. Sun drying is the traditional way of removing moisture in the grains. Different methods of sun drying are practiced by rural farmers. Drying unthreshed grains in the field is not recommended due to poor air circulation, risk of rain flooding, and uneven drying of grains, which may lead to fast deterioration. Canvas drying is the cleanest method of sun drying because grains can be easily mixed and collected and are protected from microorganism and moisture from the ground. However, it requires investment in the canvas. The most commonly used method of sun drying is pavement drying. It is usually observed in rural communities and at smaller rice mills and traders. With this method, however, grain losses are high because the grains can easily mix with dirt and stones and the grains are more prone to contamination and breakage caused by animals and vehicles.

Mechanical drying removes moisture from wet grains by blowing heated air either over or through the grain bulk. It is done until all grains have the desired MC. Its main advantage over the traditional sun drying is that since the heat and airflow are controlled, it can be done day or night under any weather condition. Other advantages are more even drying of the grains resulting in higher head rice recovery and milling yield, and reduced labor requirement.

Solar bubble dryer

The first example of a mechanical dryer suitable for CRA is the solar bubble dryer (SBD). The SBD (Figure 2.18) is a drying technology developed by IRRI, Hohenheim University, and GrainPro Inc. It is mobile and does not use fuel or electricity from the power grid, which results in very low operating cost. SBD comes in different sizes and models that have 0.5 t or 1 t batch capacity.

The SBD utilizes solar energy in two ways. First, the sun rays enter the transparent top of the drying tunnel and are then converted into thermal energy. This thermal solar energy is used to increase the temperature of the drying air for faster drying. Second, solar energy is used to move air in the drying tunnel, inflate the tunnel, and remove evaporated water from the grains using a small blower. For this purpose, the SBD has a photovoltaic system consisting of a solar panel, a deep cycle rechargeable battery, and a controller for generating the electricity for the blower. A simple roller running underneath the drying tunnel is used for mixing grains without the need to open the tunnel. Alternatively, internal mixing can be done with a rake. The SBD improves head rice coverage by buffering temperature and protecting the grains from overheating, a common result of sun drying at noon. It eliminates losses caused by spillage, animals, and vehicles and eliminates re-wetting of grains during rain.

Weather condition and initial MC determine the drying rate of grains. On drier conditions, it takes a day to reach 14 percent grain MC. Drying of wetter grains during cold weather might take two days. When the relative humidity is high, the tunnel should be kept inflated so that the grains can be kept safely inside the SBD.

Compared with other mechanical dryers, the SBD is more flexible. It requires low operating cost and uses only solar energy to heat the air and run the blower.

Heated air dryer with biomass furnace

The second example of a mechanical dryer suitable for CRA is a heated air dryer, equipped with a biomass furnace for heating the drying air. In this case, it is a Flat-Bed Dryer (FBD) (Figure 2.19). The FBD consists of a drying bin, a blower and an air distribution system that leads the drying air evenly through the grain bulk, and a heat source for heating the drying air to around 43°C or 10°C–15°C above ambient temperature in typical tropical environments. Drying bin capacity can be anywhere between 1 t and 20 t per batch, due to economics of scale the minimum batch size to break even is around 4 t. The drying rate in a well-designed flat-bed dryer is 1 percent–1.5 percent per hour, and with an air velocity of 0.2 m/s through the grain bulk and a bulk depth limited to 0.3 m–0.4 m, the moisture gradient from top to bottom at the end of drying is minimized and mixing the grains during operation of the dryer is not necessary.

Only FBD, equipped with biomass furnaces, have been commercially successful due to their low operating cost compared to fossil-fuel-fired dryers. Another advantage of a rice husk furnace is that the operation is almost carbon neutral. The CO_2 released during the operation was previously accumulated by the rice plant from the atmosphere. Only a small amount of electricity is needed to power the blower and a small electronic controller of the furnace if the semi-automatic Downdraft Rice Husk Furnace (developed

Figure 2.18. Solar bubble dryer is a drying technology developed by IRRI, Hohenheim University, and GrainPro

(Photo credit: GrainPro Philippines, Inc.)

by IRRI, the University of Hohenheim, Germany, and Nong Lam University in Vietnam) is used. The furnace is characterized by low labor requirement, constant feed rate leading to even and clean burning with minimal CO_2 emissions, and high furnace efficiency. Fuel consumption is around 6 kg rice husk per hour per ton capacity.

Dryers and sustainable rice production

Sun drying does not require a machine or fuel, so one will probably assume that it has lower GHG emission compared with mechanical drying. This assumption, however, is misleading. The losses caused by sun drying are usually higher than losses from mechanical drying, and producing those grains lost also consumes inputs and energy and, thus, cause GHG emissions. Life cycle assessment done by IRRI shows that in terms of GHG emissions, the SBD performs much better than sun drying and any heated air dryer, mostly because it does not generate any emissions during operation. The emissions created during the production of the SBD are smaller than the ones created by losses that occur in sun drying. The SBD is, therefore, a climate-resilient technology. Compared to other mechanical dryers that are fired with fossil fuel, FBD equipped with biomass (rice husk) furnace can also be considered a climate-resilient technology. GHG emissions caused by operation of the blower and manufacturing the dryer are compensated by the reduced emissions from loss reduction.

GRAIN STORAGE

Grain storage is essential in postharvest rice production. It is recommended to store grains in rough rice form rather than in milled form that is used for human consumption. In rough rice form, the husks protect the grains from insects and molds while preserving quality.

Figure 2.19. FBD with 4 t capacity and simple inclined grate rice husk furnace in Myanmar (L); Semi-automatic downdraft rice husk furnace (R)

(Photo credit: Martin Gummert, IRRI)

A good storage system must protect the product from moisture, which may re-enter the grain after drying. It must be properly constructed to prevent insect, rodent, and bird infestation. A good storage system must be easy to load or unload and must be efficient in terms of space requirement. Lastly, it must be easy to manage and maintain.

Safe storage of rice for longer periods is possible if these conditions are met:

- The grain for storing should have 14 percent moisture or less, and the seed 12 percent or less.
- Grain is protected from insects, rodents, and birds.
- Grain is protected from rewetting by rain, or from absorbing moisture from the surrounding air.

The longer the grain needs to be stored, the lower its MC should be. Grain and seed stored at MCs above 14 percent could experience the growth of molds, rapid loss of viability, and reduction in eating quality. Table 2.5 shows the safe moisture content required for different storage periods in the tropics.

In tropical countries such as the Philippines, humidity and temperature are relatively high. These factors contribute to increasing MC, which means that open storage is not suitable. It is safer to store grains in closed and sealed storage. This type of closed storage is called hermetic grain storage.

Hermetic grain storage

Hermetic grain storage is an airtight and pesticide-free means of storing grains and other dry commodities (Figure 2.20). It is effective in controlling grain MC and pest activity for stored grains and is particularly suitable for tropical regions with high average ambient air humidity.

Table 2.5. Moisture content required for safe storage and for different storage periods

Storage Period	Required MC for Safe Storage	Potential Problems
Weeks to a few months	14% or less	Molds, discoloration, respiration loss, insect damage
8 to 12 months	13% or less	Insect damage
More than 1 year	9% or less	Loss of viability

Insects, rodents, birds, and molds can cause storage losses of up to 25 percent in humid countries. In addition, use of large metal or concrete silos in temperate climates works poorly because of moisture and condensation incidence, which makes longer-duration storage impossible. With hermetic grain storage, MC is maintained, and low oxygen atmosphere inhibits pest damages. It also preserves the germination property in seeds. Humid countries such as the Philippines, Rwanda, Ghana, and Sri Lanka store grains using this method.

The MC of stored grains remains the same once an airtight barrier is placed between the grains and outside atmosphere in closed storage. The rapid reduction of oxygen inside the sealed container will prevent insects from multiplying. The oxygen level in the sealed container is reduced to 5 percent–10 percent, enough to halt insect activity. It is observed that hermetic grain storage increases seed viability by 6 to12 months and increase rice yields by 10 percent.

Hermetic grain storage ranges from 3 liters to 1,000 t in size. It can be used to store rough rice, brown rice, corn, coffee, and other dry commodities. Hermetic grain storage systems are made from specially designed containers such as the commercially available Cocoon™ and GrainSafe™. IRRI also co-developed the locally available and affordable super bags (50 kg) for farmers and seed producers. In rural settings, locally available containers can be easily converted into hermetic grain storage at a low cost.

For storage of small seed lots, a variety of plastic bags or packages can be used. Glass jars, hard PVC, or bags containing aluminum liners, or a gas barrier will provide very good protection against moisture re-entry.

When using hermetic storage system:

1. Follow the guidelines. Set up the hermetic system as recommended by the manufacturer. Make sure the plastic enclosure is tight and without folds so that rodents cannot sharpen their teeth and damage the liner.
2. Seal the hermetic system properly.
3. Monitor oxygen in large systems (e.g. Cocoons™)
    - During the first days, until the oxygen level has dropped to 10 percent (better if below 5%), measure the oxygen level daily.
    - When the oxygen level has stabilized, measure weekly to monitor whether the system remains sealed. If the oxygen increases, check the system for damages.

Figure 2.20. Hermetic grain storage in a Cocoon™, an airtight and pesticide-free method of storing grains and other dry commodities

(Photo credit: IRRI-RKB)

4. Do not open the hermetic storage for sampling. Opening would bring oxygen into the system and since all insects are already dead, the oxygen will drop very slowly after re-sealing. Open the system only once storage is completed.
5. Prevent mechanical damage. Instruct workers not to smoke around hermetic storage system. Do not use hooks to handle super bags.
6. Shade the system, if the storage is to be set up outdoors and exposed to the sun, e.g. by using the provided GrainShade™ for the Cocoons™.
7. Store empty systems properly. Put empty systems in the storage bag that comes with it to prevent damage by rodents.

Grain cooling

Safe storage time can be greatly extended by cooling the grain. Grain cooling should not be confused with cold storage. In cold storage, the cooling system runs permanently, thus creating very high storage cost. Grain cooling is usually done by forcing cold air through a grain bulk contained in a silo and, when the bulk is cooled to the desire temperature, the cooling is stopped. Mobile grain coolers are available for this purpose. A grain bulk with its inter-granular air space is a good insulator, so once cooled down and once the blower is stopped and the silo sealed, the grain bulk will stay cool for a long time. Grain cooling inhibits insects, prevents fungal growth, and minimizes grain respiration. It is ideal in order to maintain quality and minimize physical loss.

In addition, the cooling process reduces around 0.75 percent moisture in the grains, so drying can be stopped earlier, reducing the drying cost. One grain cooling unit can be used for several silos. Generally, grain cooling becomes economically feasible at storage capacities of 600 t or more. Repeated cooling might be required after several months.

METHODOLOGY

A precondition for minimizing losses and maximizing quality in postharvest operations is harvesting at the right time. Harvesting too early will result in a lot of immature grains and thus reduced yields. Late harvesting will result in fissuring of grains in the field caused by re-wetting of dry grains at night or during rain and thus to reduced head rice recovery. An overmatured crop also leads to more shattering increasing losses. All losses translate into unnecessary GHG emissions created by manufacturing and applying the farm inputs used for producing those lost grains.

Drying

For optimum drying results and minimized energy requirement or emission:

Before drying

1. Before drying clean the grain thoroughly using a grain cleaner or a winnower to remove unfilled grains, straw and leaves, dockage, and insects. This improves airflow and leads to lower energy requirement.
2. Avoid loading batches of grain with different moisture content sequentially. Mix them first before loading the dryer, or better dry them separately.
3. Load and spread the grains evenly. In an overflow dryer like the SBD or in sun drying do not exceed 4 cm grain depth. In FBD, do not exceed 30 cm–40 cm. Level the surface carefully.

During drying

1. Start the dryer. In a heated air dryer set the temperature to not more than 43°C. If the rough rice is exposed to 60°C for an hour, the seed germination rate will be reduced from 95 percent to 30 percent, while two hours will reduce it by 5 percent.
2. Monitor temperature at least hourly and re-adjust if necessary. Lower temperature increases drying time but does not affect grain quality negatively. Higher temperature increases the moisture gradient at the end of drying and can cause more broken grains in the final phase of drying at lower grain MC.
3. Monitor moisture content at least hourly. Towards the end of drying take samples from the bottom and the top of the grain bulk.

4. A properly designed FBD does not require mixing the grains. In the SBD, it is necessary to mix every hour or every 30 minutes using the mixing device provided with the unit.
5. Stop the dryer when the final average grain MC 14 percent or lower, depending on your anticipated storage time.
6. Some flat-bed dryer owners claim that they get better grain quality if they keep the blower running without the furnace to cool down the grains for half an hour. This extends drying time and increases fuel consumption and production cost
7. Unload the dryer and store the grains safely.
8. Clean the dryer thoroughly after the last batch

Storage (Hermetic storage)

Before storage

1. Check your hermetic storage equipment for damages (e.g., visual inspection and inflate it and observe whether it losses air after sealing).
2. Clean the storage area and remove any sharp objects from the ground.
3. Check the rodent control measures.
4. Check the calibration of the oxygen meter, if any. (Is the sensor still good?)
5. Dry the grains or seeds properly to less than 14 percent MC. Make sure they are cleaned. If not, clean them.

Setting up the storage system

1. Load the hermetic storage container as per instructions found in the owner's manual
2. Remove the excess air, then seal the container. Refer to the owner's manual on how to do this properly.
3. If the storage system is set up outside, shade it to avoid condensation after the sun shone on it. Use shading devices included in the product like the GrainShade™ for Cocoons ™ or construct your own shade

During storage

1. For Cocoons™, GrainSafe™, and other large hermetic storage containers, initially check the oxygen level daily until it has dropped and stabilized. If it does not drop, or if oxygen level increases, check the system for leaks or damages.

2. Check the Super bags visually without opening them on a regular basis for damage and for life insects inside. If damage or insects are found, identify the leak, repair or use a new bag.

3. Never open a hermetic system for sampling or re-drying. This will disturb the modified atmosphere and since most insects are dead, the oxygen that has re-entered the system will not be consumed easily. Open the system only when the grains or seeds are ready to be used.

After storage

1. Before unloading, measure the oxygen again to see whether the system is still undamaged.
2. Open and unload the grains.
3. Clean and store the hermetic storage system in the storage bag or in the container provided by the supplier. Store the bag in a safe place to avoid damage by rodents.

Storage (Non-hermetic storage)

Good hygiene in the grain store or storage depot is important in maintaining grain and seed quality. Guidelines for hygiene in the grain store include the following:

1. Store grain at low MC.
2. Make sure the grain is properly cleaned.
3. Keep storage areas clean. Sweep the floor, remove cobwebs and dust, and collect and remove any grain spills.
4. Store grain bags in tidy stacks set up on pallets, ensuring that there is a one-meter space around the stack. Maintain pathways around grain lots for easy inspection and control. Don’t store bags on rice husk.
5. Clean storage rooms after they are emptied. This includes spraying walls, crevices, and wooden pallets with an insecticide before using them again.
6. Store any empty or old bags and fumigation sheets on pallets, and, if possible, in separate stores.

Grain cooling

Grain cooling equipment is an addition to a silo or a warehouse. Both must be equipped with aeration facilities.

1. Clean the silo or warehouse before filling it with new grains.
2. Dry the grains to around 0.7 percent–1 percent above the desired final storage moisture content.
3. Load the silo.
4. Attach the grain cooler and start operating it
5. Finish cooling when the temperature at around 20 cm below the top surface reaches around 2°K–4°K above the air temperature at the grain cooler outlet. The cooling process must not be stopped too early or it may cause serious problems in the upper area of the grain bulk.

6. A cooling cycle may only be interrupted for a short period of time such as to prioritize another endangered lot. Once the interrupted cooling cycle is resumed, the cooling must be continued at the same set of temperature values.
7. After the cooling cycle is completed, all openings and connections must be closed.
8. The temperature of the bulk of grain must be checked regularly. If the temperature becomes too high, re-cooling will be necessary.

APPLICATION

Adaptation

Grain drying and storage work hand in hand to improve the shelf life of grains and the germination rate of seeds. By drying and properly storing, postharvest losses are reduced, and more grains are ready for human consumption and market distribution. This way, meager production and food insecurity will be avoided while quality and marketability of grains are improved. This promotes higher income for farmers. Properly dried and stored seeds can increase seed germination and seed viability, which means that fewer seeds are used per hectare.

Mechanical dryers and hermetic storage also help farmers and processors adapt to changing weather conditions caused by climate change since they allow weather independent operation. The hermetic storage systems also protect grains in case of floods.

Mitigation

The solar bubble dryer does not use any fuel to operate. It only utilizes solar energy to dry grains, which makes it suitable for CRA. Heated air dryers equipped with biomass (rice husk furnaces) have much lower GHG emissions than dryers that use fossil fuel and can therefore also be considered climate-smart. Meanwhile, hermetic grain storage is a practical and environment-friendly technology because it prevents pesticide and fumigant usage during storage. The system automatically inhibits pest infestation because storage is airtight and sealed. It protects farmers and consumers from the associated risks of chemicals and other toxic materials. The storage comes in many forms (e.g., small grain bag, bulk container), which is convenient for farmers.

Approaches

PalayCheck system. The *Palay*Check System is a rice integrated crop management (RICM) system that applies the principles of seed quality, land preparation, crop establishment, nutrient management, water management, pest management, and harvest management (Figure 2.21). It envisions that yield improvements should be developed and transferred to farmers as an integrated package rather than by components (e.g., integrated nutrient management or integrated pest management).

It showcases the best technology and management practices in the form of Key Checks, which guide farmers on what to achieve, how to assess the Key Checks, and how to achieve the Key Checks. This aids the farmers to learn from their experiences in the field while improving their crop management practices. *Palay*Check encourages farmers to measure crop performance and to analyze results in order to set yield targets.

The *Palay*Check system compares farmers' practices with the best practices through focus group discussions, which are helpful in sustaining productivity improvement, high profitability, and environment safety.

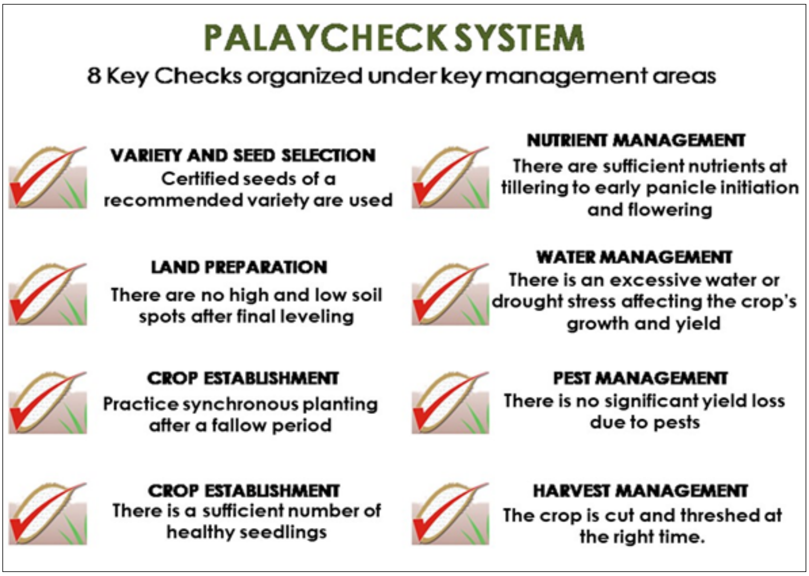
There are four principles in the *Palay*Check system:

Principle 1. A holistic rice integrated crop management comprises interdependent and interrelated management methods and practices that have the same impact on yield, grain quality, and environmental outcome.

Principle 2. The inputs (e.g., practices and methods) must attain the optimum level of outputs (e.g., results from the applied practices and methods) at all stages of growth and areas of management, to achieve the optimum outcome (e.g., impact on yield, quality, profitability, and environment). *Palay*Check offers recommendations for optimizing inputs and outputs, which can be revised depending on new findings and field experiences.

Principle 3. Key checks are considered the key outputs that determine yield, profit, grain quality, and environmental outcomes.

Figure 2.21. *Palay*Check is an RICM system that offers yield improvement to farmers



PALAYCHECK SYSTEM

8 Key Checks organized under key management areas

VARIETY AND SEED SELECTION
Certified seeds of a recommended variety are used

NUTRIENT MANAGEMENT
There are sufficient nutrients at tillering to early panicle initiation and flowering

LAND PREPARATION
There are no high and low soil spots after final leveling

WATER MANAGEMENT
There is an excessive water or drought stress affecting the crop's growth and yield

CROP ESTABLISHMENT
Practice synchronous planting after a fallow period

PEST MANAGEMENT
There is no significant yield loss due to pests

CROP ESTABLISHMENT
There is a sufficient number of healthy seedlings

HARVEST MANAGEMENT
The crop is cut and threshed at the right time.

(Photo credit: IRRI-RKB, PhilRice)

Principle 4. *Palay*Check promotes experiential group learning. Farmers must assess themselves through analyses of strengths (practices that contribute to outcome improvement) and weaknesses (practices that limit outcome improvement). By doing so, they can make a strategic plan to maximize their strengths and address their weaknesses. Experiential group learning promotes collaborative learning among farmers and between farmers and resource persons. It is also conducive for hands-on, shared, and guided learning.

METHODOLOGY

Selected sites will consist of *Palay*Check demonstration fields that are owned by farmer-partners. Participants in a *Palay*Check group are 15 to 25 rice farmer-partners who belong to a specific community or neighborhood. A group of selected rice farmer-partners and one resource person or facilitator will oversee the application and management of recommended practices for each demo field. The demo field should be at least 0.5 ha, located along the road, within a non-technology intervened field, and near the meeting area of the farmers.

To ensure that the recommended practices are followed, inputs such as seed variants and fertilizers may be provided. The demo field will serve as the basis for the evaluation of the strengths and weaknesses of farmers' management. It will also be the basis for determining necessary adjustments for yield and profit improvement. Farmer-cooperators (neighboring members of the farmers' group) have the option to adopt or not to adopt the *Palay*Check recommendations.

The groups of farmer-partners must meet before, during, and after the cropping season to discuss and review management practices, pest incidence, growth and yield results, and weather conditions. The groups must record activities and results from the *Palay*Check demo fields and farmers-cooperators' fields. Comparisons between *Palay*Check demo fields and farmer-cooperators' fields must be noted. Lastly, the groups must identify factors that contributed to the achievement of the Key Checks, as well as factors that hindered it.

Evaluation of identified management practices, achievement, and non-achievement of Key Checks, and yield results should be done per site. Results should be presented at the last meeting, which is after the harvest. Achievement of Key Checks and yield results per farmer-partner and farmer-cooperator should be analyzed and interpreted.

The learning process through the *Palay*Check system should be highlighted since learning takes place before, during, and after each planting season. Through the indicators from the achieved Key Checks, farmers can compare their actual performance with the projected outputs (yield, quality, and environmental outcomes). However, it should be noted that limited resources can hinder the adoption of *Palay*Check recommendations. Therefore, the identified success and failure factors should be addressed and improved in the coming seasons.

The following are the key features of implementing the *Palay*Check system:

- Key technologies and practices are packaged as Key Checks.
- Comparison of crop management practices, yield and crop quality, and profit to farmer-cooperators can stimulate the farmer-partners in identifying rice-farming problems, demonstrate Key Checks, and learn the *Palay*Check system thoroughly.
- Using Key Checks, farmers can be taught to evaluate and improve their current crop management practices.
- Monitoring and documenting management inputs and Key Check achievements per stage are essential.
- Farmers should be aided in assessing the Key Checks and in identifying reasons for achieving and not achieving them.

Application

Adaptation

Through the assessment and evaluation of Key Checks, the identified best practices can be adapted for the next cropping seasons. Productivity improvement, high profitability, and environment safety are considered in selecting the positive attributions of the Key Checks. Resilience to climate change can be built by improving and replicating these best practices.

Mitigation

Land preparation and nutrient management are among the principles covered in RICM. Land preparation and nutrient management that take into consideration the reduction of GHG emissions are considered as mitigation strategies.

Rice straw management. Rice straws are rice by-products when harvesting. Each kilogram of milled rice can yield 0.7 kg–1.4 kg of rice straw depending on the variety. Rice straws are considered agricultural wastes. Farmers usually burn them or leave them in the field until the next planting season. However, this practice greatly contributes to environmental degradation. Various rice straw management techniques have been developed to convert or use agricultural wastes for farming and household purposes.

Methodology

Straw as livestock feed

In Southeast Asia, rice straw as livestock feed is common. For ruminants, the maximum intake of rice straw on a daily basis is about 1 kg–1.2 kg per 100 kg live weight.

Rice straw is utilized as livestock feed and is enhanced by adding nutrient supplements (Figure 2.22). The stems of the rice straw are more digestible than the leaves because they contain lower silica (Drake et al. 2002). Leaves from rice straw are considered as poor feed for animals because of their high silica content (Singh and Sidhu 2014). If the rice straw is to be fed to livestock, the rice crop should be cut close to the ground for more stem parts. However, raw and non-supplemented rice straw have low essential nutrients for growing cattle. Nutrient supplements such as urea can be added to rice straws. Urea is safer and more practical to use than anhydrous or aqueous ammonia. Treating the rice straw with sodium hydroxide or ammonia can also improve digestibility of the cellulose.

Mushroom production using rice straw

Mushroom production is a profitable and low-cost agri-business endeavor that uses agricultural wastes as culture medium. It facilitates proper disposal of by-products and provides extra livelihood for farmers. Mushroom culture takes up less space compared to livestock raising or crop production and requires minimum investment cost.

In humid tropical regions, paddy straw mushroom (*Volvariella volvacea*) thrives well in dry areas, while oyster mushroom (*Pleurotus* sp.) can be successfully raised in the cold season. Paddy straw mushroom is easy to cultivate because of its short incubation period (Figure 2.23). Mushroom culture using rice straw can increase yield of about 5 percent–10 percent (Zhang et al. 2002; Ngo 2011).

Steps in growing Volvariella volvacea (paddy straw mushroom) on outdoor beds

1. Prepare the mushroom bed either directly on the soil or on a concrete floor with bamboo or lumber, which acts as a support for the concrete floor to provide enough space underneath.
2. Sun-dry the freshly cut rice straws before bundling with abaca fiber. Cut the end of each bundle evenly.
3. Soak all the rice bundles in water overnight.
4. Place spawn every 4-inch apart and 2 to 3 inches from the end of each bundle.
5. Continue to arrange the bundles and inoculate spawns in each layer accordingly.
6. To avoid overheating inside the bed during summer, place approximately two bottles of spawns for every meter row in 4 to 5 layers. Using a plastic or sack, cover the bed to prevent moisture loss and heat production inside the bed. Do not put the bed directly under the sun.
7. After 10 to 15 days, mushrooms are ready to harvest. Pick the mushrooms by hand before they are completely open.

Figure 2.22. Rice straws are utilized as an alternative livestock feed to promote a more sustainable approach to agricultural waste management

(Photo credit: ZM Estareja)

Steps in growing Pleurotus sp. (oyster mushroom)

1. Compost rice straws with supplements for seven days.
2. Pack the composted rice straws in heat-resistant bags and seal with cotton plugs.
3. Sterilize the bags by steaming them for two to four hours. Allow them to cool.
4. Inoculate spawns into each bag.
5. Incubate the bags for at least a month or until molds spread throughout the substrate.
6. In the cropping room with 20°C–28°C temperature, open the bags for the mushroom to shoot, which will take three to six days. One bag should yield one-fourth the weight of the bag.

Rice straw for papermaking

The feasibility of rice straw as a material for making paper is highly disputed when compared with wood. However, the ecological soundness of using rice straw is forwarded as an alternative in papermaking. High-quality paper made from rice straw is now being exported by the Philippines. The rice straw paper-making business provides a viable livelihood option to many Filipinos.

Figure 2.23. Paddy straw mushroom (*Volvariella volvacea*) using rice straw as culture medium

(Photo credit: IRRI-RKB)

Steps in making rice straw paper

1. Cut the rice straw into 5 cm–7 cm length; wash with running water.
2. Boil the rice straw in 2 percent sodium hydroxide solution using a solution-to-rice straw ratio of 10:1 for two to three hours, or until rice straw becomes soft.
3. Drain the rice straw immediately after boiling and wash thoroughly with water.
4. Pound the rice straw with a wooden mallet. Screen the rice straw pulp using a double-decked screen-bottom box (20-mesh screen placed on top of a 100-mesh screen) under high-pressure water.
5. Bleach the rice straw pulp in a solution of 10 percent bleach and 90 percent water for 15 minutes.
6. Allow the rice straw pulp to swell in water for 30 minutes. Drain the rice straw pulp and form the rice straw pulp into balls.
7. Pound the balls with a wooden mallet to make the rice straw pulp finer. Transfer the fine pulp into the paper vat.
8. Add water to the fine pulp. To make slurry based on desired consistency, add more water for thin paper and put less water for thick paper.
9. Add rosin size (1%) to alum (2%) to make a solution. Pour the solution into the paper vat to mix with slurry.
10. Start sheet forming by dipping the mould (a fine screen that strains the fine pulp) and deckle (a wooden frame that confines the fine pulp) into the paper vat to catch an amount of slurry.

11. Tilt the mould and deckle back and forth and throw excess slurry into the paper vat. Shake the mould and deckle; tilt them back and forth again until most of the water goes through the screen.
12. Separate the mould from deckle and lay it on cheesecloth. Cover the mould with another piece of cheesecloth.
13. Press the covered mould with a roller, then separate the mould slowly from the sheet.
14. Lay the sheet on a plan galvanized iron. Cover it again with cheesecloth and press it four times with a roller.
15. Remove the cheesecloth and hang the sheet to dry.

APPLICATION

Adaptation

Farmers are learning to utilize agricultural wastes to develop innovative products. Using rice straw as an alternative livestock feed is cost-efficient. In mushroom production and papermaking, the farmers are given opportunities to earn extra income even after the cropping season. The resilience brought by proper rice straw management is essential for the farmers because they learn to make use of available and potential materials while improving their productivity.

Mitigation

Farmers are becoming aware of the harmful effects of rice straw burning. Rice straw burning also contributes to grassfires during hot seasons. To mitigate this, various methods of rice straw management are being adopted by the community benefitting both the community and the environment.

RAINFED LOWLAND

Technologies

Stress-tolerant varieties of corn in rainfed lowland. The production capacity of corn in irrigated systems in South Asia and Southeast Asia is closed to saturation. About 80 percent of the total corn production is produced in rainfed areas (Figure 2.24). Thus, productivity in rainfed areas must play a greater role in meeting the increasing demand for corn. The erratic distribution pattern of monsoon rains has caused low yields of rainfed corn. Erratic rainfall patterns may cause severe drought or waterlog in a single crop season. The development of stress-tolerant corn varieties is timely and urgently needed to address the low productivity yield of corn in rainfed areas.

The International Maize and Wheat Improvement Center implemented a project entitled *Abiotic Stress-Tolerant Maize for Increasing Income and Food Security Among the Poor in*

South and Southeast Asia. This project aims to develop open-pollinated varieties (OPVs) and hybrid corn varieties that are drought and waterlogging-tolerant, to enhance yield productivity in rainfed areas.

METHODOLOGY

The project consists of four major components. The project continuously develops new corn hybrids and OPVs with relatively higher tolerance to drought and waterlogging. Mapping of quantitative trait loci (QTL) that affect waterlogging tolerance has been done to facilitate the marker-assisted selection. New hybrid varieties and OPVs have been evaluated in stress-prone sites by Asian regional rainfed corn testing and the germplasm exchange network in Bangladesh, India, Philippines, and Vietnam. The socioeconomic and cultural determinants of hybrid varieties and OPV adoption and risk-mitigating impacts of available technologies in rainfed corn production have been analyzed.

The top two-hybrid corn varieties, TNAU-CO6, and BIO-9544 have been identified as water stress-tolerant in several sites. The Indian corn program recommended these hybrid varieties for release to India’s stress-prone rainfed areas intended for corn production.

Figure 2.24. Corn production using stress-tolerant corn varieties in rainfed lowland

(Photo credit: RVLabios)

There are new lines of hybrid varieties derived from either drought- or waterlogging-tolerant populations (85 from backcross populations and 144 from biparental populations). These lines are to be tested with new hybrid combinations in stress-prone environments in South and Southeast Asia.

Application

Adaptation

The project seeks to build resilience in marginalized farming families living in stress-prone areas in South Asia and Southeast Asia. By providing stress-tolerant hybrid corn varieties, smallholder farmers will be able to cope with the erratic pattern of monsoon rains in rainfed areas. The developed varieties are expected to produce respectable yields and will be useful for crop diversification and intensification.

Mitigation

The development of stress-tolerant corn varieties mitigates the impact brought about by low productivity yield in rainfed areas due to the erratic pattern of monsoon rains in the regions.

Alternate wetting and drying (AWD) using pump irrigation. Controlled irrigation is used to increase efficiency of farm inputs and at the same time conserve water especially during the dry season (Figure 2.25). The field is alternately flooded and non-flooded when irrigation water is applied a few days after unavailability of ponded water. The right timing of irrigation is observed when executing safe AWD during the crop's growth period.

AWD reduces water consumption in rice production by 16 percent–35 percent without affecting yield. An average of 20 percent of water saving can be attained in both deep well and shallow tube well system. AWD aids in proper seed germination, seedling survival, tillering, and grain uniformity. It helps in optimizing soil nutrients and applied fertilizers. Alternate flooding and non-flooding of the field helps keep a good balance of available soil nutrients and stabilizes soil and plant base, which reduces crop lodging. Controlled irrigation minimizes weed growth and golden apple snail infestation. AWD lessens use of farm inputs such as oil, fuel, and labor, and significantly decreases costs in pump-irrigated areas.

AWD is favorable in areas with supplemental irrigation, such as small water impounding, small farm reservoir, and pump irrigation system (e.g., shallow tube well and deep well).

Figure 2.25. AWD using pump irrigation in rainfed lowland helps in reducing water consumption without affecting crop yield

(Photo credit: IRRI-RKB, PhilRice)

METHODOLOGY

In implementing controlled irrigation, the following should be considered:

Planting method

- Transplanting is a common method used during the wet season and in areas with limited water.
- Direct seeding, especially dry seeding, consumes less water.

Planting season

- Supplemental irrigation is critical since more water input is needed.
- Less frequent irrigation is needed.

Type and texture of soil

- Fine-textured soil has longer water retention capabilities of 3 to 5 days at 5 cm initial depth. Irrigation is less frequent.

- Medium- to coarse-textured soil retains pond water for less than 12 hours. Irrigation is more frequent. It is important to note that pond-water depth should be at 2 cm–3 cm during irrigation.

The textural classification of soil can be determined by simply moistening soil samples and rubbing them between the thumb and fingers. The soil is fine-textured when the sample is sticky, cohesive, and forms ribbons when pressed and rubbed (e.g., clay, clay loam, and silty or sandy clay loam). The soil is medium- to coarse-textured when the sample is less cohesive, gritty, and does not form ribbons when pressed and rubbed (e.g., loam, silt loam, and sandy loam).

Application

Adaptation

AWD is a water-saving technology that offers a way of changing traditional practices to improve production and livelihood of rice farmers. It is an adaptation measure for water scarcity without affecting rice yield.

Mitigation

AWD has been proven to reduce methane emissions. Methanogenic bacteria produce methane, a GHG that thrives well in rice fields. Flooded rice fields are the second largest anthropogenic source of methane emission, next to ruminant livestock. AWD can reduce methane emission up to 50 percent because periodic aeration in soil restrains methanogenic bacteria from producing methane (Siopongco et al. 2013).

Site-specific nutrient management for corn after rice. In a study conducted by Gerpacio et al. (2004), three sites in Mindoro Occidental were surveyed to represent the rainfed lowland agro-ecozone where corn is cultivated after lowland rice. Corn is preferred as “relay crop” for its assured commercial value. Corn cultivation is done toward the end of the rainy season and before the onset of dry season. The sites are favorable for corn production since the condition is neither too wet nor too dry. Corn cropping is totally dependent on rainfall because only a few farmers own pump irrigations. The wide-scale adoption of hybrid corn varieties is a cropping trend in the province.

Land preparation across the sites consists of one to two plowing to level the field and reduce soil clods. Soil moisture condition dictates the timing of plowing. The first plowing is done right after harvesting the previous crops, to incorporate the residue in the soil. The field is plowed once and harrowed twice to the prepared land for the dry-season corn crop after the rice cropping. Sowing and basal fertilizer applications are done immediately after furrowing.

Site-specific nutrient management (SSNM) was first developed in irrigated rice production in Asia (Dobermann et al. 2002; Witt et al. 2007; IRRI 2008; Ocampo et al. 2015). The concept of SSNM is to adjust fertilizer application (right time, right place, right rate, and right source of nutrients) to fill the deficiency between nutrient needs of a high-yielding crop and the nutrient supply from indigenous sources (e.g., soil, crop residue, and irrigation water) (Figure 2.26). It is the sufficient and efficient use of fertilizers N, P, and K in filling nutrient deficiency, to prevent depletion of soil nutrient supply. SSNM for rice has been adopted by national programs and R&D initiatives in the Philippines.

To follow the SSNM strategy for rice, the principles of SSNM for corn production were developed through a series of researcher-managed on-farm and on-station experiments, taking into account the wide range of biophysical and socioeconomic conditions in the Philippines (Pasuquin et al. 2014; Ocampo et al. 2015).

Methodology

Attainable yield and yield responses estimation in farmers' fields

The required fertilizers N, P, and K for corn are calculated based on the difference between attainable yield and nutrient-limited, yield where the difference is called yield response. Yield response can be measured using the nutrient omission plot technique, where the farmer's field is placed with 36 m^2 plots with the following treatments:

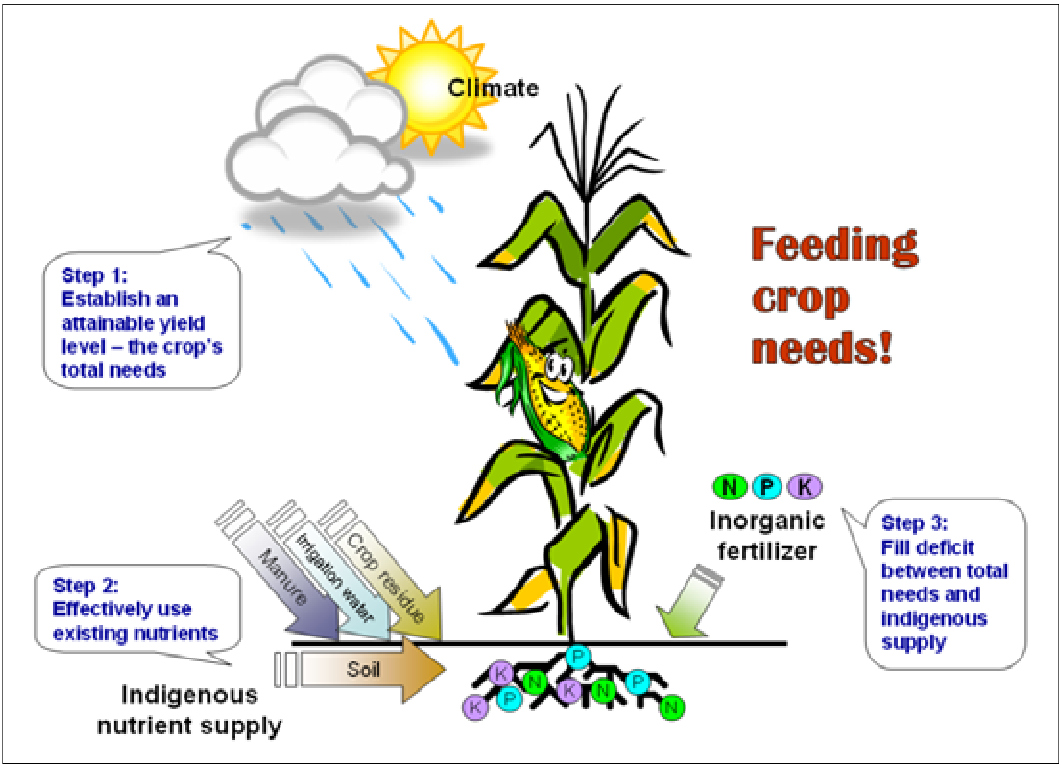
- Full fertilization: ample fertilizers N, P, and K applied
- 0 fertilizer N, fertilizers P and K applied
- 0 fertilizer P, fertilizers N and K applied
- 0 fertilizer K, fertilizers N and P applied

Special fertilizer recommendation rates and splitting patterns are recommended to avoid nutrient limitation during plant growth.

In the fully fertilized plot, also called NPK, sufficiently high rates of N, P, K are applied to ensure that yield is not nutrient deficient. Rates typically range from 150 kg N/ha to 250 kg N/ha, 70 kg P_2O_5/ha to 150 kg P_2O_5/ha, and 60 kg K_2O/ha to 180 kg K_2O/ha. Given that nutrient supply is ample and good crop management is practiced, grain yield in NPK plots is used to estimate attainable yield. Meanwhile, nutrient-limited yields are determined from the nutrient omission plots. For example, N-limited yield is identified in N omission plots meaning no fertilizer N is applied but with sufficient P and K to make sure that yield is not affected.

Fertilizer N can be applied in two splits, with 40 percent in the early season and the rest, before tasselling stage. Split application can be done in rainfed systems with erratic

Figure 2.26. SSNM process for corn production



(Photo credit: IPNI)

rainfall and where expected yield response to N is <3 t/ha. All fertilizer P is given at crop establishment, while fertilizer K is equally split for crop establishment and V10–V12.[3]

SSNM tailored guidelines using experimental data from farmers' fields

The deficit between crop demand for N and indigenous supply of N can be seen in the grain yield difference between the NPK plot and the N omission plot. Thus, this deficit must be met through the use of fertilizers. Likewise, the deficit between the crop demand for K and indigenous supply of K can be seen in the grain yield difference between the NPK plot and the K omission plot, which also must be met through the use of fertilizers. Estimated total fertilizer requirement for N should be using yield response to fertilizer N and the expected agronomy efficiency of N. In estimating total fertilizer N needs and optimizing N management, agronomic efficiency is used as an indicator.

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[3] Vegetative growth stages are based upon the number of visible leaf collars. So, V10–V12 is when 10th to 12th leaf collars are visible.

Agronomic efficiency of N (AEN) represents the yield increase per unit of applied fertilizer N. AEN is calculated by subtracting nutrient-limited yield from the attainable yield and dividing the difference by the amount of fertilizer N applied. There are benchmark values of AEN for corn-growing environments (a low AEN value compared with benchmark value means suboptimal N management or yield-limiting constraints other than N; a higher benchmark value indicates insufficient N supply).

The suggested total N, P, and K requirements are given in Tables 2.6–2.8. The expected grain yield response to fertilizer N and the expected AEN estimate the rate of fertilizer N (Table 2.6). Data in the table assumes that agronomic efficiency of fertilizer N is attributed to the yield response to fertilizer N application in which climate, biophysical growing conditions, and management are influential factors.

Meanwhile, requirements for fertilizers P and K are estimated based on attainable target yield and expected grain yield response to fertilizer application (Tables 2.7–2.8).

Meeting the crop demand for nutrients at critical growth stages

Yield response to fertilizers N, P, and K depends on field environment and seasons. Additional yield can be attained in years with favorable conditions, which can be assured by SSNM strategy for nitrogen (total N rate, split N applications, and dynamic N management) using the leaf color chart (LCC) (Table 2.9). If conditions are favorable for higher-than-average yields, SSNM strategy for P and K can aim for a 1–2 t/ha additional grain yield.

During the growing season of the crop, the required fertilizer N is given in several applications. In the crop growth stages, sufficient amounts of fertilizers P and K are applied to address deficiencies and maintain soil fertility. Fertilizer K is often applied early in the season and near mid-season.

The requirement of corn for N is strongly linked to growth stage, with a window for N application between establishment of the crop and tasselling stage. Fertilizer N is crucial during determination of kernels per row before the tasselling and ripening stages to

Table 2.6. Fertilizer N requirements of corn based on expected grain yield response and expected AEN

	Total Fertilizer N Rate (kg/ha)						
	100	120	140	160	180	200	220
Expected yield increase (t/ha) to fertilizer N application over 0 N	≤ 2	2–3	3–4	4–5	5–6	6–7	7–8
Expected agronomic efficiency (kg grain increase/kg applied N)	15–17	17–25	21–29	25–31	28–33	30–35	32–36
Yield Response to N[a]	V-L	L	L-M	M	M-H	H	V-H

Notes: [a]very low-low; low; low-medium; medium; medium-high; high, high-very high
Source: Witt et al. (2009)

Table 2.7. Total fertilizer P_2O_5requirement of corn in non-P fixing soils based on yield target and yield response to fertilizer P application[a]

Expected Yield Response to Fertilizer P over 0 P Plot (t/ha)	Fertilizer P_2O_5 Rate (kg/ha) for a Yield Target of:		
	4–6 t/ha	7–9 t/ha	10–12 t/ha
0	10–20	20–30	30–40
0.5	20–30	30–40	40–50
1.0	30–40	40–50	50–60
1.5	40–50	50–60	60–70
2.0	50–60	60–70	70–80
2.5	60–70	70–80	80–90

Notes: [a]Based on P requirement of 20kg P_2O_5/t grain yield response (AEP of 112 kg grain/kg P) plus a 75 percent return of P removal with grain. Apply 100 percent of fertilizer P as basal application

Table 2.8. Estimated fertilizer K_2O requirements for corn based on yield target and estimated yield response to fertilizer K[a]

Expected Yield Response to Fertilizer P over 0 P Plot (t/ha)	Fertilizer K_2O Rate (kg/ha) for a Yield Target of:		
	4–6 t/ha	7–9 t/ha	10–12 t/ha
0	15–25	25–35	35–45
0.5	30–40	40–50	50–60
1.0	45–55	55–65	65–75
1.5	60–70	70–80	80–90
2.0	75–85	85–95	95–105
2.5	90–100	100–110	110–120

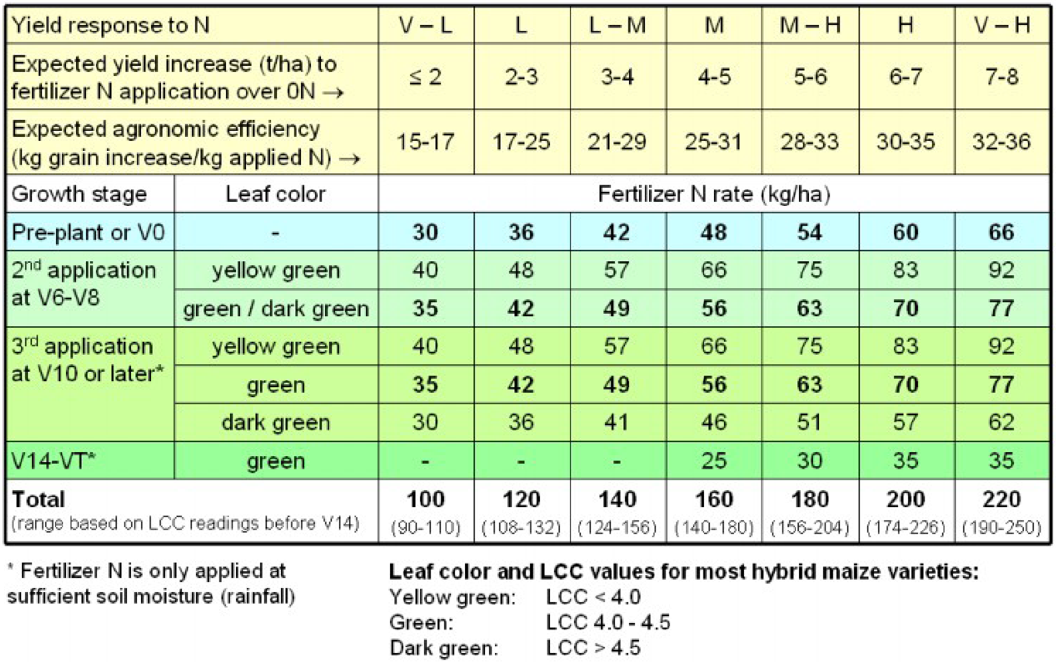
Notes: [a]Based on a K requirement of 30 kg K_2O/t grain yield response (AEK of 40 kg grain/kg K) plus a 100 percent return of K removal with grain. Apply 100 percent of fertilizer K_2O as basal application, if ≤60 kg K_2O/ha. Apply each 50 percent of fertilizer K_2O basal and mid-season, if >60 kg K_2O/ha

enhance grain filling. In SSNM, farmers are able to apply fertilizer N in several doses to maintain sufficient supply of N that must be synchronized with the crop's need for N. Additional N application before tasselling is encouraged to attain high yield or when deficiency for N is observed using an LCC.

Efficient nutrient use

SSNM for corn demands adjustable N management strategies that allow changes in N rates based on rainfall events and plant N demand by using the LCC. Standard LCC for rice is also applicable to corn leaves (Witt et al. 2004). Guidelines in using LCC in corn are given in Table 10. To ensure soil moisture, specific time for N fertilization is preset at crucial stages of crop growth with adjustments in rainfed environment. Farmers rely on leaf color to adjust N dose. Planting date, good crop management, and sufficient supply of fertilizers P, K, and other macro- and micro-nutrients are considered in the effective management of N if the goal is to attain high and profitable yield.

Table 2.9. LCC guidelines for the timing and splitting of fertilizer N application (at yield responses of <2 t/ha, fertilizer N is often applied in only two splits)



Yield response to N		V – L	L	L – M	M	M – H	H	V – H
Expected yield increase (t/ha) to fertilizer N application over 0N →		≤ 2	2-3	3-4	4-5	5-6	6-7	7-8
Expected agronomic efficiency (kg grain increase/kg applied N) →		15-17	17-25	21-29	25-31	28-33	30-35	32-36
Growth stage	Leaf color	Fertilizer N rate (kg/ha)						
Pre-plant or V0	-	**30**	**36**	**42**	**48**	**54**	**60**	**66**
2nd application at V6-V8	yellow green	40	48	57	66	75	83	92
	green / dark green	**35**	**42**	**49**	**56**	**63**	**70**	**77**
3rd application at V10 or later*	yellow green	40	48	57	66	75	83	92
	green	**35**	**42**	**49**	**56**	**63**	**70**	**77**
	dark green	30	36	41	46	51	57	62
V14-VT*	green	-	-	-	25	30	35	35
Total (range based on LCC readings before V14)		**100** (90-110)	**120** (108-132)	**140** (124-156)	**160** (140-180)	**180** (156-204)	**200** (174-226)	**220** (190-250)

* Fertilizer N is only applied at sufficient soil moisture (rainfall)

Leaf color and LCC values for most hybrid maize varieties:

Yellow green:	LCC < 4.0
Green:	LCC 4.0 - 4.5
Dark green:	LCC > 4.5

Source: Witt et al. (2009)

APPLICATION

Adaptation

The SSNM approach in corn production increases efficiency by identifying the proper application of fertilizer (right time, rate, place, and with right source of nutrients). The approach is convenient, adaptable, and easy to use with the available materials. Corn farmers are taught to manage their farm inputs, with the goal of increasing yield and income despite changing weather conditions.

Mitigation

Through SSNM, improper fertilizer application and management of soil can be prevented. SSNM as a mitigation measure lessens the impact of soil degradation, crop failure, and GHG emission. The variable rainfall conditions in rainfed environments can prevent the farmers from attaining their target yield. To manage this risk, N management strategies such as pre-season alternative plan for adjustment of fertilizer rate should be taught to farmers.

Water harvesting technique. Water harvesting is a technique of collection and storage of rainwater in natural reservoirs, tanks, or the infiltration of surface water into subsurface aquifers. Rainfed lowland and upland farms benefit the most from this technique since it provides supplementary irrigation during the dry season. Water harvesting stabilizes water supply and improves food production in the country. There are different methods of water harvesting commonly practiced in the Philippines. These are small water impounding, small farm reservoir, and shallow tube well.

METHODOLOGY

Small water impounding

Small water impounding is a water-harvesting storage structure composed of an earth embankment spillway, outlet works, and canal facilities (Figure 2.27). It is designed as a micro-catchment for soil and water conservation and flood control by holding as much rainwater as possible during the wet season. By reducing volume and the force of runoff, the eroding power of water is subsequently reduced. This mitigates soil erosion and the silting of bottomlands. The rainwater collected in the reservoir is vital during the dry season as supplemental water source for agricultural production and management of inland fisheries. As part of sustainable land management, the development of watershed enhances water infiltration and minimizes soil loss. Agroforestry is the most common form of watershed. Agroforestry uses high-value crops that minimize the use of water on a controlled basis.

Small farm reservoir

A small farm reservoir (SFR) is a water-impounding earth dam structure that collects rainwater and soil runoff. It is designed for single farm use with an area of 300 m^2–2,000 m^2. The embankment height above ground level is less than 4 m. This reservoir can be constructed with a bulldozer or by manual labor, while irrigation is done with PVC siphon pipes or pumps. In rainfed cultivation area, SFR supplements wet-season crops with irrigated water and only partial irrigation to dry-season crops (Figure 2.28). SFR is also intended for inland aquaculture, small-scale livestock watering, and wallowing areas for ducks.

Activities in establishing SFR:

- Laying out/staking
- Cleaning of area
- Basal fertilizing
- Planting
- Rotovating or plowing
- Embankment construction

Figure 2.27. Water harvesting in micro-watershed is done by constructing earth embankments called small water-impounding structures

(Photo credit: *subaybayan.dilg.gov.ph*)

- Scrapping the topsoil
- Orienting the bulldozer operator on one technique of embankment and clearing the layout area
- Site survey and examination of soil profile

Maintenance activities

- Minimum tillage
- Irrigation
- Planting

Figure 2.28. SFR collects rainwater and soil runoff, which supplements crops in rainfed cultivation areas

(Photo credit: Labios et al. [1997])

- Irrigation
- Weeding
- Fertilization
- Canal maintenance
- Watershed protection and maintenance

Shallow tube well

A shallow tube well is established to access water from shallow groundwater table with sandy or clay soft soil (Figure 2.29). The tube well is less than 50 ft deep, hence the name. In constructing this water system, dig into the sandy or clay ground until the water table is reached. Shallow tube wells can be protected or unprotected. Without a proper top cover, a shallow tube well is unprotected from dirt and dust carried by surface water or wind. If fitted with a proper lid, it is protected from water pollutants. A hand pump can also be constructed on top of additional protection. This water system can be built at a low cost.

Shallow well siting and shallow well digging are steps in establishing shallow tube wells. In shallow well siting, the site where the shallow tube well is to be dug is identified through hydroecological setting. The site is usually a thick-soiled, low-lying area with vegetation that has a shallow water table. People living in the area usually know if their location has a shallow water table. It is also determined by tasting the groundwater (deep water table has salty water; shallow water table has better quality).

On the other hand, shallow well digging is done with hand tools or by machine. A hand-dug shallow tube well is about 1 m–2 m in diameter, depending on the tool used for digging. The most common tool for digging is a hand-held hoe. The dug soil is removed from the hole using a small bucket tied to a rope. Wooden ladders are sometimes used to go down the hole. The well is abandoned when a hard formation of rock is reached before striking water. It takes about a week to finish a hand-dug shallow tube well.

Some communities have the appropriate equipment for fast, uniform digging. Machine-dug shallow tube well goes up to 15-m-deep and the diameter is the borehole size. Digging takes two to three days, requiring the work of 10 people. Mechanized drilling usually takes a maximum of only one day. A concrete slab is placed on top of the well to prevent water contamination. A pulley system or a handpump for lifting water is installed if resources allow.

Drip irrigation systems. Frequent droughts due to climate change have led to persistent threat of food security and severe poverty in the country. The utilization of more efficient irrigation methods such as drip irrigation (Figure 2.30) becomes more important. Drip irrigation technologies can help farmers adapt to the impacts of climate change.

Figure 2.29. An example of a shallow tube well pump

(Photo credit: Romeo Buan Gavino through ResearchGate)

Many Filipino farmers need access to irrigation water and an efficient way of utilizing irrigation water. An efficient system should meet the following criteria:

- **Affordability.** Commercially available drip irrigation systems are too expensive for smallholders.
- **Expandability.** Systems must be adaptable to farm size. Farmers must be able to buy an appropriately sized system and to be able to scale-up should they need to.
- **Rapid payback.** Most farmers are highly risk-averse and are reluctant to invest in innovations unless the returns are significantly high.
- **Water efficiency.** Systems that help stretch scarce water supply can enable the expansion of cultivated areas, increase yields and thus, raise incomes.

Drip irrigation allows the optimal utilization of water and fertilizer through their application close to the crop roots. This is achieved by delivering small water flows at low pressure through several emission points, called drippers. Water is saved in two ways: it is made to seep into the soil without evaporating or running off, and it is delivered at the root zone, just where the plants need it. The system is easy to design and set up, and it generally consists of a water source, a pumping unit, filters, distribution network, and drippers.

The government, through the Department of Science and Technology, is now providing support to vegetable farmers in ways that enable them to invest in new technologies.

Figure 2.30. Drip irrigation is an efficient irrigation method in rainfed lowland

(Photo credit: Espino, CLSU)

For example, it has established a flexible loan system for highland farmers to provide them with financial capital to purchase drip irrigation equipment.
The advantages of drip irrigation are as follows:

- **Water savings.** In drip irrigation, conveyance losses are eliminated. Because water does not meet the foliage, the interception losses are also eliminated. In addition, because the method wets only the desired soil root zone keeping other portions of the soil dry, the losses in application are also reduced. Due to regulated flow and application of water in low volumes, deep percolation losses are also reduced to a great extent. The method can save water 40 percent–60 percent without compromising crop growth.
- **Improved plant growth and crop yield.** Drip irrigation allows the efficient application of water in low volumes. This maintains a favorable air-water ratio in the soil root zone, and thus, improving plant growth. It has been reported that drip irrigation increases the yield from 10 percent–60 percent depending on soil and crops, compared with conventional methods.
- **Labor saving.** A well-designed drip irrigation system requires less labor during installation.
- **Energy savings.** Less time is required to supply the desired quantity of water and, therefore, the method saves energy. Only a low-horsepower pump is required, which means more savings in energy.
- **Suitability to poor soil.** Very light soils are difficult to irrigate by conventional methods due to deep percolation of water. Likewise, very heavy soils with low infiltration rates are difficult to irrigate even by the sprinkler method. Drip irrigation has been found successful in both types of soils.
- **Weed control.** Weeds are reduced since there is no watering between plants. The need for expensive and environmentally hazardous chemicals and laborers to apply these chemicals is reduced.
- **Enhanced fertilizer application efficiency.** In the drip irrigation system, water-soluble fertilizers are applied only in the root zone of the crop. Losses of fertilizers in the process of deep percolation, leaching, and runoff are considerably eliminated.

The affordable drip system for farmers frees the farmers from the limitations of rainfed farming, enabling them to cultivate all year round, grow a wider variety of crops, and attain higher cropping intensity.

METHODOLOGY

1. Here are steps in implementing a drip irrigation system:
2. Identify the crop and the area of the farm where the drip irrigation system will be set up.
3. Analyze the soil characteristics and the amount of water needed for the crops.
4. Design the system.
5. Assemble the system, lay the pipes, install the filters, and distribute the network of pipes. Install the drippers at the irrigation points in the network.
6. Carry out system maintenance, ensuring that the drippers do not get clogged by suspended or dissolved solids in the water.

The affordable gravity-type drip irrigation system consists of a 200-liter plastic drum reservoir raised to a height of at least 1.5 m, a screen filter, an on/off ball valve, mainline, and drip laterals with emitters (Figure 39). The reservoir can be manually filled with water or water can be pumped into the reservoir. Available drip kits can irrigate a vegetable garden, 500 m^2–1000 $m^{2,}$ depending on the plant spacing. A drip kit costs about PHP 15,000.00.[4]

Drip irrigation systems are suited for both flat and inclined fields because they do not cause erosion. They are particularly useful in areas with prolonged dry season and a reliable water source(such as a reservoir), and where there is an interest in increasing yields or lengthening cultivation periods by allowing water to drip slowly to the roots of plants, either from above the soil surface or buried below the surface. If there is enough difference in height between the water source and the field, distribution may be gravity-based rather than pump-based.

Crops that can be irrigated by the drip system include vegetables such as tomato, hot pepper, eggplant, bell pepper, lettuce, cabbage, broccoli, and other similar crops. Drip systems can also be used for field crops such as corn and sugarcane.

APPLICATION

Adaptation

Gravity drip system is a climate change adaptation option for resource-poor farmers in water-scarce areas to improve crop yield and save water. In seasonal droughts, drip irrigation reduces demand for water and reduces water evaporation losses by providing the water requirement direct to the plant. The system requires very simple and inexpensive maintenance, involving periodic cleaning of the filter component to prevent the drip emitters from getting blocked.

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[4] As of 2019, USD 1=PHP 50.00

Figure 2.31. Gravity drip system for farmers

(Photo credit: Espino, CLSU)

Mitigation

Gravity drip system reduces carbon emission by reducing the operational time of fossil-energy driven pumps in delivering water to the crops.

Bio-intensive gardening. Bio-intensive gardening (BIG) is a climate and nutrition-smart approach to gardening, which optimizes the use of natural resources available in the area without any application of chemical inputs (Figure 2.32). With only minimal use of external resources, BIG is considered to have a low carbon footprint. Locally-produced seeds and fertilizers are its main components. Food products from BIG are safe and free of pesticide residues since no chemical treatment is practiced.

BIG also features and uses mostly indigenous plant species that are hardy and climate-resilient. This way, climate-resilient varieties are preserved and introduced again to market farmers. And, the knowledge of indigenous heritage varieties is passed down from one generation to another. Climate-resilient indigenous plants like the lima bean, hyacinth bean, and pigeon pea, are hardy and can withstand long dry conditions.

METHODOLOGY

Farmers can take advantage of frequent droughts or flooding using the BIG approach. They can employ a deep-dug bed to conserve rainwater during the dry season or drawdown water to the lower part of the soil within the plant root reach in times of floods (Figure 2.32). Essentially, deep-dug beds should be 12 inches deep or more to trap water in the soil.

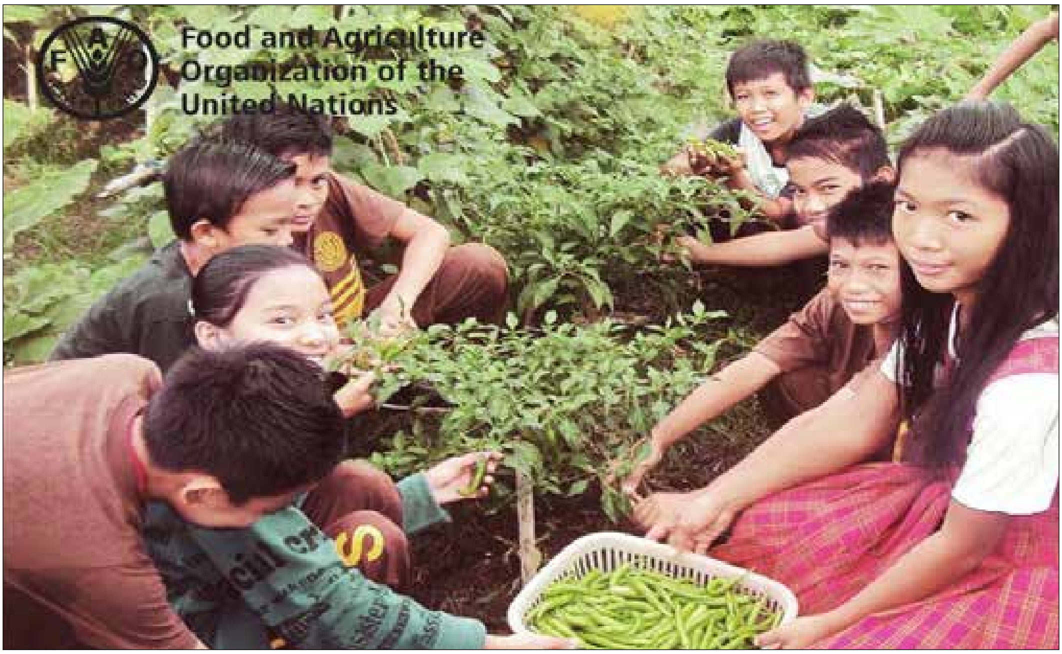
Kakawate (Gliricidia sepium) and other nitrogen-fixing trees, planted at the periphery of the garden, can serve as sources of green fertilizer (Figure 2.33). Nitrogen-fixing trees should be planted on all four sides of the plot to take full advantage of their cooling effects as the wind tends to dry up the soil. They are also utilized as windbreaks.

Green leaf manure trees are grown between every two plots to provide sufficient green leaf fertilizer. Instead of using chemical inputs, which can contribute to GHG production, use green leaves as fertilizer. It is a good way of storing carbon in the soil.

The use of indigenous crop varieties is encouraged in BIG so every garden should devote 70 percent of its area to these varieties. The rest can accommodate commercial seed sources.

Climate change manifests in the occurrence of more insects and diseases. To reduce risks from pest damage and eventually low yield, intraspecies diversity should be increased. On the other hand, interspecies diversity is equally important. Diverse gardens ensure dietary diversity.

Figure 2.32. School children participates in BIG program



(Photo credit: IIRR)

Figure 2.33. ***Kakawate* and other nitrogen-fixing trees act as green fertilizers**

(Photo credit: *schoolnutritionphils.files.wordpress.com*)

APPLICATION

Adaptation

The use of indigenous crop varieties that can adapt to extreme weather conditions promotes sustainable food production and conservation of crop heritage. Deep-dug beds are functional and advantageous in times of flooding or drought because they store rainwater and soil moisture. BIG also contributes to dietary diversity by increasing intraspecies and interspecies and reduces crop failure.

Mitigation

BIG advocates total avoidance of chemical inputs. Nitrogen-fixing trees and green leaf manure trees planted at the periphery of the garden help maintain soil fertility. Other organic matter and microbes also maintain the productivity of the soil. Planting cover crops such as legumes during idle season reduces weed growth. These approaches under BIG lower carbon footprints and are ideal for climate-smart agriculture.

Basket composting as an organic fertilizer source. The Mindanao Baptist Rural Life Center (MBRLC) in Bansalan, Davao del Sur, developed a gardening system that provides vegetable produce throughout the year. MBRLC named this gardening system as the Food Always in the Home (FAITH) garden. Three sections make up the FAITH garden: short-term vegetables (two to four months), medium-term vegetables (six to nine months), and long-term vegetables (all throughout the year).

The central feature of FAITH garden is a series of raised garden beds in which bamboo baskets are set for the production (Figure 2.34). These bamboo baskets are called "basket compost."

MBRLC has been doing basket composting for many years now. The technique has the following benefits:

- One can directly use plant nutrients derived from decomposed materials without the three to four months waiting period.
- The composting materials are held in place by the basket compost to minimize nutrient depletion through runoff.
- Free-range farm animals are prevented from scattering the compost materials.
- Farm and home wastes are collected inside the basket composts.
- Basket composts serve as reservoirs and collectors of moisture and nutrients for plants.
- The soil is strengthened by the organic matter in the compost, which makes it resistant to heavy rainfall.
- Nutritious vegetables are produced at less cost.

METHODOLOGY

Preparing the materials

Materials for basket composting are the following: long bamboo strips (2 to 3 cm wide), bamboo stakes (at least 30 cm long), home organic garbage, farm and garden wastes, *ipil-ipil* leaves, *kakawate*, rensoni, or flemingia (if available), and dried manure (goat, duck, chicken, horse, and/or carabao).

Preparing the garden plots

Clean the garden site. Save weeds and grasses for compost materials. Prepare the garden plot thoroughly.

Digging the holes

Dig holes along the center of the plots at least 12 cm deep and 30 cm diameter. Space holes 1 m apart.

Making the baskets

Drive seven stakes around the holes—uneven number of stakes makes perfect brace for weaving. Weave the long strips of bamboo around the stakes to form a basket. If there are no bamboo strips, space the stakes closely, about 1 cm apart. The baskets should be half-buried in the holes. The baskets serve as erosion control and as containers that prevent chicken and other fowls from scattering the compost.

Figure 2.34. Basket compost as source of organic fertilizer

(Photo credit: MBRLC)

Putting organic wastes

Place the rotting garbage and manure into the basket first. Fill with other organic wastes to the brim. Fresh manure can be used. Place the decomposed materials like the *ipil-ipil* leaves or any recommended leguminous leaves first, grasses and weeds next. Cover the organic wastes with a thin layer of soil.

Planting seeds or seedlings

When the materials placed at the bottom of the basket are almost decomposed (within two to three days), start planting seeds or seedlings. Plant them six to eight inches around the basket. If the composting materials placed in the baskets are green leaves (called "green manure"), plant the seeds or seedlings two to three weeks later. This will give enough time for decomposition to start. If green leaves of *ipil-ipil* are used, put 5 kg of the leaves in the basket at the start. Add 2 kg of leaves every two weeks.

Watering the seedlings

Water the newly transplanted seedlings. Water the basket when the seedlings can grow on their own. Water the center of the basket only, instead of watering the whole plant. The lower part of the basket is cool, moist, and has abundant nutrients for the crop. Later on, the roots will grow into the basket.

Incorporating the decomposed materials

After harvesting the vegetables and the compost is used up, remove the decomposed materials and incorporate them into the soil while cultivating. Add new compost materials to the basket for the next batch of plants. Avoid using diseased plants for composting. Use the basket while it is still intact. Basket composting is compatible with and can be integrated with the BIG technology.

Application

Adaptation

Basket composting is a garden system that was specifically developed to produce vegetables throughout the year. The basket composts serve as reservoirs and collector of moisture and nutrients for plants. This garden system is viable even in unproductive areas. As a result, nutritious vegetables are produced at lesser cost and shorter time since plant nutrients derived from decomposed materials can be directly used without the three to four months waiting period.

Mitigation

Basket composting promotes sustainable farm and home waste disposal, which can lessen the production of GHG. Farm and home wastes are collected and utilized in the basket composts. It also lessens the use of chemical inputs in crop production.

Hydroponics and aquaponics. Hydroponics is a method of growing plants in a water-based nutrient-rich solution. Basically, hydroponics utilizes specific culture and medium instead of soil, to support the root system of the plants (Figure 2.35). Nutrients are artificially introduced into the water-based solution. Plants absorb essential mineral nutrients as inorganic ions in water. Hydroponics allows the plant roots to come in direct contact with the nutrient solution allowing them access to oxygen, which is essential to plant growth. Nutrient solution is the heart of hydroponics, thus, maintaining its quality determines the success or failure of any investment in the technology. Soil is not crucial for a plant to grow since any growing medium will give adequate support and will keep the plant upright. When the plant's diet is modified, it can result in a better-quality yield.

Figure 2.35. Hydroponics method uses water-based nutrient rich solution for crop production

(Photo credit: C. Sace)

Aquaponics, on the other hand, is a portmanteau of two cultures, which are aquaculture (fish raising) and hydroponics (crop production). Fish and vegetables are raised in one infrastructure and function to benefit one another. Fish gives off ammonia, which the bacteria convert to fertilizer, while the plants clean the water. Almost any terrestrial plant can be grown in this setup. Both hydroponics and aquaponics improve productivity through safer, cleaner, and healthier vegetables while saving water, energy fertilizer, and space.

The advantages of hydroponics and aquaponics are as follows:

- No soil-borne diseases and minimal insect infestation;
- Efficient use of water and fertilizers;
- Faster plant maturity and long shelf-life;
- No plowing and harrowing;
- Labor and power saving;
- Clean and comfortable working condition; and
- Improved yield (e.g., tomatoes can yield 300 t/ha/year–600 t/ha/year) from 7 to 8 months growing season

However, hydroponics and aquaponics also have disadvantages:

- Set-up can be expensive;
- It needs a greenhouse or a simple protected structure;
- It requires higher technical knowledge;
- The quality of nutrient solution needs to be constantly monitored; and
- Most systems require energy input.

METHODOLOGY

Types of hydroponic system

- **Nutrient Film Technique (NFT).** This is a hydroponic technique that uses a shallow stream of water to hold all dissolved nutrients required for plant growth. The constant flow of the water-containing nutrients is re-circulated past the bare roots of plants through channels (such as a plastic or rubber hose). This system requires a user who can monitor the setup and fix it quickly when problems arise.
- **Cascade NFT.** Its main purpose is to save space in greenhouses and reduce planting costs.
- **Deep Flow Technique (DFT).** This is a hydroponic technique where plants are suspended on styrofoam boards that float on the surface of the nutrient solution, which is circulated by a pump and gravity drain to pass through the roots of the plants.
- **Tube Culture.** This is a method that uses a tube or a bag that is vertically suspended. The tube or bag is filled with aggregate, and holes are made on the sides to place the plants. The nutrient solution is pumped through a small tube into the larger tube or bag.
- **Aeroponics.** Plant roots are suspended in the air and misted with water or nutrient solution every few minutes. There are two methods to get the water-based solution to the exposed roots—by using a fine spray nozzle or by pond fogger.

Growing medium

The growing medium is any substrate material used for growing plants. It covers a vast variety of materials that are generally categorized into natural and artificial media. Natural media include organic and inorganic substrates, such as sand, gravel, pumice, peat, sawdust, rice hull, and coconut peat. Artificial media includes ceramsite sand, perlite, rock wool, mineral wool, polypropylene, vermiculite, polythene, and styrofoam.

Hydroponic structures

- Commercial greenhouse measures 8.0 m wide x 16.0 m long. Grows about 450 tomatoes, peppers, and melons, and uses 1-hp pump in gravel-bed culture.

- Backyard model measures 3.5 m wide x 7 m long, grows about 1,500 leafy vegetables and herbs, and uses a 50-watt pump.
- Household model measures 3 m wide x 4 m long, grows about 1,000 leafy vegetables and herbs, and uses a 50-watt pump.
- One-square-meter garden measures 1.6 m high x 1 m wide x 1 m long, grows about 400 leafy vegetables and herbs, and uses a 35-watt pump.
- Aquaponics polyculture (tilapia, prawn, aquarium fish, duckweed, vegetables) measures 6.0 m wide x 12.0 m long; grows swamp cabbage, basil, oregano, insulin plant, tarragon, mint, *pac choy*, and stevia; and uses a 1-hp pump in gravel-bed culture.

APPLICATION

Adaptation

Studies in the Central Luzon State University (CLSU) show that hydroponic technology can improve yield up to 300 t/ha/year–600 t/ha/year. Plants are observed to mature faster and have a longer shelf life, which can enhance productivity. With the efficient use of water and fertilizer, hydroponics can save production costs and space usage. Techniques under hydroponics and aquaponics are viable even in unproductive places in both rural and urban areas since they promote soilless agriculture.

Mitigation

Hydroponics and aquaponics do not use soil for planting, so soil-borne diseases and insect infestation are prevented. The use of chemical inputs is also lessened. In addition, there are savings in labor and power usage because no plowing or harrowing is required.

Approaches

Crop diversification. Crop diversification refers to the incorporation of new crops or cropping systems to an established agricultural production area. New crops, particularly value-added crops, are incorporated to attain economic returns and marketing opportunities, and to withstand price fluctuations and to balance food demand (Figure 2.36). The crop diversification scheme is an adaptation strategy to address the issue of decrease in land devoted to agricultural production. Crop diversification maximizes the use of land and other farm inputs to optimize productivity. It can be planting a cash crop after the main crop or interplanting a permanent or cash crop in between the cultivation of the main crop. It is a shift from the traditional less remunerative cropping system to a more remunerative one.

Physical and economic factors influence the adoption rate of crop diversification schemes (Gonzales 1989; Espino and Atienza 2016). Physical factors include land capability, rainfall patterns, water quality, crop characteristics, and available technology. Economic factors are costs, prices, market characteristics, and economic viability of other cropping schemes (Adriano and Cabezon 1989; Espino and Atienza 2016). Farmers attribute the adoption rate of this scheme to income stability, high demand for value-added crops, and high marketability per unit area. Farmers also consider their technical knowledge, available resources to finance production costs, and crop adaptability rate in choosing a cropping system (Espino and Atienza 2016).

METHODOLOGY

In general, crop diversification is categorized as horizontal and vertical. Horizontal diversification is a widely adopted concept that incorporates more crops to the existing cropping system. The cultivation of various crops in rice fields is an example of horizontal diversification. In other words, the base system is elaborated by integrating more crops, multiple cropping techniques, and other efficient management principles together. Many studies suggest that multiple cropping has increased food production and cropping intensity. Vertical diversification occurs when farmers incorporate value-added activities and enterprises (e.g., livestock, poultry and fish farming, and fruit processing) in their cropping system. It is the stage for crop industrialization and additional economic returns.

Crop diversification in rice lands became apparent the time technologies and strategies for farm productivity enhancement began. Policies for adoption to increase income and create employment opportunities were initiated by the government. IRRI explored and introduced the planting of other crops during the dry season before the cultivation of rice in the following wet season (Espino and Atienza 2016).

There are several rice-based patterns adopted in rainfed areas in the Philippines, with rice as the main crop followed by another crop (Adriano 1989; Espino and Atienza 2016). Depending on rainfall pattern and water supply, a wide range of crops are suitable for growing after rice. As part of the *Rainfed Lowland Rice Research Consortium*, rice-corn, rice-garlic, rice-mungbean, rice-sweet pepper, and rice-tomato were evaluated as potential cropping patterns for this scheme (Espino and Atienza 2016).

PhilRice determined and evaluated six major cropping patterns—rice-rice, rice-vegetables, rice-fish, rice-corn, rice-legumes, and rice-sweet potato. The cropping patterns and profitability of produce greatly depend on the geographical location of the area.

APPLICATION

Adaptation

Because crop diversification increases the availability of different crops throughout the year, the farmer's income is not dependent on a single crop. Farmers are not exposed to high risks in climate-induced events because they have other resources as backup.

Figure 2.36. Crop diversification as an adaptation strategy to maximize land usage and productivity

(Photo credit: RV Labios)

The introduction of a wide range of crops can strengthen the ability of farming systems to respond to environmental stresses, thus reducing the risk of crop failure and income instability.

Mitigation

The introduction of climate-resilient varieties is an effective strategy in mitigating production loss in times of calamity. Crop interaction in this approach helps in maintaining soil fertility through crop rotation and intercropping.

Palayamanan Plus and Palayamanan system. *Palayamanan* Plus is a rice-based production system that teaches farmers how to implement diversification, intensification, and integration in farming. The technology aims to establish agri-enterprises that will give smallholder farmers increased productivity and income opportunities. *Palayamanan* Plus benefits small-holder farmers by providing an additional livelihood, optimizing land resource and climate conditions, utilizing biomass for other production systems, reducing GHG emission, and training farmers to become "agripreneurs."

The *Palayamanan* system, on the other hand, is a synergy of farming practices implemented and managed by a farming family to contribute to food security, income stability, and environmental sustainability (Figure 2.37). It helps farming families in crop diversification and in the establishment of start-ups in fishpond, poultry, and livestock production. The system offers multiple benefits to farm families such as stable food supply, high-income opportunities, increased farm productivity, better land resource allocation, enhanced diversity and ecological balance in the lowlands, and reduced production risks due to climate-related events.

The *Palayamanan* system requires:

- capital, which depends on the farming venture that the farm family wants to integrate first;
- at least three full-time farm workers (can be family members); and
- at least one hectare of land (0.05 ha residential area, 0.75 ha field crop production area, 0.20 ha small farm reservoir area)

METHODOLOGY

Components of *Palayamanan* Plus

- Crop enterprise uses value-added products, such as hybrid rice varieties and specialty rice. Rice grains are processed into milled rice and brown rice. After harvesting rice, mung beans, corn, or melon are planted as “relay crops.”
- Livestock enterprise uses crop residues and stubbles as feed for ruminants. Fallen grains from the paddy are utilized as feeds for chickens and geese. Rice-fish and rice-duck systems are integrated into the livestock enterprise.
- Mushroom production uses rice straw as a medium for mushroom cultivation. Spent mushroom substrates are utilized in vermicomposting.
- Organic fertilizer enterprise uses animal manure, spent mushroom substrates, and crop residues in composting organic fertilizer. Organic fertilizers are utilized in the crop enterprise.

Palayamanan as a systematic farm management system

The approach implements a farm management system that combines technologies and practices that optimize available resources without compromising human health and the environment. The following technologies and practices are integrated into *Palayamanan* system:

- Crop rotation
- Diversified cropping

Figure 2.37. *Palayamanan* Plus promotes diversification, intensification, and integration in farming

(Photo credit: IRRI-RKB, PhilRice)

- Alternate wetting and drying technique
- Nutrient management
- Integrated pest management
- Farm waste utilization
- In-land aquaculture

The *Palayamanan* system comprises six stages:

- Selection of techno-demo farms and potential farmer-partners
- Participatory rapid appraisal in the selected sites
- Strategic planning
- Conduct of Farmer Field School and site visits
- Establishment of techno-demo farms
- Training of farmer-partners to become farmer researchers, extension workers, and entrepreneurs.

APPLICATION

Adaptation

By providing a livelihood to farmers and farm families, *Palayamanan* system helps alleviate poverty among marginal communities in the lowlands. It also serves as a venue for government and nongovernment agencies to introduce their programs that are anchored to this approach. Most notably, farmers are encouraged to invest in worthwhile activities such as agri-enterprises.

Mitigation

Palayamanan system is a shift from traditional monocropping to diversified cropping in the lowlands. It has resulted in the improvement of soil conditions and sustainable land management. Site-specific rice-based farming technologies are dovetailed to address climate change issues.

Adjusting cropping pattern. Changes in the climate could also result in changes in the seasonal pattern. Efforts should be made to identify adjustments in cropping systems that will fit well with the new climate. The aim is to develop a cropping system that adjusts to the new climate or is resilient to climate change. Successful adaptation will depend on how well the cropping pattern is planned.

A climate-resilient cropping system should have the following characteristics:

- Uses crops with wide adaptability to rainfall, temperature, and other climatic components;
- Involves crops with a growing period that fits well with the new climatic pattern;
- Stores and conserves soil and water;
- Requires minimum or no-tillage
- Uses short-cycle species or varieties; and
- Integrates stress-tolerant species or varieties.

METHODOLOGY

Designing a climate-resilient cropping system consists of the following steps:

1. Know the present climate condition (rainfall pattern, amount of rain, duration of rainy period [growing season], and temperature ranges).
2. Know the alternative crops to grow (consider consumption, market, and other uses).
3. Know the climatic and biophysical requirements of the crops you have chosen (water requirement, temperature requirement, soil requirement).

4. Match the requirements of your crop with the present condition:
    - Assess suitability according to soil requirement, water availability, temperature, etc.
    - Select the crops that fit with the present condition.
    - Draw a cropping pattern calendar.

5. Specify the management practices for each crop in the cropping pattern, integrating adjustments to climate change (e.g., use of drought- or salt-tolerant varieties, establishment of soil and water conservation measures, planting of the permanent trellis).
6. Assess the profitability of the adopted cropping system;

    - Potential benefits of the adaptations
    - Costs, returns, and profit
    - Stability of production and earnings

7. Assess its technical feasibility of the proposed adaptations:

    - Available resources (land, labor, capital)
    - Resource requirements
    - Compatibility of available resources with the required resources

8. Implement the cropping system.
9. Observe the performance of the adapted cropping system.

APPLICATION

Adaptation

Adjusting a cropping system to the new climatic pattern ensures the feasibility of crops used, increases resilience to climate change, and increases farm performance. A cropping pattern that involves the selection of crops and fitting of their growing period with the climatic pattern ensures high crop performance under the new climate.

Mitigation

Designing a cropping pattern involves specifying efficient management practices that will reduce GHG emissions.

Agroforestry in rainfed lowlands. Through available technologies and practices for cultivation, farmers are not only trying to maximize their rice yield, but also learning to optimize their available resources to mitigate the risks of climate change and to contribute to food and economic security.

Monocropping of rice in rainfed lowlands carries risks from both climate and market fluctuations. Agricultural diversification is a viable solution to save farmers from these adversities. Agroforestry, as part of diversification, is seen to increase resilience of farmers and their farmlands. Particularly, planting of perennial forest and fruit trees is beneficial for food production and risk mitigation. Farmers in Southeast Asia have adopted agroforestry in their rice production landscapes and it has been proven to lessen climate change risks (Wangpakapattanawong et al. 2017).

Specific tree species have ecological and socioeconomic benefits to the surrounding rice fields. Species with different abilities can withstand changes in establishing rice fields and subsequent cultivation. In some cases, trees surrounding rice fields are planted for a specific benefit to the crop. On the other hand, some farmers retain certain tree species for socioeconomic reasons. Generally, trees are grown for their potential use and their ability to improve soil fertility. Among the benefits are food and medicine, fodder source, wood fuel, value-adding tree by-products, fixing nitrogen, increasing soil fertility and stability, improving fallow in rainfed lowlands, water regulation, boundary demarcation, rice straw storage for communal grazing; and lastly, carbon storage and climate resilience (Wangpakapattanawong et al. 2017).

Farmers are careful not to cut native trees, which are necessary for establishing rice fields because they fertilize the rice. However, it is important to note that agroforestry is a long-term investment. There might be lags between initial investment and return of investment. It is important to secure land tenure of farmers over the areas they cultivate. Farmers are hesitant to spend on long-term investments if there are conflicts in land ownership. Effectively implementing policies on land tenure reduces conflict and increases social stability and farmers' income.

Adoption of agroforestry as an intensified buffer between agricultural land and forest land enables farmers to manage a wide range of agroforest products within an integrated system. The value chain for agroforest products is critical in improving the livelihood of farmers in many parts of Southeast Asia.

Integrating agroforestry in rice or crop production in rainfed lowlands also has disadvantages. Agroforestry systems need to be efficiently designed to prevent competition for light, nutrients, and water between trees and the major crop. Scattered planting of trees in the rice fields can interfere with the mechanization of rice production. Trees are better planted alongside the bunds so as not to affect rice production.

The management of trees is vital in preventing competition in the system. Trees should be planted in the sun's direction to minimize shading. They should be trimmed or pruned to maximize light and rainwater capture of rice and other crops. Tree species with small to medium canopy are ideal for planting (Wangpakapattanawong et al. 2017).

METHODOLOGY

Participatory Landscape Appraisal

This method is used to understand landscape issues such as changes in water supply (e.g., rainfall rate, water harvesting techniques), flood and drought incidence, soil erosion, insect and disease incidence, sea level rise, and pesticides and fertilizers used. Planted trees and crops are evaluated to identify the challenges and opportunities they present. Participatory Landscape Appraisal (PaLA), together with agroecological analysis, is used with participating farmers to capture local knowledge. A combination of PaLA and other related methods can be used to acquire detailed and subsequent analyses of particular issues.

The planning and design process should include demonstration and field trials. Workshops on PaLA should be conducted to farmers who have expressed interest in participating in the field trials. Workshops are done in the village of participating farmers. The workshop aims to get farmers' commitment to participating in the field trials forming partnerships and developing work plans. Confirm the farmers' interest in planting trees on their rice farms and introduce the concept of demonstration trials. A detailed discussion is important so as to incorporate results in the work plan. There should be specialists and experts who are critical to addressing some of the farmers' questions and inquiries about agroforestry and other related concepts.

Site visits to the demonstration field build interest and confidence of other farmers in adopting agroforestry as part of their rice production. A farmer who has successfully grown timber or fruit trees on the rice farm can be requested to explain the system to other farmers. Advisors or consultants should identify key aspects of successful agroforestry practices that are relevant to the farmers. Note that farmers should benefit the most from these field visits.

Designing agroforestry systems

The end goal of the agroforestry system design dictates the combination of trees, crops, and animal species to be used. Interactions with other components have to be considered if grazing animals are included. For example, if the design aims to increase food production for farmer's consumption, a possible combination is perennial fruit trees, annual food crops, and poultry raising.

In other words, designing the agroforestry system should consider the interest and livelihood of farmers and communities alike, the types of land (for this case, rainfed lowland), and farming and cultural practices. Spatial and temporal arrangements should also be considered to minimize competition for light, rainwater, and nutrients among trees and other crops such as rice.

APPLICATION

Adaptation

The adoption of agroforestry in rice-production landscapes increases resilience of the system and diversity of crops and by-products, which will bring high profits to farmers in the long run.

Mitigation

Trees are known as buffers to climate-related events. They complement other crops by providing protection against strong winds and by helping conserve water and soil nutrients. Other socioeconomic benefits of trees contribute to the overall improvement in farmers' productivity.

UPLAND ECOSYSTEM

Technologies

Multi-storey cropping. Multi-storey cropping is a cultivation of inter-planted crops of different growth characteristics that use the soil, soil moisture, and space together at the optimal level. It consists of high storey and medium storey of trees and shrubs and low storey of crops or forages (Figure 2.38). Tree canopies are essential in growing crops and forages. Multi-storey is applicable to small farms that require intensive system. This system maximizes productivity and provides income opportunities for upland farmers. The primary objectives of multi-storey cropping are as follows: production of tree products in addition to crops and forages; quality and quantity improvement of crop and forages through micro-climatic condition; utilization and conservation of soil nutrients for crops and forages; reduction of excess subsurface water; and favorable habitat for beneficial species to crops and forages.

METHODOLOGY

In multi-storey cropping, coconuts are typically planted first to establish the highest storey. Tree planting, in general, should have sufficient wide spacing to allow adequate light for shrubs and forages to absorb. The canopy of a mature tree ranges from 5 percent to 40 percent crown cover. When the coconut trees reach a height of 4.5 m, which is achievable after three to four years, banana, coffee, and papaya are planted underneath. Crops should be adapted to the soil and climate of the area. High resistance to stem and branch breakage from strong winds should be considered when choosing the medium storey-crops. In addition, root and crown spread should be low to moderate only to avoid competition with the forages. Root crops and forages should be planted if ground level has developed sufficient spacing (which usually takes 3–4 years). At full

Figure 2.38. Multi-storey cropping consists of high storey and medium storey of trees and shrubs and low storey of crops or forages

(Photo credit: PCAARRD)

establishment, the high, medium, and low storeys are observable. Multi-storey cropping does not require a specific planting layout, but the multi-storey should be present.

Some of the primary practices for this system are tree and shrub establishment, conservation-crop rotation, residue management, nutrient management, pest management, and water management. Maintenance through fertilization, weeding, and pruning is essential. Mulching using fallen leaves and stems from leguminous trees restores and conserves soil fertility. Establishment of windbreaks can counter typhoons that will hit the area. Leguminous trees such as acacia can protect the lower crops against strong winds.

Shade-tolerant vegetables

Plants should be arranged and fitted according to their above-ground growth patterns. The light and shade requirements of plants should be considered when designing plots for farming so that they can benefit from shade-light patterns and grow with minimal competition for light. Therefore, plants that thrive best in the shade should be planted underneath larger plants. A list of shade-tolerant crops is given in Table 2.10.

Table 2.10. Shade-tolerant crops

Scientific Name	Common Name	Light Requirement
Zingiberofficinale	Ginger	requires about 50% shade
Colocasia esculenta	Taro	tolerates up to 50% shade
Basella alba	Basella	requires partial shade
Apiumgraveolens	Celery	requires partial shade
Cucumis sativus	Cucumber	requires partial shade
Lactuca sativa	Lettuce	requires light shade
Brassica oleracea var. *capitata*	Cabbage	requires light shade
Talinum triangulare	Philippine spinach	tolerates light shade
Daucus carota	Carrot	tolerates light shade
Solanum tuberosum	Irish potato	tolerates light shade

Sources: National Anti-Poverty Commission (NAPC) and International Institute of Rural Reconstruction (IIRR) (2016)

Drought-resistant crops

Drought-resistant crops such as those listed in Table 2.11 can be used in crop rotation, especially if there is limited pump irrigation or rainwater in the area.

Table 2.11. Drought-resistant vegetables

Scientific Name	Common Name	Degree of Resistance
Tylosemaesculentum	Manama bean	highly drought-resistant
Arachishypogaea	Peanut	highly drought-resistant
Vigna unguiculata ssp.	Yardlong bean	highly drought-resistant
Cajanuscajan	Pigeon pea	highly drought and heat-resistant once established
Abelmoschus esculentus	Ladyfinger	fairly drought-resistant
Sorghum bicolor	Sorghum	highly drought-resistant
Vigna unguiculata	Cowpea	drought and heat-tolerant
Solanum melongena	Eggplant	drought-tolerant
Manihot esculenta	Cassava	drought-tolerant once established
Dolichos lablab	Lablab bean	drought-tolerant once established
Phaseolus lunatus	Lima bean	drought-tolerant once established
Ipomoea batatas	Sweet potato	fairly drought-tolerant
Amaranthus gracilis	Amaranth	fairly drought-tolerant
Vigna radiata	Mung bean	fairly drought-tolerant

Sources: NAPC and IIRR (2016)

APPLICATION

Adaptation

This system optimizes use of resources for increased farm income. It can be modified to suit market demands. If one crop component in the system fails, it can be compensated with other crop components, which translate to food security. Labor and input costs for multi-storey cropping are relatively high, but investment returns are guaranteed. The system has been proven effective and remunerative for upland farmers especially if high-value crops are incorporated. Strong extension support from local government units (LGUs) and organizations can translate to the wide-scale adoption of this system.

Mitigation

Multi-storey cropping maintains soil fertility through recycling of nutrients. Incorporating leguminous trees is beneficial for mulching and soil management and provides adequate soil cover throughout the year. The system is effective in mitigating soil erosion and soil fertility depletion even with extreme rainfall during the monsoon and steep sloping of the upland.

Improved village-type compact corn mill for white corn. In recent years, the Department of Agriculture (DA) has been promoting white corn as an alternative staple to rice or as rice-corn mixture (Manguiat et al. 2018). White corn is known to have low glycemic index but high dietary fiber, which makes it a potential alternative in the Filipino diet. The high demand for rice can be remedied by regular consumption of white corn to attain self-sufficiency.

In upland areas like Bukidnon, white corn production has increased since 2006 (Rola, De Mesa, and Bagares 2006). It is observed that white corns grown in upper watersheds have higher yields than in the lower watersheds since the soil in the uplands is enriched with residues from the previous crop cultivation (crop rotation). Corn farmers can shift to more productive open-pollinated varieties (OPV) and hybrids of white corn, instead of depending on low-yielding ones (Dizon 2018). Table 2.12 shows the open-pollinated white corn varieties released in the Philippines.

White corn cultivation in the upland requires less production cost and does not need intensive irrigation facilities because white corn grows in rainfed areas. However, farmers need corn mill to produce quality corn grits.

The Philippine Center for Postharvest Development and Mechanization has developed an improved village-type compact corn mill for white corn. It provides higher milling recovery and quality corn grits. This compact corn mill eliminates aflatoxin

Table 2.12. Open-pollinated white corn varieties released in the Philippines

No.	Year Approved	NSIC Registration Number	Variety Name/ Commercial Name	Owner/ Breeder	Yield (mt/ ha)	Maturity (days)	
						DS	WS
1	1972	Philippine Seed Board	Phil DMR 2	UPLB, Laguna	4.46	100–105	
2	1974	Philippine Seed Board	BPI Var 2*	Bureau of Plant Industry			
3	1975	Philippine Seed Board	Phil DMR Composite 2	UPLB, Laguna	4.62	95–100	
4	1976	Philippine Seed Board	Glutinous Comp. 41 D	Bureau of Plant Industry	4.0		
5	1977	Philippine Seed Board	Glutinous Comp. 2	Bureau of Plant Industry	5.58		
6	1978	Philippine Seed Board	BPI Var. 3 (E.G., 118)	Bureau of Plant Industry	4.32	105	
7	1980	Philippine Seed Board	DMR 2	UPLB, Laguna			
8	1980	Philippine Seed Board	Improved Tiniguib	UPLB, Laguna	3.50	87	
9	1980	Philippine Seed Board	Phil-DMR Comp. 2	UPLB, Laguna			
10	1985	Philippine Seed Board	IPB Var 2 (Tanco White)	UPLB, Laguna	5.06	107	97
11	1991	PSB Cn 91-10	IPB Var 4	IPB-UPLB	4.89	94	105
12	1996	NSIC 1996 Cn68	Cn 96-68 USM Var 12	USMARC-USM	5.15	110	101
13	2006	NSIC 2006 Cn184	USM Var 16	USMARC-USM	5.78	103	102
14	2006	NSIC 2006 Cn185	USM Var 18	USMARC-USM	5.41	103	100
15	2006	NSIC 2006 Cn186	IES 89-10	CVIARC	5.52	105	98
16	2006	NSIC 2006 Cn187	IES 89-12	CVIARC	5.48	105	97
17	2007	NSIC 2007 Cn203	USM Var 22	USMARC-USM	5.89	105	103
18	2007	NSIC 2007 Cn204	USM Var 20	USMARC-USM	5.97	107	102
19	2008	NSIC 2008 Cn222	Mt. Apo Cristal 800w	Northland Agri-Product and Services	5.78	108	102
20	2008	NSIC 2008 Cn223	IPB Var 8	IPB,College, Laguna	5.81	105	98
21	2008	NSIC 2008 Cn224	IPB Var 6	IPB,College, Laguna	5.84	105	101
22	2010	NSIC 2010 Cn249	BIO #1	Bioseed Research Phils., Inc.	5.19	106	103

Continued on next page

Table 2.12. continued

No.	Year Approved	NSIC Registration Number	Variety Name/ Commercial Name	Owner/ Breeder	Yield (mt/ ha)	Maturity (days)	
						DS	WS
23	2010	NSIC 2010 Cn250	USM Var 28	USMARC-USM	4.59	100	103
24	2011	NSIC 2011 Cn 260	IES 09-2w	CVIARC	5.38	107	100
25	2012	NSIC 2012 Cn 272	USM Var 32	USMARC, Kabacan North, Cotabato	5.52	110	100
26	2013	NSIC 2013 Cn 282	IES 10-04w	CVIARC	5.38	106	102
27	2013	NSIC 2013 Cn 283	USM Var 34	USMARC, Kabacan, North Cotabato	6.25	110	100
28	2014	NSIC 2014 Cn 287	USM Var 40	USMARC, Kabacan North, Cotabato	6.03	107	105
29	2014	NSIC 2014 Cn 288	USM Var 38	USMARC, Kabacan North, Cotabato	5.82	108	108
30	2014	NSIC 2014 Cn 289	USM Var 36	USMARC, Kabacan North, Cotabato	6.42	103	104
31	2014	NSIC 2014 Cn 291	USM nch 35	USMARC, Kabacan North, Cotabato	6.89	106	104
32	2015	NSIC 2015 Cn 302	White Flint 12-06	CVIARC	5.97	105	100

Sources: IPB, CA, and UPLB (2019)

contamination in corn grits and sorts different sizes of corn grits. It allows simultaneous operations such as sorting, cleaning, and size reduction for white corn. It is also easy to transport and affordable. The latest and improved model produces 240 kg/hr, which is a 49 percent increase over the 161 kg/hr rate of the initial model.

Figure 2.39 shows a model of corn mill processing white corn grits that is in the Institute of Plant Breeding, UPLB.

Corn grits are processed to become *bugas* or milled corn, which is being promoted by the DA as a country-wide staple. Consumption of *bugas* is common in Visayas and Mindanao.

Figure 2.39. A village-type compact corn mill for white corn is used in corn grits production

(Photo credit: Manguiat, UPLB)

Application

Adaptation

Consumption of white corn offsets the high demand for rice and can account for food sufficiency in the long run. In marginalized areas where access to rice is limited, milled white corn grits become the staple to meet their daily food requirements.

Mitigation

The improved village-type compact corn mill lessens productivity loss through high milling recovery and high-quality corn grits. Its mass commercialization can address the postharvest situation of white corn in the upland areas, where wet seasons are often intensive.

Approaches

Agroforestry. Agroforestry is a land management approach that intentionally combines agriculture and forestry for improved productivity, profitability, and environmental stewardship (Figure 2.40). It is a key tool for upland farmers for a sustainable and diversified farming system.

Agroforestry is characterized by four essential criteria:

1. **Intentional** – A combination of trees, crops, and animals is designed and managed as a whole unit.

Figure 2.40. Agroforestry is a land management approach that combines agriculture and forestry

(Photo credit: World Agroforestry Centre and World Overview of Conservation Approaches and Technologies)

2. **Intensive** – Intensive management is needed for agroforestry practices to maintain the productivity and protective functions of the unit. Annual cultivation, fertilization, and irrigation are vital.
3. **Interactive** – It enhances production and conservation benefits by manipulating biological interactions of trees, crops, and animals in the unit.
4. **Integrated** – Trees, crops, and animals are managed to form a structured and functional unit, to optimize land resources, profitability, and sustainability of the environment.

Methodology

Farmers practice a dominant agroforestry system that is composed of woody perennial trees, agricultural crops, and grasses in fallow areas. Woody perennials, which can be forest trees or fruit trees, are planted on the upper slopes, along farm boundaries, and on the edges of bunds or alleys. They are grown for home consumption and commercial purposes. Trees restore soil fertility through nutrient cycling. Other protective functions of trees include windbreaks, forest cover, and soil and water conservation. Meanwhile, agricultural crops such as rice and vegetables are planted on terraces, bunds, and paddies on the lower slopes and leveled areas. They are grown mainly for food and income generation. Terraces located at the middle slopes are fallowed for grass, to regain soil fertility until the farmer has resources to cultivate again.

The interaction of the components in an agroforestry system is what makes it functional and productive. Woody perennials as watershed protect the vegetation and terraces below by mitigating soil erosion and landslides. The terraces where agricultural crops are cultivated for market distribution provide short-term economic services for tree maintenance. In the long run, the profitability of by-products from the trees also provides capital for farmers to improve and sustain terrace farm productivity. The fallow areas maintain soil fertility and are used for raising livestock. Table 2.13 shows the different agroforestry systems.

Table 2.13. Agroforestry systems

Agroforestry Systems	Description
Agrosilvicultural (trees and crops)	1. Rotational – trees and crops are cultivated in rotation or partially overlapped 2. Spatially mixed – trees grown in cropland, multi-storey cropping, and combination of trees and crops in backyard gardens 3. Spatially zoned – alley farming, boundary planting of trees, trees grown as fences to protect crops from livestock, trees grown on rice field bunds or terraces to prevent soil erosion, and trees planted as windbreaks and shelterbelts
Silvopastural (trees and pasture)	1. Trees and shrubs grown on grazing land 2. Trees amidst crops and pasture
Trees and livestock (not pastoral)	1. Integrated system where trees, crops, and livestock are raised on the same piece of land, either in free grazing or enclosures 2. Trees grown for fodder 3. Trees grown for apiculture
Forest trees and people	1. Shifting cultivation of annual crops in forests with fallow periods for trees' growth 2. Selective planting of forest trees species for non-timber forest products
Trees and perennial crops	1. Trees grown as cover for perennial crops such as coffee or cacao 2. Multi-storey tree plantations

Sources: Sinclair (1999); Wangpakapattanawong et al. (2017)

Forest buffers and windbreaks are established to protect the system and to lessen the impact of extreme weather conditions. They also support wildlife by providing shelter and food source. Riparian forest buffers filter runoff and stabilize banks of stream and river.

Application

Adaptation

Agroforestry increases farmers' resilience through high farm profitability. Total output from combining different components such as trees, crops, and livestock is greater than managing a single component. Farmers are food-secure since the system is composed of perennial and annual crops. It is observed that crops and livestock protected from strong winds and extreme weather conditions are more productive. Thus, forest buffers and windbreaks are integral in agroforestry.

Mitigation

Agroforestry conserves and protects natural resources by mitigating pollution through carbon sequestration, soil erosion control, and provision of habitat for wildlife. A substantial improvement in the economic and sustainability in agriculture and forestry comes from the collective effort in mainstreaming agroforestry in the upland.

Livestock integration in upland farming system. Livestock integration in upland farming system increases upland farmers' productivity and income through livestock raising while maximizing farm by-products. Crops and animals are two components that improve efficiency in mixed farming system. Crop biomass that has no economic or food value can be fed to livestock alternately with forage. Forages are used as "relay crop" after harvesting food crops to restore soil fertility. On the other hand, animal manure is collected and applied to crops as fertilizer.

Biomass such as animal manure and crop residue undergoes anaerobic fermentation for biogas production. Biogas, a mixture of carbon dioxide and methane, which has a liquid petroleum gas consistency, is used by rural households and for farm operations. Its production for village use is feasible under the appropriate technology (Barnett et al. 1978; Eusebio and Labios 2001). It is more ecological and efficient than using wood, charcoal, or dried manure as power source. Slurry, the by-product of anaerobic fermentation, is utilized as fertilizer as well. Biogas production, however, may require higher investment costs, operation time, and labor requirement.

METHODOLOGY

Biogas production

Substrates that are more soluble and degradable require simpler fermentation design and biogas digester. Pig wastes, for example, are easier to process than straw bagasse because they easily produce impenetrable scum on the digester's surface. The characteristics of the substrate are the most important factors in determining gas composition (Toma et al. 2016).

Biogas production comprises the following steps:

1. Biomass or feedstock is crushed into smaller pieces and slurrified in preparation for the anaerobic digestion process. Slurrifying means adding liquid to the biomass or feedstock for easier processing. The rate of solid matter should only be around one-tenth of the total volume of the biomass.
2. Biomass that underwent slurrification is pumped into the pre-digester tank where enzymes secreted by bacteria break down the biomass into an even finer consistency.
3. Before it enters the biogas reactor (digester), the biomass is sanitized by heating the mixture to above 70°C for an hour. Once sanitized, the mixture is pumped into the biogas reactor where production takes place.

4. In the biogas reactor, the anaerobic digestion process begins, and the biomass enters a gradual process of fermentation. The microbes feed on the organic matter, such as proteins, carbohydrates, and lipids, producing methane and carbon dioxide. Microbes need warm conditions, so the biomass is heated to 35 °C–37 °C.
5. The anaerobic digestion process usually takes about 30–40 days. The biogas is collected in a spherical gas holder from the top of the biogas reactors.

Alternative feeding system

About 14.5 percent of all anthropogenic GHG emissions are caused by livestock production. Considering the important contribution of livestock to food security, the transformation of this sector, to become efficient and sustainable as possible, should be prioritized, especially because the demand for animal products is expected to increase than the current rate by 2050 (FAO 2016). Alternative feeding systems are the key to this transformation since they play a significant role in raising livestock. FAO has developed innovative approaches that integrate the efficient use of natural resources, environment protection, and socioeconomic and cultural benefits.

Supplementation to offset nutrient deficiency

Animals with mineral and nitrogen deficiency are less productive. To supplement this deficiency, tree leaves, oilseed, brans, urea-N, and mineral mixtures should be given. Through supplementation, higher animal productivity such as increased milk production and efficient reproduction can be attained.

Utilization of farm waste

Ruminants in developing countries commonly feed on crop residues and farm by-products. The method is adopted to reduce slash-and-burn practice, which worsens the environment condition (e.g., soil degradation and reduction of valuable feed source). Proper crop residue management such as the utilization of straws and stubbles, can complement technologies that process complete feed for ruminants. Silage making is suitable for reducing crops and forage wastage during the rainy season.

Technology for smart feeding options

To supply balanced feeds to dairy and livestock raisers on a wide scale, “densified total mixed ration blocks” or “densified mixed ration pellets” are developed by combining straw, oilseed meals, and nutrients. This is a viable solution to remove regional disparities on feed availability among feed manufacturers and entrepreneurs. Smallholder farmers should be given technical assistance in preparing balanced rations to satisfy the nutrient requirements of productive livestock.

Alternative feed materials

The global demand for grains has exceeded the current yield capacity, which increases competition between food and feed production. However, there are alternative resources that can be utilized for feed production. Among them are cassava residue, sweet sorghum residue, palm kernel meal, jatropha seed meals, pongamia meal, and algae residue. Black soldier fly, yellow mealworm, silkworm, and grasshoppers, which are good sources of protein and macro-micro minerals, are promising feed resources. Leaf meal from moringa plants is also a good protein source. It yields higher protein per unit than soybean.

Application

Adaptation

The quest for alternative energy and feed source has been a long-term goal of climate change initiatives. Livestock production is considered a large contributor to the carbon footprint. Thus, biogas production and alternative feeding systems are important steps in reducing harmful emissions during production. The efficient use of available and viable resources combined with proper farm waste management can sustain livestock production in the long run.

Mitigation

Production of biogas from anaerobic digestion process offers socioeconomic and environmental benefits. Some farm wastes that are converted as slurry can be a good crop fertilizer. Biogas as renewable energy is reliable and cost-efficient. The use of methane and carbon dioxide has reduced GHG emission. It converts high energy wastes into fuel and diverts them from landfills.

HILLY LAND ECOSYSTEM

Technologies

Sloping agricultural land technology. Sloping agricultural land technology (SALT), also known as contour hedgerow intercropping (agroforestry) technology, is a system that involves planting of field crops and perennial crops in 3-to-5-meter-wide bands between double rows (hedgerows) of nitrogen-fixing trees and shrubs along the contour lines in hilly areas (Figure 2.41). It serves as a living barrier, which traps sediments and gradually modifies sloping land to terraced land. The nitrogen-fixing hedgerows help improve soil fertility through nitrogen fixation and prevent soil erosion. Field crops (e.g., legumes, wheat, and vegetables) and perennial crops (e.g., cacao, coffee, and banana) provide cyclical cropping, which enables farmers to harvest throughout the year. SALT as a diversified farming system establishes stability in the

Figure 2.41. SALT 1 is a low-cost farming system designed for small-scale farmers

(Photo credit: World Agroforestry Centre/Bindu Johnson)

ecosystem. The technology was developed by the Mindanao Baptist Rural Life Center (MBRLC) in Kinuskusan, Bansalan, Davao del Sur, Philippines.

SALT is a timely, simple, and low-cost farming method specifically designed for small-scale farmers with few tools and little capital for farming. SALT farms require low maintenance and can proliferate on their own. Nitrogen-fixing trees and shrubs (NFTS) continue to grow and overshadow the crop area. Eventually, the soil enriched by the NFTS will be suitable for cultivation and will prevent soil erosion.

The most common and basic system for farmers is SALT 1, but there are several variations. MBRLC has developed variations of SALT, such as the Simple Agro-livestock Land and Technology (SALT 2), Sustainable Agroforest Land Technology (SALT 3), and Small Agrofruit Livelihood Technology (SALT 4).

SALT 2 is small livestock-based farming devoted to 40 percent agriculture, 20 percent forestry, and 40 percent livestock. Similar to the traditional SALT system, it plants hedgerows of different NFTS on the contour lines. Manure from livestock, preferably dairy goats, is utilized as fertilizer for both agricultural and forage crops.

SALT 3 is a farming system that consists of marketable fruit production and forest trees plantation. SALT 3 establishes food production for personal consumption. The farmer can plant fruit trees, such as rambutan and lanzones between the contour lines. Leaves from NFTS are piled to serve as fertilizer for the fruit trees and to help conserve the soil. Meanwhile, one hectare of land is devoted to forest trees, which are intended for firewood and charcoal for short-range production. Other forest trees species are grown for building materials for medium-long range production. Contour lines that are 2 m–3 m apart are planted with flemingia or other hedgerow species in areas where the soil is too steep for row crops. In between those hedgerows, permanent crops such as coffee and cacao can be planted.

SALT 4 is a system that requires half a hectare of sloping land devoted to fruit trees and food crops. Along the contours of the SALT farm, farmers can plant hedgerows of different NFTS such as flemingia, gliricidia, and rensonii.

METHODOLOGY

1. **Make the A-frame.** Use an A-frame to layout the contour lines across the slope. It is a simple device made of three wooden or bamboo poles nailed or tied together to form a capital A shape. Its base is about 90 cm wide while a carpenter's level is mounted on the crossbar.
2. **Determine the contour lines.** Plant the front leg of the A-frame on the ground and swing the rear leg until the carpenter's level shows that both legs are touching the ground at the same level. With a helper, drive a stake beside the A-frame's rear leg. The process is repeated across the field. It is important to note that the contour lines should have 4 m–5 m spacing.
3. **Cultivate the contour lines.** Plow and harrow a meter strip along the contour lines to prepare the area for plantation. During plowing, use the stakes as a guide.
4. **Plant seeds of different nitrogen-fixing trees and shrubs.** Make two furrows along each prepared contour lines. Plant two to three seeds per hill with a 12 cm distance between hills. Make sure that the seeds are completely covered with soil. Once the hedgerows are fully grown, they will firmly hold the soil and provide fertilizer for the crops. The following hedgerow species are recommended: *Flemingia macrophylla* (syn. *congesta*), *Desmodiumrensonii, Calliandracalothyrsus, Gliricidiasepium, Leucaena diversifolia*, and *L. leucocephala.*
5. **Cultivate alternate strips.** Spaces between rows of NFTS are called strips or alleys where crops are to be planted. Cultivate alternate strips (strips 2, 4, 6, and so on) so that the uncultivated soil will hold the soil in place to prevent erosion.
6. **Plant permanent crops.** When the NFTS is sown, plant permanent crops such as cacao, coffee, and banana (same height). The spots for these permanent crops are only to be cleared and dug. Use weeding until the hedgerows are tall enough to hold the soil in place. Plant permanent crops in every third strip. Take note that tall crops should be placed at the bottom while short ones are placed on top.
7. **Plant short-term crops.** Pineapples, corn, sorghum, upland rice, and sweet potato are short and medium-term crops that can provide regular food source and income to farmers. Plant these crops between strips of permanent crops; wait for the permanent crops to bear fruits.

8. **Trim nitrogen-fixing trees.** Trim the growing hedgerows to a height of 1 m–1.5 m from the ground every 30–45 days. Pile the trimmings on the soil surrounding the crops. These will serve as an excellent natural fertilizer. This method is cost-efficient and environment-friendly since only a minimal amount (1/4 of the total fertilizer requirement) of commercial fertilizer is needed.
9. **Practice crop rotation.** Good crop rotation is when cereals like corn, upland rice, or tubers are planted on the area where legumes were previously cultivated. The practice maintains the fertility and rich condition of the soil. Pest control and weeding should be done regularly.
10. **Build green terraces.** Pile rice straws, stalks, twigs, branches, leaves, rocks, and stones at the base of NFTS rows to enrich the soil and control erosion. Permanent green terraces will be formed as the years pass, which will eventually hold the soil in its place.

APPLICATION

Adaptation

SALT adoption level is relatively high. The holistic approach in this system not only conserves the ecosystem but also provides extra income to farmers throughout the year. Improvements and continuous adoption of SALT, together with the implementation of best practices, can build resilience to erosion, soil degradation, income loss, and food insecurity. The efficient use of land in all aspects is what makes SALT viable as CRA.

Mitigation

SALT requires minimum usage of commercial fertilizer since a bulk of its fertilizer is sourced from the nitrogen-fixing trees and shrub trimmings. The method enriches and firmly holds the soil to prevent erosion and water runoff.

Natural vegetative strips. Natural vegetative strips (NVS) are narrow strips of naturally occurring herbs and grasses left unplowed to allow vegetation to flourish. These strips are used as barriers or buffers to prevent soil erosion caused by heavy rains and intensive cultivation (Figure 2.42). Some farmers were already practicing the method before the intervention of other organizations. NVS is a low-cost method since planting materials are not required and minimal labor for maintenance is needed. Land users find NVS favorable because it effectively mitigates soil erosion and surface runoffs. The strips filter pesticides, nitrates, and soluble phosphorus to avoid surface runoffs. NVS controls soil erosion by more than 90 percent and improves water infiltration during heavy rains. During and after the establishment of the contour lines, farmers can plant fruit and timbers above the NVS. These trees and other perennial crops can be a source of additional income for farmers throughout the year, however, the practice could cause shading to the adjacent annual crops.

Figure 2.42 Natural vegetative strips are used as barriers for soil erosion prevention

(Photo credit: FAO)

The number of strips in the area depends on the slope's steepness. If the slope is steeper, more areas should be allotted for strips. It is recommended that the number of strips is increased when the slope is steep. Weed infestation is not a problem if farmers continuously maintain the NVS area through steady cultivation.

METHODOLOGY

Layout contour lines with an A-frame, or use the "cow's back" method (cow determines the contour by walking across the slope; the cow's back must be leveled to confirm the contour). The contours serve as initial guide for plowing. To allow the establishment of vegetation, leave the 0.3 m–0.5 m wide strips unplowed. The vegetative strips slow down and infiltrate runoff during intense rains. The collected eroded soil on and above the strips will form natural terraces over time. This formation is assisted by soil movement through tillage (tillage erosion) and plowing along the contour between the NVS. Trim the vegetation on the established NVS (once before crop planting and once or twice during cropping)and maintain it at a height of 5 cm–10 cm. Use the trimmed materials during land preparation and apply them as mulch to the cropping area. These can also be used as fodder for livestock.

APPLICATION

Adaptation

NVS technology is easy to establish and maintain. Farmer groups and cooperatives can take it as an opportunity to intensify information and learning campaign for its wide-scale adoption. Since NVS uses naturally occurring grass species, less labor and input requirements are needed. Cut materials from NVS can be used as fodder for livestock and mulch for preserving soil moisture and weed suppressant. In terms of productivity, planting perennial crops and timber trees above the NVS can provide additional income for farmers and land users.

Mitigation

The NVS technology mitigates soil erosion and surface runoffs. It can effectively reduce such incidence by 90 percent. Soil nutrients are conserved in the NVS, which means that fertilizer usage may decline after some years.

Stone bunds and small basins. Stone bunds and small basins is a low-cost technology that primarily prevents soil erosion and excessive runoff. Rocks and stones are piled along the contour to control erosion and runoff (Figure 2.43). These 0.4-meter-wide stone bunds slow down the runoff and impound soil that moves downslope. The small basins are created by removing rocks and using them as barriers. Water is impounded and allowed to infiltrate in the small basins. When the soil is carried with the runoff, it is deposited in these basins. Collected soil will be used for high-value-crop cultivation. Areas that are rich in limestone and have shallow soil are suitable for this technology. Natural terraces can form in the area through time. Limestone or other rock outcrops are used to build check dams along small waterways. Eventually, these check dams form flat-bottom valleys where transplanted rice can be grown. In the long run, a series of check dams can form terraces along the valley floor.

Figure 2.43. Stone bunds and small basins is a low-cost technology that controls soil erosion and excessive runoff

(Photo credit: PhilCAT SLM [2016])

The effects of stone bunds on erosion can be categorized into short- and long-term, based on the duration of their effectiveness in controlling soil erosion (Morgan 1995; Bosshart 1997; Nyssen et al. 2006). The potential short-term benefits are the reduction of slope length and the formation of small retention basins intended for runoff and sediments (Bosshart 1997; Nyssen et al. 2006). In return, the volume and erosion risk of overland flow is reduced. Medium and long-term benefits include reduction of hill slope gradient due to progressive formation of terraces, development of vegetation cover on the bunds, and land management changes.

The stone bunds are built along the natural contour of the land using quarry rock and stones. The stone bunds should be 20 cm–30 cm from the ground and spaced 20 m–50 m apart, depending on the terrain inclination. Pile the stone bunds to form a barrier that will slow down water runoff and allow the rainwater to seep into the soil and be evenly distributed throughout the area. Fine, nutrient-rich layers from soil and manure particles are built-up with the slowing down of water runoff.

Stone bunds are efficient measures for soil water content improvement through runoff control. Soil water can reach 59 percent in plots with barriers and 84 percent in plots with barriers and organic matter. Stone bunds conserve soil moisture longer during erratic rainfall, which aids in alleviating water stress during dry seasons. Crops planted in plots with contour stone bunds can yield two to three times more.

This low-cost technology needs to be usually implemented by the community with development project support for sustainability and replication purposes.

Methodology

Stone bunds help to control drainage basin erosion and allow water to seep into the soil, providing better crop yields and better access to potable water. Combined with other agricultural production techniques, stone bunds increase production while preserving and improving soil quality. In constructing stone bunds, follow these steps:

1. Select eroded or abandoned land for constructing stone bunds.
2. Using a water tube level, survey contours for the bunds from the top of the field then downward.
3. Mark the ground with lines using a hoe.
4. Dig each bund to form a shallow foundation trench. The foundation trench should be 5 cm deep and 30 cm–40 cm wide.
5. Place large stones at the rear of the trench (downslope side).
6. Use smaller stones to construct the rest of the bund. The stones must be carefully packed, especially at the foundation. Pile up the soil from the trench in front of each bund.
7. The spacing of the stone bunds should be 15 m–30 m apart. The bunds should be 25 cm–30 cm high and 30 cm–40 cm wide at the base.

8. If the selected land is an abandoned plot, leave the stone bunds for a year to catch sediment. Begin cultivation in the second season.
9. During wet seasons, plant Andropogon grasses and tree seedlings alongside the bunds for support.

APPLICATION

Adaptation

As a climate change adaptation measure, stone bunds protect the hilly land during years of heavy rainfall. In drought years, increased water availability for plants can result from improved rainwater harvesting, retention, and infiltration into the soil through stone bunds and small basins. Lower soil temperature can be achieved if good vegetation cover is established on the stone bunds. This provides protection from wind erosion and conserves biodiversity.

Mitigation

Under wetter and drier climate change scenarios, stone bunds are proven beneficial. The technology reduces climate-induced runoff and erosion during wetter years. In drier years, it significantly contributes to water harvesting. Sturdy and effective soil erosion control structures constitute an important mitigation measure. In addition, if grass strips and tree lines are planted along the contour, they can immensely contribute to carbon sequestration in the soil.

Approaches

Sustainable corn production in sloping areas. Corn is considered one of the staple crops in the Philippines. The introduction and adoption of various technologies for corn production have been significantly increasing due to the high demand for corn. Idle and barren lands that are used for corn production have also been increasing. These areas will become vulnerable to soil erosion and surface runoffs in the long run. Sustainable land-use management that integrates soil and water conservation practices is needed to restore ecological balance in sloping areas and sustain productivity level of corn farmers.

The Department of Agriculture (DA), in cooperation with the DA-Bureau of Soils and Water Management (BSWM) and Croplife Philippines, has implemented the sustainable corn production in sloping areas (SCoPSA), which aims to increase productivity of corn farmers by promoting sustainable land-use management (Figure 2.44). Technologies that focus on soil and water conservation and soil fertility improvement with mitigation strategies against soil erosion are used in the techno-demo farms.

Figure 2.44. SCoPSA aims to increase productivity of corn farmers by promoting sustainable land-use management

(Photo credit: DA-Agricultural Training Institute)

Methodology

To establish a techno-demo farm for SCoPSA, follow these steps:

1. Establish contour lines in sloping areas using the A-frame.
2. Establish buffer strips such as natural vegetative strips (NVS), hedgerow intercropping, buffer cropping system, and improved multi-storey buffer strip cropping. Place buffer strips that are 50 cm wide along the contour lines to prevent soil erosion and surface runoffs. Plant perennial crops and hedgerows species to serve as vegetative barriers along the contour. Plant corn alternately with legumes to preserve good soil condition.
3. Improve soil fertility through contour tillage, crop rotation, improved fallow or alternate strip arrangement, and crop residue management (e.g., composting, residue incorporation, and mulching)
4. Install erosion pins to monitor soil and surface runoffs between contour lines.

APPLICATION

Adaptation

The SCoPSA project of DA, DA-BWSM, and Croplife Philippines has been well-received by corn and hilly land farmers in the Philippines. SCoPSA teaches these farmers to sustain the land they have been using for corn production instead of abandoning it after harvest. Like SALT and NVS, SCoPSA promotes food production for both consumption and income generation for corn farmers. Crop rotation is practiced to improve soil fertility by incorporating nutrients in the soil.

Mitigation

SCoPSA mitigates soil erosion and surface runoffs by establishing buffer strips along with the contour and gully stabilization structure. One of the primary objectives of the project is to conserve soil and water in sloping areas through sustainable corn production and thus prevent the expansion of idle and barren lands in the country. Adoption of climate-friendly agronomic practices such as crop residue management and contour tillage farming, which are integrated in SCoPSA, can significantly reduce GHG emission (PhilCAT SLM 2016; Labios and Malayang 2015).

Conservation farming village. There is a need to address pressing problems in the uplands, which include high influx of farmers in search of areas to till due to increased land conversion, poverty, and low productivity. Soil erosion and land degradation are major problems in the uplands. Equipping farmers and communities with skills and technical information on land management can reverse the current situation in the uplands.

Conservation farming village (CFV) is a system that promotes adoption of sloping land management technologies through science and technology (S&T)-based farming methods (Figure 2.45). CFV aims to capacitate farmers and stakeholders in efficiently managing fragile upland resources and to conduct interventions to sustain the development of upland communities. Linkages and partnership building between research-extension agencies and organizations are vital in capacity building. CFV establishes a support system from LGUs to mobilize upland resources using various strategies and technologies. It seeks to catalyze transformation of traditional farming systems into resilient and sustainable production systems in the uplands.

METHODOLOGY

The implementation of CFV uses the following approaches:

- Capacity building trainings that are focused on conservation farming, sloping land management, agroforestry, climate change, organic farming/fertilizer production, and rainfall and soil erosion measurement.

Figure 2.45. CFV Model Farm in Ifugao

(Photo credit: Catherine C. de Luna CFNR-UPLB)

- Establishment of S&T-based conservation model farms in selected locations in the Philippines.
- Incorporation of CFV-related activities in the LGU Annual investment plan.
- In relation to the annual investment plan, forwarding and lobbying for provisions to livelihood and support mechanisms for farmers.
- Through CFV, building linkages and partnerships with service providers to give access to other technology options, livelihood opportunities, credit and financing sources, and exposure to other possible donors.

APPLICATION

Adaptation

CFV develops, applies, and validates integrated farming systems (e.g., conservation farming, sloping land management, agroforestry, and organic farming or fertilizer production).

Mitigation

By establishing CFVs, the impact of soil erosion and land degradation in the uplands will be mitigated. Efforts in implementing CFV translate to the restoration of land and development of protective measures against climate change.

Soil conservation guided farming system. Soil conservation guided farming system (SCGFS) is an approach to land-use management that uses technologies such as terracing, multi-storey, contouring, and agro-pastoral technology to optimize the development of soil and water resources (Figure 2.46). It primarily aims to give agricultural livelihood to farmers while protecting and sustaining the ecosystem in hilly lands. Specifically, SCGFS establishes community-based techno-demo farms and learning centers to promote soil and water conservation, as well as small-scale irrigation projects. The learning centers focus on promoting and disseminating approaches on effective soil and water conservation for wide-scale adoption. Linkages and partnerships among local stakeholders are vital in protecting the upland resources and watersheds. Thus, it involves farming systems that utilize appropriate land use, proper combination of crop and livestock commodities, and best practices in soil and water conservation.

SCGFS was designed as a participatory approach by the DA-BSWM. Field surveys, particularly topographic and land resources surveys, are employed in different sites of the techno-demo farms. Using the maps developed from the survey results, farm development plans are drafted. LGUs, farmers, and other stakeholders modify the presented farm development plan. Capacity building for farmers commences after finalizing the farm development plan. When the farmers have the right skills and knowledge on SCGFS, the farm development plan is implemented. DA-BSWM monitors and evaluates the outcomes from the implementation of SCGFS.

Methodology

In selecting appropriate soil conservation practices for hilly land, consider the following:

- Multi-storey cropping is a cultivation of a mixture of crops with different height and growth characteristics (multi-storey), which optimizes soil, moisture, and space utilization. It is a combination of planting tallest storey such as coconut trees, medium storey such as coffee and banana, and lowest storey such as pineapples and other root crops.
- Residue incorporation of corn stalks for the succeeding crop enriches the soil during land preparation.
- Planted vegetative strips are economic crops and forages planted in strips. The strips are located along the contour to avoid soil loss from erosion. The technology establishes alley crops, contouring, and planting of vegetative strips.
- Windbreak is a method of planting herbaceous plants or trees along the property boundaries to reduce the force and shelter the crops from the force of the wind. Windbreak technology can also be a source of fodder and fuel.

Figure 2.46. SCGFS uses technologies such as terracing, multi-storey, contouring, and agro-pastoral technology to optimize the development of soil and water resources

(Photo credit: PhilCAT SLM [2016])

- Contour farming using hedgerows is a technology commonly practiced in sloping areas. Hedgerows are established along the contours. Annual and cash crops are planted in the alleys between the hedges.
- Seed production of multipurpose shrubs and legumes is a popular soil conservation practice in sloping areas where flemingia (*Flemingia macrophylla*) and indigofera (*Indigofera tinctoria*) are proliferated along the contours.
- Vegetable terracing establishes point terraces from the contours along the mountain slope. These point terraces are intended for crop production.
- Trees as buffer zones are established in the area to inhibit pests from infesting between the blocks. Trees that are indigenous and endangered are used for this purpose. They also provide shelter and food source for wildlife.
- Contour straight block layout is a packaged soil and water conservation technology that integrates contouring, bedding, and blocking

- Natural vegetative strips establish strips of land, which are marked out on the contour. These strips are unplowed to form permanent cross-slope barriers of naturally occurring grasses and herbs.
- Small water impounding is a soil and water conservation technology that supplements irrigation during the dry season in the uplands. It is a water harvesting and storage structure that is made of earth embankment spillway, outlet works, and canal facilities. It reduces the volume and force of runoff, which minimizes the eroding power of water. As a result, soil erosion and silting of fertile bottomlands are minimized.

APPLICATION

Adaptation

SCGFS seeks to improve the socioeconomic conditions and resilience of upland farmers. Enhanced productivity is sustained through time while conserving resources. Eventually, the stability in production ensures self-sufficiency in food and other basic necessities. Upland farmers are taught to cope by maximizing the available resources combined with CRA practices like SCFGS.

Mitigation

Soil conservation alone is enough to mitigate GHG emissions, which results from improper use of fertilizers and pesticides. The selection of various soil and water conservation practices promotes a diversified farm layout which benefits both the farmers and the environment. These practices mitigate soil erosion and water runoff and protect the fertility of the land and the hilly land ecosystem.

HIGHLAND ECOSYSTEM

Technologies

Firebreak and green break technology. Firebreaks and green breaks are established barriers to prevent and control the spread of forest fires to other areas. They protect forest trees from wildfires and simultaneously protect wildlings from disturbances (Figure 2.47). Wildlings grow from seeds scattered by birds and insects during cross-pollination. They are gaps in vegetation that are intended for fire control. Typically, 1,000-m long and 10-m wide firebreaks are located along the periphery, boundary, or top of the ridge, where they can slow or stop the fire from spreading. Green breaks are established in the gap portions of the firebreaks where fire-resistant plant species are grown. *Kakawate* (*Gliricidiasepium*), banana (*Musa*), abaca (*Musa textilis*), *malunggay* (*Moringa oleifera*), and cassava (*Manihot esculenta*) are examples of fire-resistant plants. The green breaks are also planted with cash crops as immediate and regular food source and income generator for upland farmers.

Figure 2.47. Firebreaks and green breaks prevent and control the spread of forest fires to other forest areas

(Photo credit: PhilCAT SLM [2016])

Firebreaks are located every 10 ha to form a block. However, the slope of the area should be considered when establishing firebreaks. Fire spreads more quickly in higher slopes than in leveled areas. Therefore, it is recommended that more firebreaks be established in areas with higher slopes.

Methodology

Remove all combustible materials such as dead woods and cogon grasses with a hoe or plow. On either side of a 10-m wide firebreak, plant fire-resistant species like *kakawate*, with 1.5 m spacing between plants. These will serve as the green break. *Kakawate* is believed to have high nitrogen content and is fire-resistant and drought-resistant. Firebreaks and green breaks are maintained before the onset of the dry season. Maintenance is done by weeding invasive grasses and planting of root crops, while pruning of *kakawate* is done every three years. For a community, establishing and maintaining firebreaks and green breaks are best done through *bayanihan* or rotational schedule of labor.

Forest reserves are concrete examples of established firebreaks and green breaks. They have high biodiversity and, therefore, significantly contribute to the prevention of forest fires and conservation of indigenous plants and animal species. Smallholder farmers have applied the technology and have been maintaining it to secure their forest reserve.

Application

Adaptation

The firebreak and green break technology aids in the conservation of biodiversity in mountains and forest reserves. Cash crops planted on green breaks are beneficial to farmers as immediate food source and income generator even in off-seasons.

Mitigation

Firebreaks are effective mitigation strategy for forest fires. *Kakawate* planted between firebreaks also serve as soil erosion control during the wet seasons. *Kakawate*, which is fire-resistant and drought-resistant, can be planted along with other annual and fire-resistant cash crops.

Rainfed rice terraces. Rainfed rice terraces are usually seen in the mountainous area of the Cordillera Administrative Region (CAR) in the Philippines. Rice planted in terraces on steep mountain slopes is an ancient method of rice cultivation that is still practiced to this day in CAR. The terraces were manually constructed on steep slopes, while small terraces are located in narrow valley bottoms (Figure 2.48). The terraces curve along the contour and are 1-m–5-m wide, depending on the slope. Riser's height is between 1 m and 2 m. Rainfed water, which is the primary water source for the crops, is impounded in the terraces, preventing soil erosion. Organic matter that enriches soil fertility is preserved by the impounded water and prevents erosion. Thus, the terraces are beneficial to farmers because of their agricultural use and assistance in protecting the environment through flood mitigation.

METHODOLOGY

Traditionally, terraces are prepared manually. The soil is puddled using the farmer's bare feet and levelled by moving the soil from the upslope to the downslope. Bunds are constructed at about 50 cm–100 cm, while lip is established at the edge of the terrace. The contour lines are determined by eye estimation. Bunds are maintained by adding a few centimeters of soil to breached bunds. In addition, farmers plant napier grass to strengthen the bunds and can serve as animal fodder. Soil disturbances may lead to breaching of bunds. The technology is mostly practiced in areas between 2,000–2,500 MASL. The cool climate due to high elevation slows down crop maturity. Cabbage and sweet potato are grown after harvesting rice.

APPLICATION

Adaptation

Proper land use to increase productivity and conserve biodiversity is observed in rainfed paddy rice terraces. Since this traditional method has been around for a thousand years, upland farmers have learned to continually develop the method to cope with the changing climate.

Mitigation

The water impounding abilities of the terraces have contributed to soil erosion control in the mountain slopes.

Figure 2.48. Rice planted in terraces are manually constructed on steep slopes or narrow valley bottoms

(Photo credit: CM Santos)

Approach

Community-based forest management. Community-based forest management (CBFM) is an integrated approach that is based on organized efforts to work with communities in forestlands to protect, manage, rehabilitate, conserve, and sustain resources in partnership with various stakeholders (Figure 2.49). CBFM aims to develop and protect forestlands through sustainable forest management practices such as agroforestry. It also aims to provide forest communities with additional income sources to slowly alleviate poverty and hunger in the uplands. CBFM supports the provision of long-term land tenure, access to forest resources, and forest stewardship (issuance of CBFM agreements) among community members. CBFM agreement holders undergo capacity building trainings to become managers of climate-resilient forestland resources. Participatory development paradigm enables communities to plan and implement policies to protect forests and promote sustainable use since forest resources are the communities' assets (Guiang et al. 2001).

Methodology

CBFM employs methods in agroforestry, plantation establishment, enrichment planting, and forest protection and conservation. Agroforestry is a land use management system in which forest and fruit trees, shrubs, annual crops, and livestock are grown on the

Figure 2.49. CBFM organizes communities in forest lands to protect, manage, rehabilitate, conserve, and sustain forest reserves

(Photo credit: Forestland Management Project DENR-JICA -2)

same land. Combining agriculture and forestry approaches has reaped various benefits such as increased biodiversity and mitigation of climate-induced events. Plantation establishment is the rehabilitation of degraded grassland areas through replanting of forest trees. Enrichment planting, on the other hand, improves forest cover and species diversification by planting rattan, fruit trees, and other indigenous tree species along with existing trees in the forestland. Forest protection activities against fires, illegal encroachments, and illegal cutting are prescribed in the communities. Apprehending illegal encroachers and patrolling the forest are two CBFM provisions for forest and forestland protection. Selective cutting of timber (both planted and naturally growing trees), thinning and timber stand improvement, assisted natural regeneration of trees, and biodiversity conservation are sustainable practices for forest conservation. Other sustainable forest management practices in the community forestry sites include zoning and forest planning, and plantation development and management.

Technical support (e.g., capacity-building trainings and awareness-raising activities) is provided to the land user, field staff, and agricultural advisor. Moreover, demonstration areas and site visits are established and conducted to assess the progress of CBFM in the target location.

APPLICATION

Adaptation

Forest communities are given opportunities to protect and sustain the forestlands while still earning some income. CBFM empowers forest communities to actively coordinate and build linkages with local government units and other stakeholders in achieving forest protection and conservation. It also promotes social justice through security of tenure and right to reclaim and rehabilitate forestlands.

Mitigation

Through CBFM efforts, increasing forest cover, species diversity, and proliferation of forest and fruit trees mitigate impact of climate change on forest communities and forestlands. Trees grown along crops are proven to further decrease carbon development. They increase carbon storage in biomass vegetation and in soil.

COASTAL ECOSYSTEM

Technologies

Artificial reef. The concept of artificial reefs has been around for decades. It started when submerged shipwrecks were naturally converted to nesting grounds and shelters of marine species. Bridges, lighthouses, and other offshore structures also function as artificial reefs. Some materials used for artificial reefs, such as wood and car tires, have been discontinued due to their poor durability and toxic properties. Thus, new techniques began to focus on smart and sustainable restoration of coral reef ecosystems (Figure 2.50).

Stability over time and structure type should be considered in constructing artificial reefs. It is equally important to consider the engineering aspect and scope of the artificial reef in reef unit restoration. Reef units can range from simple to intricately designed structures intended to mimic a real reef environment. Durable and safe materials for construction include concrete, steel, limestone, rocks, and fiberglass. The shape, height, and weight of the reef units and sets should also be considered for stability and durability. Furthermore, the ratio of weight of material to surface area is crucial for the stability of reef units and sets.

Figure 2.50. Sustainable restoration of coral reef ecosystems

(Photo credit: PCAARRD)

Initial data gathered from the nationwide assessment of Philippine coral reefs from 2015 to 2017 in 166 stations in Luzon, Visayas, and Mindanao (31 provinces) indicate that more than 90 percent of the sampled reefs are in the poor and fair categories. Based on the weighted reef area of each biogeographic zone, the average hard coral cover was 22 percent (95% confidence intervals: 19.4, 24.9), indicating a marked decline in the condition of local reefs over the last four decades (Licuanan et al. 2017).

Concrete is most commonly utilized in structuring artificial reefs because it is readily available, and it can settle on the seabed despite strong current. Juvenile corals and other invertebrates need a hard substrate where they can attach themselves and grow--concrete facilitates a good environment for that. Prefabricated concrete structures called reef balls and jackstone-type artificial reefs are recent developments in the artificial reef system.

After Typhoon Haiyan slammed into the coast of Western Visayas, the municipality of Concepcion, Iloilo, together with concerned organizations, initiated coral reef rehabilitation. Local communities in Concepcion built jackstone-type artificial reefs made from concrete. Coral fragments were attached to these artificial reefs for anchor. Eventually, these coral fragments will grow into full-sized reefs.

Artificial reefs are built to increase fish yield, conserve reef ecosystem and biodiversity, and prevent coastal erosion by holding sediment on shallow areas. It plays a critical role in coral reef restoration. Using the right material for structuring reefs that are similar to the natural basis for coral growth must be further researched and developed.

METHODOLOGY

In installing artificial reefs on seabeds, follow these guidelines:

1. Choose low-current locations or sites that are conducive to reproduction and feeding.
2. Test reef units or set first in outside water before the actual installation to save valuable building time and material. This may be necessary in case the units need further adjustments. In this case, jackstone-type artificial reefs made from concrete are used.
3. Transport the jackstone-type artificial reefs to the chosen building site and carefully drop them one by one into a leveled seafloor. The weight of the jackstone-type artificial reef is enough to hold them in place, but anchoring may be needed if the tidal current is strong.
4. Attach coral fragments to the jackstone-type artificial reefs using cable wires. These fragments will grow into full-sized reefs over time.
5. Monitor, maintain, and protect the installed artificial reefs. It takes one to two years before the structure is completely covered with budding corals, invertebrates, and fish shelters.

APPLICATION

Adaptation

Artificial reefs provide habitat and protection for biodiversity. It is an innovative management solution for coral reef recovery and resilience.

Mitigation

Although artificial reefs do not directly mitigate ocean acidification, they can provide additional protection and resilience to marine animals

Postharvest facilities and technologies (the solar tunnel fish dryer). Dried fish is a staple product in coastal areas. Traditionally, the fish is preserved by salting or smoking method, and then by direct sun drying. Maintaining quality and shelf life can be a problem. Sun drying could lead to high moisture content, uncontrolled drying, and contamination. Moreover, the action of enzymes and bacteria on fish and the chemical oxidation of the fat in an open environment cause fast decay in unpreserved fish. This problem can be addressed through improved methods such as the solar tunnel dryer. This type of dryer is a semi-cylindrical walk-in type natural

Figure 2.51. Solar tunnel dryers maintain the quality of fish products and other commodities while promoting energy conservation

(Photo credit: IRRI, Mechanization and Postharvest Cluster file photo)

convection solar-powered dryer that has been developed for drying of products. Drying with a solar tunnel dryer not only maintains the quality of fish products and other commodities, but also contributes to energy conservation (Figure 2.51).

With worsening climate conditions, fish catch volume declines every year, greatly affecting the livelihood of fishermen and coastal communities. Thus, fish drying reduces production loss from fish spoilage and limited storage facilities.

METHODOLOGY

Construction and maintenance of the solar tunnel fish dryer

- The essential components of the solar tunnel fish dyer are blower, UV-stabilized plastic cover with round steel bar support frame, insulated drying floor, galvanized iron and wood frame, makeshift legs from tile bricks, and an air outlet.
- The cover of the solar tunnel is made of 200 microns UV-stabilized plastic sheet to trap heat from the sun. It also serves as a cover to protect the commodity from rain.

- About 20 percent of the total area of the drying floor is painted black to function as heat absorber.
- The heated air passes directly through the commodity being dried and the fan blows the heated air. The heated air also removes moisture from the commodity, which is being driven out through the air vent at the end of the tunnel.
- Moisture from the fish is carried with the heated air as it passes through the fish that are placed on plastic trays. The fish is not directly placed on the insulated drying floor to avoid sticking on the surface during the drying process.
- The commodity is loaded and unloaded into the drying bed by unrolling the UV-stabilized plastic cover with a handle that is connected to the GI pipe tubing that holds the plastic cover in place.

Preparing fish for drying

1. Clean and degut the fish before applying salt.
2. Place the salt-covered fish inside the solar tunnel to dry.
3. The fish can be dried from an initial moisture content of 75-85 percent down to 45–50 percent in six to eight hours drying under full sunlight. Drying can be extended for more than 10 hours when the condition is cloudy and rainy.

Application

Adaptation

Another viable option for fishermen who have limited storage facilities is fish drying using the solar tunnel fish dryer. Unlike direct sun drying, the solar tunnel fish dryer allows for quality, fast, and even drying. Since the process is controlled, the right moisture content inhibits contaminants that cause deterioration of the fish. This method is efficient and reliable even during the wet season because the dryer uses saved solar energy to function. It also improves fish products to enhance fisherfolks' productivity and income.

Mitigation

The use of solar energy for this drying equipment reduces fuel consumption and food waste by preventing fish spoilage.

Approaches

Ridge-river-to-reef approach: Reforestation, enhancement, and protection of wetlands and critical coastal ecosystems. Mangroves, locally known as *bakawan*, are planted along coastlines to form barriers against storm surge, tsunamis, and coastal erosion. Mangroves mitigate the impact of typhoons that bring strong winds and high tidal waves (Figure 2.52). Densely clustered mangroves

Figure 2.52. Mangroves, locally known as *bakawan*, serve as barriers against storm surge, tsunamis, and coastal erosion

(Photo credit: CM Santos)

obstruct the strong entry of waves and winds. Mangroves are also used for household consumption such as building materials and charcoals. However, the cutting of mangroves is prohibited by the government. Various coastal resource sustainability programs implement mangrove reforestation in coastal communities to protect mangroves from illegal loggers. The dense roots of mangroves serve as binder of soil, which prevents soil erosion. Utilizing mangroves as buffers is widely adopted in coastal communities with the support and intervention of coastal resource management programs.

Methodology

The establishment of a mangrove area is done after evaluating the potential site for rehabilitation. The ideal area should have sand dunes during low tide. A site layout is drafted to represent the adopted planting design. There are three planting designs used in mangrove area establishment:

- High-density planting of propagules with no layout. About 30,000 propagules can be accommodated per hectare using this design.
- Propagules are planted in rows with a spacing of 1 m x 1 m. This planting design can accommodate 10,000 propagules per hectare.

- Block or cluster design, which establishes clusters with 750 propagules each. The distance between propagules is 30 cm, while the distance between clusters is 10 m. This design can accommodate 5,000 propagules per hectare.

Propagules are either propagated in nursery areas or provided to the fishermen by the aiding organization or agency. Propagules are directly planted in the designated mangrove area. Planting materials are cigar-shaped mature propagules from the harvested male species of mangroves. Mangrove propagules must be directly planted after collection. They should not be exposed to direct sunlight to avoid loss of moisture. To maintain the mangrove propagules, the crop status should be monitored at all times. Missing hills should be replanted and sea weeds, barnacles, or sea debris that may damage the mangroves should be removed.

Application

Adaptation

Using mangroves as buffer to natural hazards not only protects the communities from storm surge, butalso reduces land degradation, improves production, preserves biodiversity, and protects watershed areas. Mangrove plantations have the potential to establish and develop the ecotourism of an area. Most importantly, they provide livelihood to fishermen because mangroves can be utilized for aquaculture and aquasilviculture. Planting designs for propagules are developed to cope with local conditions, such as depressed grounds and vegetation patches.

Mitigation

Mangroves mitigate the impact of extreme climate hazards such as sea level rise, storm surge, and coastal erosion. They are known to have buffering capacity to cut through wind and current forces due to their dense and extensive ground roots.

Community-based fish stock enhancement. Community-based fish stock enhancement is a method of releasing cultured juveniles into wild populations to increase natural supply and optimize harvest of fish stocks (Figure 2.53). On the other hand, restocking is a method of releasing cultured juveniles into wild populations to aid in restoring heavily depleted spawning biomass to self-sustaining levels. For large-scale harvesting, the sea ranching method is employed. This allows for the recurring release of cultured juveniles into unenclosed marine and estuaries environment (a put-grow-take operation).

In general, programs on community-based fish stock enhancement seek to promote or accelerate recovery rate by rebuilding spawning stock biomass and to ensure the survival of threatened stocks. Stock enhancement mitigates losses brought about

Figure 2.53. Community-based fish stock enhancement increases natural supply and optimizes harvest of fish stocks

(Photo credit: BFAR Region 4A)

by anthropogenic effects and natural hazards, while increasing the productivity of fishermen and coastal communities.

Observed differences in larval duration, predation, and maturity among species highly influence the approach needed for applying stock enhancement. Stock enhancement has no generic methods because each case requires its own research.

METHODOLOGY

According to Lorenzen et al. (2010), responsible approach to marine stock enhancement has three stages:

Stage 1. Initial assessment and goal setting

1. Analyze the existing fishery system.
2. Engage the stakeholders and develop an accountable decision-making process.
3. Assess the fishery performance and the potential contribution of stock enhancement to the goals of fisheries management.
4. Prioritize and choose target species and stocks for enhancement.
5. Draft system designs for stock enhancement that are anchored to fisheries management goals.
6. Assess costs, as well as economic and social benefits, of stock enhancement.
7. Develop an institutional arrangement for effective operations.

Stage 2: Research and technology development

1. Develop appropriate husbandry systems.
2. Use genetic resource management to prevent adverse genetic effects.
3. Apply disease and health management.
4. Ensure that released juveniles are identifiable.
5. Employ an empirical process for optimal release strategies.

Stage 3: Operational implementation and adaptive management

1. Identify quantitative measures of success.
2. Assess ecological impacts of stock enhancement.
3. Use adaptive management to resolve uncertainties.

Establishment of community-based multi-species hatchery

The establishment of community-based multi-species hatchery is a facility for stock enhancement. Basically, it spawns fish or crustaceans (e.g., mud crab) that are caught in the wild. Their offsprings will be saved and cultured to produce fingerlings source and seed stocks.

APPLICATION

Adaptation

Community-based fish stock enhancement improves the management of coastal fishery and aquaculture ecosystems. It increases efficiency in sustaining and intensifying production through better integrated systems, improved fish stocks, and control over losses from diseases and abiotic stresses.

Mitigation

Stock enhancement mitigates decline in fish volume brought about by anthropogenic factors, while increasing productivity of fishermen and coastal communities through sustainable management of aquatic resources, particularly fish species.

Aquasilviculture. Aquasilviculture is a management system of rearing fish, crabs, shrimps, and other crustaceans along with mangrove development. It can be defined as the integration of two systems, mainly aquaculture with mangrove forestry, otherwise known as silviculture (Figure 2.54). This integrated system facilitates good biodiversity of aquatic animals and mangroves and provides livelihood opportunities to augment farmers' income.

In the Philippines, the Bureau of Fisheries and Aquatic Resources (BFAR) has implemented its banner program on aquasilviculture called *The Philippine National Aquasilviculture Program*. The program aims to intensively rehabilitate denuded mangrove areas and conduct stock enhancement activities to conserve indigenous aquatic species intended for aquasilviculture. To accomplish the goals of the program, fishermen and coastal communities attend a series of trainings and livelihood provisions to orient them on aquasilviculture and its proper management.

The conversion of mangrove areas to aquaculture is attributed to the loss of half the total hectares of mangrove forests in the last decade. The conversion of mangrove areas to fishponds, prawn farms, salt ponds, and other industrial development is very alarming. It has caused severe deterioration of the coral reef ecosystem and reduced productivity in coastal fisheries (Flores, et al. 2016).

Integrating fish and crustacean production with mangrove rehabilitation is a sound solution to reducing mangrove deforestation rate and in establishing sustainable livelihood programs in coastal communities.

Figure 2.54. Aquasilviculture is an integration of aquaculture with mangrove forestry

(Photo credit: CM Santos)

METHODOLOGY

Mangrove rehabilitation

In 3–4 years, BFAR has targeted planting a hundred million mangrove trees to replenish the denuded coastal cover. The potential areas for mangrove rehabilitation are abandoned, undeveloped, and underutilized fishpond lease agreements and areas identified by the Department of Environment and Natural Resources (DENR) (e.g., key biodiversity areas, reforestation areas, and co-management agreement areas). Fishermen are encouraged to collect, plant, and nurture propagules in exchange for incentives. They get paid PHP 1.50 for every collected propagule, PHP 2.00 for every planted propagule, and PHP 2.50 for every live, full-grown mangrove. This management scheme has motivated fishermen to participate in collecting and nursing propagules for the rehabilitation.

Mangrove nurseries are established to plant mature and healthy propagules (e.g., *Rhyzophoraapiculata* and *R. mucronata*) at a standard distance of 1.5 m by 2.0 m between propagules at about 0.1 m deep. In every hectare, at least 3,000 mangrove propagules should be planted. Planted propagules should be supported with 0.7-cm bamboo stakes to increase survival rate. Monitoring propagule survival is by visual inspection and manual counting.

Aquasilviculture

The DENR recommends a ratio of 70:30 or 80:20 mangrove plantation to open a pond area or a water canal area. The mangroves are typically located at the center, surrounded by nipa shingles, while fishponds are at the sides. By keeping the area closed, the fisherman protects the planted mangroves against illegal firewood cutting. Each unit is stocked with tilapia fingerlings, milkfish fingerlings, mud crabs, and shrimps. The stocked species are grown to harvestable size. The aquasilviculture farm is enclosed with nets to prevent fish and crustacean stocks from escaping. Aquasilviculture increases adaptable fish production and profitability of fishermen.

APPLICATION

Adaptation

The integration of mangrove forestry, with aquaculture as a management system, addresses the goals of food security and climate change adaptation, namely, better productivity yield, additional income for marginalized communities, and conservation of natural resources such as mangroves.

Mitigation

Aquasilviculture and related national programs mitigate loss of mangrove forest cover caused by illegal firewood cutting and excessive conversion to industrial developments. Mangroves are natural buffers against extreme disasters such as storm surge and tsunamis. Therefore, initiatives on mangrove reforestation and protection are critical to both climate change mitigation and ecosystem conservation.

INFORMATION TECHNOLOGY MANAGEMENT

Technologies

Rice crop manager. The rice crop manager (RCM) is a comprehensive decision-support tool that helps Filipino farmers increase farm yield and income with minimal production costs. It was developed by IRRI as part of a research collaboration with PhilRice. The RCM aims to provide farmers with timely and regular farming advice through information and communication technology (ICT)-based decision support (Figure 2.55). All information provided is location-specific crop management. RCM also seeks to provide the Department of Agriculture (DA) with data on rice production as basis for interventions or decisions at the barangay level or municipal level.

Figure 2.55. RCM is an ICT-based decision support tool for rice farmers

(Photo credit: IRRI-RKB)

The RCM is an application that can be accessed via smartphone or computer with internet connection. It can be accessed for free at *webapps.irri.org/ph/rcm,* or downloaded for free as an app named "RCM PH" via Google Playstore. The RCM allows extension officers to give farmers a specific recommendation on nutrient, pest, weed, or water management. Usage of this tool depends on the specific variety the farmers used in their field the previous season, and the site-specific conditions of their field.

Farmers answer a series of questions and with the help of an extension officer, receive recommendations provided by the RCM. These recommendations are transferred to the farmer's phone through email or short message service.

This decision-support tool has become a rice advisory service that helps widen and strengthen the reach of extension efforts. Based on research, fertilizer applied at the proper crop stage and in the right amount to match location-specific condition is more effective, which results in improved yield. Yield improvement translates to more income for farmers.

Following the success of the RCM, field research implemented through PhilRice and IRRI has expanded to include rainfed areas, in addition to irrigated rice locations. IRRI monitors the sustained operation of RCM and provides technical assistance to the DA regional field offices and the Agricultural Training Institute.

METHODOLOGY

The following are the steps in using the RCM:

1. An extension agent downloads the RCM application on the internet.
2. The extension agent will interview the farmer using a questionnaire.
3. The extension agent submits and encodes all information to the RCM application on a cloud-based server.
4. The RCM automatically generates tailored recommendations based on the farmer's inputs.
5. The recommendations sent via email may be printed by the extension agent as hard copies for farmers or sent directly to the farmer's smartphone via SMS.
6. Each farmer's field will be given specific recommendations on improved fertilizer management (N, P, K, Zn), seed rate for direct-seeded rice, weed management, crop health management, and controlled irrigation (AWD).

APPLICATION

Adaptation

The RCM is an important decision support tool that guides farmers in properly managing their crops from planting to harvest. Aside from increasing farmers' yield and income, it efficiently utilizes every farming input, which allows farmers to prepare and adjust.

It increases resilience of farmers to the changing climate by enhancing their productivity at an optimal level. It also teaches farmers to adapt and evolve with technology (e.g., internet and mobile applications).

Mitigation

By combining climate-resilient agriculture technologies and approaches such as fertilizer management, weed management, and controlled irrigation, RCM helps reduce the production of GHG by providing safe alternatives to productivity enhancement.

Nutrient Expert® for Hybrid Maize. High corn yields in favorable growing conditions in Southeast Asia is feasible through relative adjustments in crop and nutrient management. Hybrid corn has been widely adopted in the region primarily because of its high-yielding characteristic in favorable rainfed areas. However, the domestic production of high-yielding hybrid corn has not satisfied the growing demand for corn in Southeast Asia. The International Nutrition Plant Institute launched a research project that seeks to develop a new site-specific nutrient management (SSNM) approach for hybrid corn in favorable environments and identify the best crop management practices. Since hybrid corn has climatic-genetic yield potential (12–14 t/ha), SSNM is used to close the yield gap in corn production in the region.

As part of the project, the Nutrient Expert® for Hybrid Maize was developed to help farmers increase their yield and profit by suggesting site-specific fertilizer management strategies to attain a yield goal. Based on the principles of SSNM, this computer-based decision support tool helps formulate fertilizer guidelines in cultivating tropical hybrid corn for farmers and local experts alike (Witt et al. 2009). It is a downloadable software that only requires information that can be easily provided by farmers or local users (Figure 2.56).

METHODOLOGY

The software requires the farmer or user to provide the following information:

- Current yield and nutrient management practice
- Current planting density
- Characteristics of cultivation or growing environment, as well as an estimate of current yield (if available)
- Estimate of yield responses to fertilizers N, P, and K (if known) and soil fertility determinants (e.g., texture, color, history of organic inputs)
- Crop residue management, organic input usage, nutrient carryover from previous crop (used to adjust fertilizers P and K as merited)

Figure 2.56. Nutrient Expert® for Hybrid Maize is a software for site-specific fertilizer management strategies

Nutrient Expert® for Hybrid Maize

Southeast Asia (Version 1.11, June 2013)

First time user? Working in a new location? Make sure to have the 'Settings' right!

Nutrient Expert for Hybrid Maize helps you to:

- develop an optimal planting density for your location
- evaluate current nutrient management practices
- determine a meaningful yield goal based on attainable yield
- estimate fertilizer NPK rates required for the selected yield goal
- translate fertilizer NPK rates into fertilizer sources
- develop an application strategy for fertilizers (right source, right rate, right time, right place), and
- compare the expected or actual benefit of current and improved practices.

To start, click a button

(Photo credit: IPNI)

Tailored guidelines (based on farmer's location) on fertilizer management and local sources of available fertilizer are given after responding to the questions. The application offers a simple profit analysis that compares the costs and benefits of the current practice versus those of the recommended and improved practice.

Nutrient Expert® for Hybrid Maize is a learning tool designed for quick and instant infographics. It also has user-friendly navigation commands for accessing modules. Specifically, it helps to:

- develop location-based optimal planting density;
- assess and evaluate the current practice on nutrient management; identify meaningful yield goal based on attainable yield;
- estimate rates of fertilizers N, P, and K required by the yield goal; provide fertilizer sources for the identified fertilizers N, P, and K rates;
- formulate fertilizer application strategies based on the four-nutrient stewardship of SSNM; and
- cross-analyze expected and actual benefits of current practices versus improved practices.

Most importantly, the principles of SSNM are consistent with the guidelines provided by the Nutrient Expert® for Hybrid Maize software. The tool is also guided by the primary goals of SSNM, namely:

- utilization of indigenous nutrient sources found on-farm;
- reduction of nutrient-related constraints and achievement of high yield by applying appropriate amounts of fertilizers N, P, and K;
- short-and medium-term high profitability;
- prevention of under- and over-fertilizing; and
- mitigation of soil fertility loss.

APPLICATION

Adaptation

SSNM helps in doubling the current high-yield rate and high profitability of hybrid corn in favorable environments in the Philippines. With its mobile and accessible Nutrient Expert® for Hybrid Maize software, corn farmers and local experts can easily adapt and apply SSNM in cultivating their crops. The SSNM approach shows significant agronomic and economic potentials in the long run.

Mitigation

As in any other crop, the use of SSNM in hybrid corn cultivation mitigates the depletion of soil fertility because of the adequate application of fertilizers N, P, and K. Oversaturation and emission of nitrogen oxide, which is harmful to the environment, are prevented.

Smarter pest identification technology: Using mobile applications for remote and real-time pest and disease monitoring and reporting. Crop insects and pests remain a growing constraint to achieving high yields. Plant diseases can lead to 14 percent crop loss amounting to USD 220 million and reduce crop yield by 10 percent and 16 percent of the global harvest (Agrios 2005; Oerke 2006). The problem is exacerbated by climate change, which can extend the range of pests and spread them to other areas. Crops can be protected with timely management practices; however, unknown insects and diseases left untreated may lead to further yield loss. With the rise in the usage of mobile phones and computers in modern society, web-based and digital approaches in identifying insects and pests can be utilized. Smarter pest identification technology (SPIdTech) is a web and mobile application that can identify pests, recommend management protocols, and remotely report agricultural pests and diseases (Figure 2.57).

The application will help the user determine what pests are infesting the crop, monitor the status of insect and disease infestation in the farm, and connect with plant protection experts. Created during Phase 1 of the *Smarter Approaches to Reinvigorate Agriculture as an Industry in the Philippines* (SARAI) project, the application can identify limited insect species for rice and corn through image recognition algorithms. For phase 2, SPIdTech will expand its capacity to identify pests to other SARAI crops, namely, coconut, coffee, cacao, banana, sugarcane, soybean, and tomato.

Methodology

Pest and disease identification

The insect and disease identification application can recognize insects and diseases through image processing and machine learning technology. There are three ways of using the application.

Capturing live image using built-in camera

This allows the user to capture unfamiliar pests or diseases on the farm. It works by taking a picture of the insect or disease and then selecting the crop on which it was found. The result will show the list of possible insects or diseases with a certain level of accuracy. When the user clicks the image of a pest that closely resembles the one on the farm, the app will provide the basic information such as common name, other name, Filipino name, scientific name, and description. It will also provide damage characteristics and ways to control the pest.

Uploading image from the gallery or phone storage

This allows the user to select the image from the photos stored in the gallery. Once uploaded, it will follow the same procedure in taking a picture.

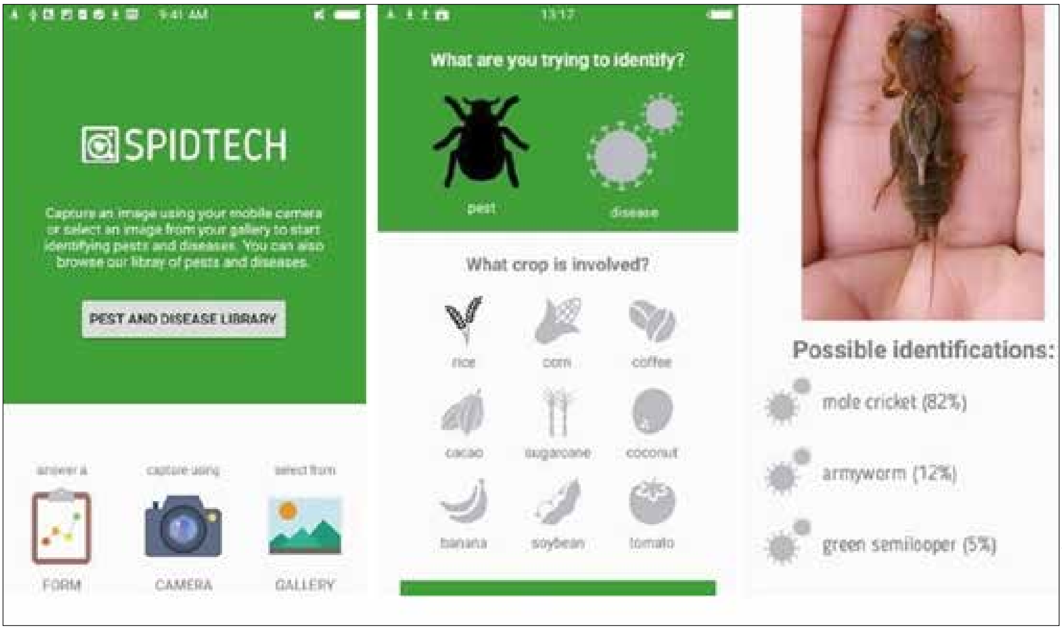
Taking a dichotomous key quiz

The user answers a series of questions describing the unfamiliar insect or disease. This feature is still being developed.

Pest and disease library

The pest and disease library is a knowledge archive of major insects and diseases of the SARAI crops. It provides relevant information for each insect and disease, including ways to control pests on the farm. It works by capturing an insect on its dorsal view with the object oriented north, and capturing the part of the plant affected by the disease. This feature is also in the development stage.

Figure 2.57. SPIdTech is a web and mobile application and database for pests and disease identification



Capture an image using your mobile camera or select an image from your gallery to start identifying pests and diseases. You can also browse our library of pests and diseases.

(Photo credit: Project SARAI)

Application

Adaptation

SPIdTech can serve as an adaptation measure in terms of early detection of the insect and disease and control of the identified pest. Through the management practices provided by the application, farmers can protect their crops from further pest attacks and crop damage, and can reduce production costs.

Mitigation

SPIdTech prioritizes management practices that apply integrated pest management (IPM). Pesticides contain fumigants that contribute to the amount of GHG in the atmosphere. IPM involves pest control methods that reduce the use of synthetic pesticides that are harmful to the environment.

AutoMon. AutoMon is an information and communications technology (ICT) tool for rice irrigation management that is based on the principle of AWD. It enables the generation of precise information on the field water status and the development of linkages among stakeholders involved in irrigation management (Figure 2.58). The tool is used for reducing water usage, computing GHG emission, minimizing labor input, and strengthening the decision platform. In addition, AutoMon allows information sharing using simple language and increases return on investment in the long run.

Figure 2.58. AutoMon is an ICT tool rice irrigation management

AutomonPH-3: The water level (from the sensor) in your field is 8.53 cm.

(Photo credit: IRRI Water-Rice Project)

APPLICATION

Adaptation

In rainfed lowland areas, AutoMon is a reliable ICT tool that helps in improving water-use efficiency based on the concept of AWD.

Mitigation

AutoMon is used in computing GHG emission, minimizing labor input, and strengthening the decision platform.

Approaches

Use of automatic weather station and unmanned aerial vehicle for proactive farming. Farming is more than just a labor-intensive endeavor; it also relies heavily on available and up-to-date weather information. Farmers, especially rice and corn farmers, depend on available weather data to make their daily farming decisions and activities. However, available weather data usually come in nonusable formats and are often not local-based. On a sectoral level, the agriculture sector is also challenged by the magnitude of logistics it entails to monitor farms and provide site-specific recommendations.

In this light, Project SARAI installed automatic weather station (AWS) units in selected agricultural areas nationwide. These are 18 sites maintained by partner state universities and colleges. The AWS units provide local and real-time weather data that can be translated to crop advisories (Figure 2.59). These crop advisories answer farmers' questions such as when to plant, how much fertilizer to apply given the weather forecast, and what insects and diseases to watch out for during the season.

The unmanned aerial vehicles (UAVs) are used to fly over selected agricultural areas, and the resulting images are processed to come up with various analyses (Figure 2.59). Some of the analyses that can be performed include vegetation index, crop stage, crop health status, and soil moisture condition.

Methodology

AWS: Proactive weather monitoring

Project SARAI has installed AWS units in 18 agricultural areas nationwide and has established a central data receiving hub in the University of the Philippines Los Baños. The AWS units can provide data on temperature, rainfall, wind speed, relative humidity, and barometric pressure. The central hub makes sure that the AWS units are working and are providing reliable weather data. The real-time weather data are then processed to usable day-to-day, farm-specific information, such as advisory on whether to start the land preparation activities, start the fertilization application regimes, or harvest earlier to avoid damages brought about by impending typhoons and other extreme weather events.

UAV: Remote monitoring for agricultural analysis

The UAV units are flown over the SARAI sites during different planting stages— from land preparation to harvesting. The images are processed and analyzed. The analysis, coupled with the real-time weather data from the AWS, can be used to provide the following information to farmers and local DA units:

- crop- and site-specific fertilizer amount;
- advisories whether the farms need to irrigate or not; and
- advisories on what possible insects or diseases the farmers can expect given the weather condition and their current crop stages.

Application

Adaptation

Project SARAI's initiatives using the AWS pose adaptation potential in terms of helping farming communities build a proactive behavior toward farm monitoring and activities.

Figure 2.59. An established AWS (top); and a UAV for proactive farming (below)

(Photo credit: Project SARAI)

Instead of waiting for the natural hazards to come, farming communities can now make decisions ahead of time. They can also adjust their farming activities depending on the weekly weather forecasts. They can decide whether to continue fertilizing in the coming week or to postpone it.

Mitigation

Project SARAI's effort to promote the UAV as a viable monitoring tool and mechanism can help in terms of providing farmers site-specific nutrient management recommendations. Instead of continuing with their usual fertilization practice, farmers have the option to reduce usual inputs depending on the analysis of the UAV images.

Water Advisory for Irrigation Scheduling System: Proactive monitoring for crop-water stress. The need for rational water management has increased because of climate change and its effects on water availability. While the traditional inundating irrigation system is still being used in many of the country's fields, many farms have been progressively using drip and sprinkler irrigation systems, especially for high-value crops. Precision farming, which uses irrigation systems, can minimize the environmental impacts of agriculture while increasing farm productivity and profitability through smart sensor technologies. An irrigation schedule and water management recommendation can be derived from the soil moisture measurements made by smart sensors and computed in a developed program. This information should be provided to farmers through simple and concise means. However, the ability of small-scale farmers to adopt this technology for crop farming is limited due to the complexity of the hardware and software components, as well as the high acquisition cost. To improve its adoptability, smart sensors should be designed to provide farmers with useful information while considering cost-effectiveness, simplicity, and minimal time investment. In this light, Project SARAI developed the Water Advisory for Irrigation Scheduling System (WAISS). WAISS uses cost-effective soil moisture sensors and meters that can provide farmers with real-time soil moisture content data and immediate recommendations on whether to irrigate or not (Figure 2.60).

This technology is to be deployed for monitoring and demo farms in 22 Project SARAI Phase 2 sites in Cebu, Nueva Ecija, Bukidnon, Misamis Oriental, North Cotabato, Isabela, Oriental Mindoro, Palawan, Ilocos Norte, Pampanga, Isabela, Leyte, Capiz, Batangas, Laguna, and Negros Occidental.

METHODOLOGY

Soil moisture sensor and data logger development

WAISS uses open-source hardware and software. The system includes one set of field units (soil moisture sensors and data logger) and WAISS software. Off-the-shelf capacitance-type sensors are wired to an Arduino-based data logger to convert analog readings to soil moisture data. The sensors are inserted in a waterproof, 3D-printed enclosure with the terminals extended out. Typically, a single set of sensors (two to three at different depths, depending on the root zone depth of the crop) is installed for

Figure 2.60. WAISS provides farmers with real-time soil moisture content data and immediate recommendations for irrigation schedule

(Photo credit: Project SARAI)

a 1-ha level field with homogeneous soil texture. An additional set may be needed for sloping areas and spatially variable soil textures.

Relevant field and laboratory work will be conducted to test and calibrate the field unit. Soil moisture data measured will be validated in the field. Meanwhile, the sensor stability test is conducted at varying soil moisture levels. The wireless transmission (via GSM) of the reliability of soil moisture readings at different battery levels is also tested. The meters and sensors produced will eventually be deployed for farmer's field use after thorough tests, calibrations, reliability assessments, and field demonstrations.

Determination of evapotranspiration using atmometers

Atmometers are water-filled devices with a wet, porous ceramic cup covered with a green fabric canvas that simulates the canopy of a crop, and in which the evaporated water is measured as reference crop evapotranspiration. Essentially, an atmometer acts as a mini-weather station at a fraction of a cost. The units are calibrated with reference to crop evapotranspiration (FAO Penman-Monteith) results at the field demo site and at different weather stations. Eventually, local fabric (canvas) materials are tested.

Irrigation water management system

The WAISS software uses the measurements sent by the field unit/s and provided crop information, and site characteristics, to provide irrigation advisory and recommendation. Users are provided with a graphical summary of water balance calculations. The calculated soil moisture content is regularly verified in the field by actual soil moisture measurements. Information from soil moisture measurements is needed for farms with no AWS and atmometer nearby. These readings taken from the soil moisture sensors are used as a tool in making irrigation decisions through WAISS. To make accurate and sound irrigation advisories and recommendations, there are different factors to consider in the customization of the WAISS software. The sensors are installed at different soil depths depending on the effective root zone depth of the crop.

Spectral reflectance of crops under different water stress conditions

A method widely used in irrigation scheduling is to determine the crop evapotranspiration based on FAO-derived reference evapotranspiration and estimated crop coefficients. The study intends to use canopy spectral reflectance in estimating crop coefficients and to improve the accuracy of predicting crop evapotranspiration for irrigation scheduling. The crop of interest from among the priority crops (except perennials) is grown in potted conditions in a screen house. Appropriate crop management practices are applied during the growing period to ensure that only drought stress will be affecting the parameters to be observed. The drought treatments to induce different water stress levels are imposed on the phenological stage of the crop when water is most critical (usually during the reproductive stage) and is done either by limiting or withholding irrigation during that period. Farmer's awareness of the benefits of irrigation scheduling can be achieved through its deployment to SARAI sites. The deployment plan includes the integration of soil moisture sensors to the irrigation scheduling advisory and recommendation. Each of the identified stakeholders is provided with WAISS that has been customized according to site and crop. Each set of WAISS consists of one field unit (two to three capacitance-type soil moisture sensors and data logger) and software.

The automated soil moisture monitoring system is deployed in farms not covered by the AWS network. Crop irrigation advisories are obtained based on soil moisture readings and outputs from the standalone irrigation scheduler software (soil moisture-based). Emphasis is given on the real-time crop advisories, such as crop water use, percent of available water, soil moisture deficit, number of days until water stress, and the amount of irrigation to be applied. A layout of equipment installation is prepared when a reconnaissance of SARAI project sites has been conducted.

APPLICATION

Adaptation

The decrease in water supply attributed to climate change has necessitated more efficient use of water in agriculture. In the face of increased use of irrigation systems in farms, WAISS enables different stakeholders to maximize their crop growth and health through proper water management.

Mitigation

Promoting the efficient use of irrigation systems can decrease impacts of agriculture on the environment without sacrificing productivity. One such system involves the use of smart sensors for crop water management, which aims to improve farm water productivity by optimizing water inputs and maximizing crop yield.

SARAI-Enhanced Agricultural Monitoring System. The Philippines is located at the Pacific typhoon belt and is visited by an average of 20 typhoons every year. These severe weather conditions cause significant damage to the agriculture sector. In 2018, the National Disaster Risk Reduction and Management Council (NDRRMC) reported that Typhoon Ompong (international name Mangkhut) brought crop losses of PHP 8.96 billion in rice and PHP 4.49 billion in corn. The damages were due to very strong winds and intense rain, which caused flooding. Filipino farmers feel helpless in this kind of situation. According to the Food and Agriculture Organization and the Asian Development Bank (2015) as cited by Cabangbang et al. (2019), agricultural monitoring and forecasting is a helpful tool in the context of food security.

The SARAI-Enhanced Agricultural Monitoring System (SEAMS) makes use of geographic information system (GIS), remote sensing (RS), and historical agrometeorological data to produce near real-time information on crop area, stage, and status (Figure 2.61). This information is useful in monitoring crop production areas in different levels, from national, regional, provincial, down to the farmer level. The system can also be utilized as an early warning system and can provide timely advisories to stakeholders when there is severe weather condition such as typhoons and droughts. SEAMS can also be used as a damage assessment tool and can provide immediate agricultural damage assessments to local government units.

METHODOLOGY

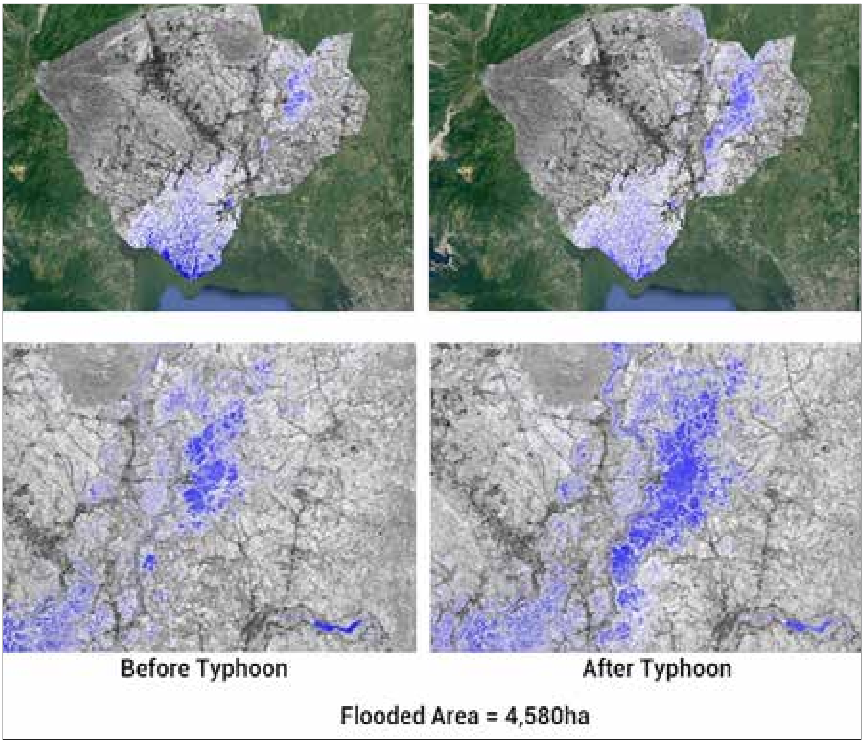
Near real-time agriculture monitoring and forecasting

SEAMS makes use of data from different platforms to come up with timely crop monitoring information. Free GIS and RS data are obtained from satellite images produced by the National Aeronautics and Space Administration and the European Union. The images are processed using a free GIS processing software. Data obtained from crop models developed by crop modeling experts from UPLB are integrated to generate crop production maps for delineating crop production areas, to provide crop health and status, and generate potential yields.

Agricultural damage assessment

The method is used in the generation of damage assessment reports. GIS and RS sensing images are used in generating crop production maps before and after a severe weather event.

Figure 2.61. SEAMS uses GIS, RS, and historical agrometeorological data to produce near real-time crop information



(Photo credit: Project SARAI)

Early warning system

SEAMS also has the ability to forecast flooding due to intensive rains brought by typhoons. The systems utilize remotely sensed historical rainfall data and flooding models to predict the potential flooding of a given agricultural production area.

APPLICATION

Adaptation

Near real-time agricultural monitoring information produced by SEAMS can be a support tool for policymakers in making sound decisions with regard to food security and sustainability. By providing immediate damage assessment reports to concerned stakeholders, there will be better allocation of government resources during severe weather disturbances. Also, timely crop-weather advisories can help farmers adjust their daily farming activities to minimize the effects of climate change on crop production.

Mitigation

The information produced by using SEAMS technology allows farmers and other stakeholders to create better decisions in daily farm activities. This will result in improved resource utilization, improved efficiency, and reduced crop losses, thereby contributing to the mitigation of climate change.

Appendix Table 2.1. Stress-tolerant rice varieties released in the Philippines from 1990 to 2019

Philippines Released Varieties For Stress Tolerance						
Variety	Ecosystem	Year Released	Breeding Institute	Maturity (Days)	Average (tha^{-1})	Maximum (tha^{-1})
PSB Rc1	Upland	1990	IRRI	121	2.4	3.9
PSB Rc3	Upland	1997	Trad var	123	2.9	6.0
PSB Rc5	Upland	1997	IRRI	122	2.9	4.2
PSB Rc7	Upland	2001	PhilRice	121	2.9	4.0
NSIC Rc9	Upland	2001	IRRI	119	2.9	5.5
NSIC Rc11	Upland	2001	PhilRice	125	2.6	4.9
NSIC Rc23	Upland	2011	IRRI	108	3.0	7.6
NSIC Rc25	Upland	2014	IRRI	107	3.0	5.3
NSIC Rc27	Upland	2014	IRRI	107	2.7	4.3
NSIC Rc29	Upland	2014	IRRI	108	2.3	3.9

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Appendix Table 2.1. continued

Philippines Released Varieties For Stress Tolerance						
Variety	**Ecosystem**	**Year Released**	**Breeding Institute**	**Maturity (Days)**	**Average (tha^{-1})**	**Maximum (tha^{-1})**
PSB Rc12	Rainfed lowland	1992	UPLB	109	3.5	6.0
PSB Rc14	Rainfed lowland	1992	UPLB	110	3.6	6.1
PSB Rc16	Rainfed lowland	1993	Trad var	125	2.7	4.5
PSB Rc24	Rainfed lowland	1994	PhilRice	117	3.1	5.8
PSB Rc36	Rainfed lowland	1995	Trad var	127	3.1	5.3
PSB Rc38	Rainfed lowland	1995	Trad var	127	3.2	5.0
PSB Rc40	Rainfed lowland	1995	Trad var	130	3.1	4.9
PSB Rc42	Rainfed lowland	1995	PhilRice	114	3.2	4.9
PSB Rc60	Rainfed lowland	1997	IRRI	113	3.6	4.5
PSB Rc62	Rainfed lowland	1997	PhilRice	117	3.7	4.7
PSB Rc68	Rainfed lowland	1997	IRRI	116	3.4	4.4
PSB Rc70	Rainfed lowland	1997	IRRI	114	3.2	4.5
PSB Rc98	Rainfed lowland	2001	UPLB	116	2.6	4.5
PSB Rc100	Rainfed lowland	2001	PhilRice	118	4.1	4.5
PSB Rc102	Rainfed lowland	2001	IRRI	117	2.3	4.4
NSIC Rc192	Rainfed lowland (drought)	2009	IRRI	106	3.7	5.7
NSIC Rc194	Rainfed lowland (flood prone)	2009	IRRI and PhilRice	112	3.5	-
NSIC Rc272	Rainfed lowland	2011	PhilRice	110	3.0	6.4
NSIC Rc274	Rainfed lowland	2011	IRRI	116	3.0	6.7
NSIC Rc276	Rainfed lowland	2011	UPLB	119	2.6	5.5
NSIC Rc278	Rainfed lowland	2011	IRRI	110	2.4	5.3
NSIC Rc280	Rainfed lowland	2011	IRRI	123	2.5	5.6
NSIC Rc282	Rainfed lowland	2011	UPLB	120	2.9	6.4
NSIC Rc284	Rainfed lowland	2011	IRRI	114	3.7	5.7
NSIC Rc286	Rainfed lowland	2011	UPLB	115	3.5	5.0
NSIC Rc288	Rainfed lowland	2011	PhilRice	118	3.0	6.6
NSIC Rc346	Rainfed lowland	2013	PhilRice	105	3.3	6.2
NSIC Rc348	Rainfed lowland	2013	IRRI	103	3.0	5.0
NSIC Rc416	Rainfed lowland	2015	PhilRice	103	3.4	5.0
NSIC Rc418	Rainfed lowland	2015	PhilRice	116	3.8	5.7
NSIC Rc420	Rainfed lowland	2015	UPLB	108	3.7	6.0
NSIC Rc422	Rainfed lowland	2015	IRRI	112	3.4	5.3
NSIC Rc424	Rainfed lowland	2015	PhilRice	110	3.6	5.4
NSIC Rc426	Rainfed lowland	2015	PhilRice	110	3.7	5.8
NSIC Rc428	Rainfed lowland	2015	PhilRice	107	3.5	4.9

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Appendix Table 2.1. continued

Philippines Released Varieties For Stress Tolerance						
Variety	Ecosystem	Year Released	Breeding Institute	Maturity (Days)	Average (tha^{-1})	Maximum (tha^{-1})
NSIC Rc430	Rainfed lowland	2015	PhilRice	111	3.5	5.4
NSIC Rc434	Rainfed lowland	2016	IRRI	105	3.4	4.6
NSIC Rc474	Rainfed lowland	2016	IRRI GSR	116	3.2	4.5
NSIC Rc476	Rainfed lowland	2016	PhilRice	113	3.6	4.7
NSIC Rc478	Rainfed lowland	2016	IRRI	113	3.8	5.8
NSIC Rc480	Rainfed lowland	2016	UPLB	107	3.2	4.4
PSB Rc44	Cool elevated	1995	IRRI	144	4.1	5.7
PSB Rc46	Cool elevated	1995	IRRI	135	4.3	5.8
PSB Rc92	Cool elevated	2001	IRRI	131	3.6	6.7
PSB Rc94	Cool elevated	2001	IRRI	133	3.3	8.6
PSB Rc96	Cool elevated	2001	IRRI	136	3.6	5.3
NSIC Rc104	Cool elevated	2001	PhilRice	154	4.3	6.3
PSB Rc48	Saline prone	1995	IRRI	126	2.7	5.3
PSB Rc50	Saline prone	1995	IRRI	118	3.0	4.3
PSB Rc84	Saline prone	2000	IRRI	111	2.0	3.7
PSB Rc86	Saline prone	2000	IRRI	113	2.1	4.3
PSB Rc88	Saline prone	2000	IRRI	116	2.2	7.0
PSB Rc90	Saline prone	2001	PhilRice	124	3.4	4.2
NSIC Rc106	Saline prone	2001	IRRI	117	2.9	4.8
NSIC Rc108	Saline prone	2001	PhilRice	128	2.9	3.8
NSIC Rc182	Saline prone	2009	IRRI	113	2.8	5.7
NSIC Rc184	Saline prone	2009	PhilRice	120	3.1	6.3
NSIC Rc186	Saline prone	2009	PhilRice	115	3.1	4.2
NSIC Rc188	Saline prone	2009	PhilRice	114	3.2	3.8
NSIC Rc190	Saline prone	2009	PhilRice	120	2.9	5.1
NSIC Rc290	Saline prone	2011	PhilRice	113	3.6	5.7
NSIC Rc292	Saline prone	2011	PhilRice	111	3.0	4.8
NSIC Rc294	Saline prone	2011	PhilRice	117	2.9	3.5
NSIC Rc296	Saline prone	2011	IRRI	117	3.2	4.6
NSIC Rc324	Saline prone	2013	PhilRice	113	2.4	6.0
NSIC Rc326	Saline prone	2013	IRRI	115	2.4	4.9
NSIC Rc328	Saline prone	2013	IRRI	113	2.4	5.7
NSIC Rc330	Saline prone	2013	PhilRice	114	2.7	5.6
NSIC Rc332	Saline prone	2013	PhilRice	113	2.3	5.2
NSIC Rc334	Saline prone	2013	IRRI	115	2.5	4.7
NSIC Rc336	Saline prone	2013	IRRI	115	3.0	5.9
NSIC Rc338	Saline prone	2013	PhilRice	114	2.5	5.1

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Appendix Table 2.1. continued

Philippines Released Varieties For Stress Tolerance						
Variety	**Ecosystem**	**Year Released**	**Breeding Institute**	**Maturity (Days)**	**Average (tha^{-1})**	**Maximum (tha^{-1})**
NSIC Rc340	Saline prone	2013	IRRI	113	2.5	4.8
NSIC Rc390	Saline prone	2014	IRRI	112	4.0	5.5
NSIC Rc392	Saline prone	2014	IRRI	113	3.2	5.0
NSIC Rc462	Saline prone	2016	PhilRice	111	3.0	4.3
NSIC Rc464	Saline prone	2016	IRRI	111	3.0	4.1
NSIC Rc466	Saline prone	2016	IRRI	115	3.2	3.8
NSIC Rc468	Saline prone	2016	IRRI GSR	121	3.6	6.1
NSIC Rc470	Saline prone	2016	IRRI	120	3.4	6.0
NSIC Rc472	Saline prone	2016	PhilRice	117	3.3	4.3

Source: PhilRice (2019)

CHAPTER 3

Prioritization of CRA Technologies and Approaches

A stakeholder workshop on CRA in the Philippines was conducted from 31 January to 1 February 2019 at the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA) headquarters, to assess technologies and approaches that increase the productivity and resilience of farmers, as well as mitigate greenhouse gasses emission. The workshop was attended by experts from different fields of agriculture, forestry, coastal and marine resources management, and information technology management (See Table 3.21). The drafted CRA compendium was introduced to the participants, and guidelines assessing and prioritizing the technologies and approaches were presented to them. Questions and suggestions on the guidelines, particularly the indicators for assessment, were raised and discussed among the participants.

For the afternoon session, the participants were grouped according to their expertise and were assigned with one rapporteur to document the discussion. Each group was given assessment and prioritization templates. The indicators and templates could be edited and modified based on what each group thought was appropriate for each technology and approach, as well as for the ecosystem.

The CRA assessment tool was used to determine the identified technologies and approaches' productivity rate in the absence of biotic/abiotic stress, resilience rate in the presence of biotic/abiotic stress, and greenhouse gas (GHG) emission rate.

The outputs of the four groups are given in Tables 3.1–3.20.

IRRIGATED AND RAINFED LOWLAND ECOSYSTEM

For the lowland irrigated ecosystem, the **alternate wetting and drying (AWD) technique** got the highest score (1.10) among the assessed CRA interventions. AWD minimizes water usage by alternating flooding and draining during rice production. Minimizing water usage during production increases farmers' resilience when drought occurs. AWD also reduces methane emissions during partial draining. **Site-specific nutrient management (SSNM)** was second with a score of 0.99. SSNM increases resilience of crops, particularly rice, by adjusting N, P, and K application to satisfy supplemental nutrients requirement. The ***Palay*Check system** approach ranked third, with a score of 0.92. *Palay*Check system increases farmers' resilience by providing guides or "Key Checks" in crop management, which ensure productivity improvement, high profitability, and environment safety (Table 3.1a).

Table 3.1a. Summary of assessment scores of CRA technologies and approaches for irrigated lowland ecosystems

CRA Intervention	Assessment			
	Productivity	Resilience	Emission	Average Score
Controlled irrigation (alternate wetting and drying technique)	0.60	1.28	1.42	1.10
Site-specific nutrient management	1.13	0.69	1.14	0.99
*Palay*Check system	1.69	0.25	0.82	0.92
Stress-tolerant rice varieties	0.65	1.15	0.71	0.84
Rice-duck system	1.24	0.67	0.39	0.77
Laser-controlled land leveling	1.26	0.60	0.29	0.72
Rice straw management	0.94	0.56	0.50	0.67
Grain drying, grain storage, grain cooling for postharvest	1.01	0.83	0.08	0.64
Sorjan system	1.21	0.40	0.20	0.60
Rice-rish system	0.94	0.31	0.20	0.48
Floating garden	0.58	0.40	0.20	0.39
Ecological engineering for biological pest control	0.44	0.50	0.06	0.33

For lowland rainfed ecosystems, **adjusting cropping pattern** ranked the highest among the assessed CRA interventions, with a score of 1.30 (Table 3.1b). Adjusting cropping pattern is an approach that develops a cropping system that adapts with and is resilient to the changing climate. The intervention includes diversified cropping, good water management practices, minimum to no soil tillage, and integration of stress-tolerant species and varieties. **Drip irrigation system** ranked second, with an average score of 1.28. Drip irrigation system is an efficient irrigation method that conserves water, improves crop yield, saves labor work and energy usage, reduces weed growth, and enhances fertilizer application. **Stress-tolerant corn varieties in rainfed lowland** ranked third, with an average score of 1.18. Stress-tolerant corn varieties identify proper application of fertilizer at the right time, rate, place; and with the right nutrients to lessen the impact of soil degradation, crop failure, and GHG emission.

Table 3.1b. Summary of assessment scores of CRA technologies and approaches for lowland rainfed ecosystems

CRA Interventions	CRA Assessment			
	Productivity	Resilience	Emission	Average Score
Adjusting cropping pattern	1.90	1.80	0.17	1.30
Drip irrigation systems	1.58	1.88	0.38	1.28
Stress-tolerant varieties of corn in rainfed lowland	1.25	2.00	0.30	1.18
Crop diversification	1.92	0.92	0.40	1.08
Site-specific nutrient management for corn after rice	0.92	1.13	1.10	1.05
Palayamanan system	1.79	0.75	0.40	0.98
Hydroponics and aquaponics	1.00	1.00	0.67	0.89
Alternate wetting and drying using pump irrigation	0.92	1.25	0.25	0.81
Agroforestry in rainfed lowland	1.33	0.50	0.38	0.74
Basket composting as organic fertilizer source	0.65	0.58	0.5	0.58
Bio-intensive gardens	0.67	0.58	0.38	0.54

Implementation feasibility determined whether the intervention is technically, fiscally, ethically, and administratively feasible. For the lowland irrigated ecosystem, **stress-tolerant rice varieties** ranked the highest, with an average score of 3.14, followed by **laser-controlled land leveling** (average score of 3.01), and **grain drying and storage for postharvest** (average score of 2.92) (Table 3.2a). Among the CRA technologies and approaches for the lowland irrigated ecosystem, the top three interventions are the most feasible since they have been developed, implemented, and funded by both international organizations such as International Rice Research Institute (IRRI), and government agencies such as the Department of Agriculture and the Philippine Rice Research Institute (PhilRice). Facilities for these interventions are also readily available in the market.

For the lowland rainfed ecosystem, **stress-tolerant corn varieties** ranked the highest, with an average score of 2.56, followed by **crop diversification**, with an average score of 2.46, and ***Palayamanan* system**, with an average score of 2.34 (Table 3.2b). The top three interventions for the lowland rainfed ecosystem have relatively high technical feasibility and social inclusivity/ gender and development (GAD) sensitivity scores as they are widely practiced by rural farmers in the Philippines. On the other hand, the cost of implementing these top interventions was higher, compared with other technologies and approaches available for the lowland rainfed ecosystem.

Table 3.2a. Summary of assessment scores of implementation feasibility for irrigated lowland ecosystems

CRA Intervention	Implementation Feasibility				
	Technical Feasibility	Cost of Implementing Intervention	Social Inclusivity and GAD Sensitive	Synergy with government plan	Average Score
Stress-tolerant rice varieties	2.88	3.38	2.31	4.00	3.14
Laser-controlled land leveling	2.88	3.50	2.27	3.40	3.01
Grain drying, grain storage, grain cooling for postharvest	2.875	3.00	2.41	3.40	2.92
Rice straw management	2.50	2.50	1.56	4.00	2.63
Rice-duck system	2.38	3.00	1.9	2.60	2.47
Site-specific nutrient management	2.75	2.63	1.54	2.71	2.41
*Palay*Check system	2.38	2.00	1.96	3.20	2.38
Sorjan system	2.33	2.83	2.00	2.00	2.29
Rice-fish system	2.38	2.88	1.88	2.00	2.28
Controlled irrigation (alternate wetting and drying technique)	2.50	2.25	1.51	2.71	2.25
Ecological engineering for biological pest control	2.75	1.88	1.78	2.20	2.15
Floating garden	2.33	2.50	1.90	1.80	2.13

Adoption barriers determined the different external and internal constraints that can affect the level of adoption of farmers and other stakeholders. The top three interventions in lowland irrigated ecosystem were assessed according to the availability of resources, access to extension service and market, and awareness and acceptability by farmers. **Laser-controlled land leveling** ranked highest, with an average score of 3.20, followed by **grain drying and storage for postharvest** (average score of 2.93), and **stress-tolerant rice varieties** (average score of 2.78) (Table 3.3a).
Table17a. Summary of assessment scores of adoption barriers for irrigated lowland ecosystems.

The top three interventions in lowland rainfed ecosystem were assessed according to availability of resources, access to extension service and market, and awareness of and acceptability to farmers. **Drip irrigation system** ranked the highest, with an average score of 2.56, followed by **AWD** (average score of 2.93), and **stress-tolerant rice varieties** (average score of 2.78) (Table 3.3b).

Table 3.2b. Summary of assessment scores of implementation feasibility for lowland rainfed ecosystems

CRA Intervention	Implementation Feasibility				
	Technical Feasibility	Cost of Implementing Intervention	Social Inclusivity and GAD Sensitive	Synergy with government plan	Average Score
Stress-tolerant varieties of corn in rainfed lowland	2.42	3.00	2.08	3.50	2.56
Crop diversification	2.29	3.14	1.90	3.40	2.46
Palayamanan system	2.43	2.71	2.04	3.17	2.34
Bio-intensive gardens	2.60	3.00	1.38	3.00	2.16
Drip irrigation systems	3.14	3.29	1.42	2.50	2.15
Adjusting cropping pattern	2.14	2.71	1.50	3.50	2.14
Basket composting as organic fertilizer source	2.29	2.14	1.63	2.67	2.12
Alternate wetting and drying using pump irrigation	2.71	2.71	1.28	3.00	2.01
Hydroponics and aquaponics	2.60	2.71	1.38	2.75	1.99
Agroforestry in rainfed lowland	2.33	2.50	1.33	3.33	1.97
Site-specific nutrient management for corn after rice	2.57	2.71	1.25	2.50	1.84

Incentive mechanism is a measure that motivates or encourages farmers and other stakeholders to adopt and replicate the CRA technologies and approaches. The top three interventions garnered high scores in accessibility to subsidy, affordable credit, capacity building, and linkage with potential market. **Rice-duck system** ranked the highest among the CRA interventions in the lowland irrigated ecosystem, with an average score of 2.61, followed by ***Palay*****Check system** (average score of 2.54), and **stress-tolerant rice varieties** (average score of 2.44) (Table 3.4a). Rice-duck system has high profitability as it utilizes both rice and duck by-products. *Palay*Check and stress-tolerant rice varieties have high resilience to crop failure.

The top three interventions for their accessibility to subsidy, affordable credit, capacity building, and linkage with potential market were the ***Palayamanan*** **system**, with an average score of 2.65, followed by **crop diversification system** (average score of 2.57), and **adjusting crop pattern** (average score of 2.34) (Table 3.4b). All three interventions are integrated crop management practices that are subsidized and promoted by farmers' cooperatives and NGOs.

Table 3.3a. Summary of assessment scores of adoption barriers for irrigated lowland ecosystems

CRA Interventions	Adoption Barrier									
	Availability of Finance	Availability of Machineries	Awareness among Farmers	Acceptability by Farmers	Availability of Labor	Availability of Reliable Water	Availability of Government Support	Access to Extension Service	Access to Market (by the Potential Users)	Average Score
Laser-controlled land leveling	3.67	4.20	4.00	3.33	2.33	2.67	2.80	3.17	2.67	3.20
Grain drying, grain storage, grain cooling for postharvest	2.67	3.67	3.14	2.86	3.29	1.67	3.33	3.00	2.80	2.93
Stress-tolerant rice varieties	2.80	2.43	2.14	2.86	3.00	2.86	3.29	3.00	2.67	2.78
Ecological engineering for biological pest control	1.75	2.67	3.83	3.33	2.50	1.50	3.33	3.17	2.80	2.77
Floating garden	1.33	2.40	3.17	2.83	3.00	2.67	3.50	3.17	2.50	2.73
Rice straw management	1.67	2.83	3.29	3.00	3.57	1.67	3.17	3.00	2.20	2.71
Rice-duck system	1.50	2.00	3.00	2.71	2.86	2.86	3.17	3.00	2.71	2.65
Rice-fish system	2.00	2.00	2.83	2.50	2.83	2.67	3.33	3.17	2.50	2.65
Controlled irrigation (alternate wetting and drying technique)	2.29	1.86	3.43	3.00	2.57	3.14	3.14	2.71	1.50	2.63
Sorjan system	1.33	2.50	3.25	2.50	2.80	2.80	3.40	2.80	2.25	2.63
*Palay*Check system	1.33	2.20	3.50	2.75	2.40	2.20	3.00	2.80	2.00	2.47
Site-specific nutrient management	2.57	2.00	2.71	2.43	2.29	2.43	3.14	3.00	1.50	2.45

Table 3.3b. Summary of assessment scores of adoption barriers for irrigated lowland rainfed ecosystems

CRA Intervention	Adoption Barrier									
	Availability of Finance	Availability of Machineries	Awareness among Farmers	Acceptability by Farmers	Availability of Labor	Availability of Reliable Water	Availability of Government Support	Access to Extension Service	Access to Market (by the Potential Users)	Average Score
Drip irrigation systems	3.33	2.67	2.33	2.67	2.67	3.33	2.33	2.33	1.33	2.56
Alternate wetting and drying using pump irrigation	2.33	2.67	3.33	2.67	2.00	3.33	2.33	2.33	1.67	2.52
Palayamanan system	2.33	2.00	2.67	2.67	2.33	3.00	2.67	2.33	1.67	2.41
Basket composting as organic fertilizer source	2.00	2.00	3.33	2.67	2.00	2.67	2.33	2.33	2.00	2.37
Crop diversification	2.75	2.50	2.75	2.50	2.60	1.40	2.00	2.75	2.00	2.36
Stress-tolerant varieties of corn in rainfed lowland	3.25	2.75	2.25	2.00	2.00	1.40	2.40	2.50	2.25	2.31
Hydroponics and aquaponics	2.33	2.00	2.33	2.33	2.00	2.67	2.67	2.33	2.00	2.30
Agroforestry in rainfed lowland	2.33	2.00	2.67	2.00	2.00	2.67	2.33	2.33	2.00	2.26
Adjusting cropping pattern	1.67	2.00	2.00	2.00	2.00	2.67	3.00	2.67	2.00	2.22
Site-specific nutrient management for corn after rice	2.33	1.67	2.67	2.33	2.00	2.33	2.33	2.33	1.33	2.15
Bio-intensive gardens	1.67	1.67	2.00	2.00	2.00	2.67	2.33	2.00	2.00	2.04

Table 3.4a. Summary of assessment scores of incentive mechanisms for irrigated lowland ecosystems

CRA Intervention	Incentive Mechanism				
	Access to Subsidy	Access to Affordable Credit	Access to Capacity Building	Linkage with Market	Average Score
Rice-duck system	2.57	2.29	2.71	2.86	2.61
*Palay*Check system	2.57	2.43	2.86	2.29	2.54
Stress-tolerant rice varieties	2.50	2.27	2.57	2.43	2.44
Grain drying, grain storage, grain cooling for postharvest	2.43	2.29	2.57	2.43	2.43
Rice-fish system	2.17	1.83	2.33	2.33	2.17
Laser-controlled land leveling	2.17	2.17	2.67	1.33	2.08
Site-specific nutrient management	1.86	1.86	2.71	1.86	2.07
Sorjan system	2.00	1.83	2.17	2.17	2.04
Controlled irrigation (alternate wetting and drying technique)	1.86	1.43	2.71	1.71	1.93
Ecological engineering for biological pest control	1.57	1.43	2.29	1.43	1.68
Rice straw management	1.43	1.29	2.43	1.43	1.64
Floating garden	1.50	1.20	2.00	1.80	1.63

Table 3.4b. Summary of scores of assessment of incentive mechanism for lowland rainfed ecosystem

CRA Intervention	Incentive Mechanism				
	Access to Subsidy	Access to Affordable Credit	Access to Capacity Building	Linkage with Market	Average Score
Palayamanan system	2.43	2.29	2.71	3.17	2.65
Crop diversification	2.57	2.29	2.57	2.86	2.57
Adjusting cropping pattern	2.29	2.14	2.43	2.50	2.34
Stress-tolerant varieties of corn in rainfed lowland	2.33	2.17	2.50	2.33	2.33
Site-specific nutrient management for corn after rice	2.00	1.67	2.67	1.83	2.04
Agroforestry in rainfed lowland	2.00	1.00	3.00	2.00	2.00
Hydroponics and aquaponics	2.00	1.00	3.00	2.00	2.00
Drip irrigation systems	1.86	1.71	2.43	1.50	1.88
Basket composting as organic fertilizer source	1.57	1.50	2.00	2.17	1.81
Bio-intensive gardens	1.60	1.33	1.83	2.20	1.74
Alternate wetting and drying using pump irrigation	1.57	1.43	2.43	1.33	1.69

The top three CRA interventions, which were most likely to be disseminated by key institutions and players were **grain drying and storage for postharvest**, with an average score of 2.88, followed by **laser-land guided land leveling technique** (average score of 2.86), and **the *Palay*Check system** (average score of 2.72) (Table 3.5a).

Table 3.5a. Summary of assessment scores of key institutions/players in disseminating CRA for irrigated lowland ecosystems

CRA Intervention	Key institutions/players in disseminating CRA							
	Government	Custom Hiring Center	Youth Farmers Based Agro-Advisory Groups	Women Self-Help Groups	Farmers/ Producers/ People's Organizations	NGO/ CSO	Private Sector/ Retailers	Average Score
Grain drying, grain storage, grain cooling for postharvest	4.00	2.83	1.67	1.33	3.50	3.33	3.50	2.88
Laser-controlled land leveling	4.00	3.50	2.00	1.00	3.17	3.00	3.33	2.86
*Palay*Check system	3.83	2.00	2.20	2.20	3.67	3.33	1.83	2.72
Rice-duck system	4.00	2.00	2.40	2.20	3.17	3.00	2.17	2.70
Stress-tolerant rice varieties	4.29	1.40	1.67	1.50	3.57	3.33	3.00	2.68
Rice straw management	3.17	1.50	1.67	1.50	3.67	3.17	2.83	2.50
Controlled irrigation (alternate wetting and drying technique)	3.67	1.83	1.67	1.33	3.33	3.00	2.33	2.45
Site-specific nutrient management	4.00	1.20	1.67	1.50	3.17	2.67	2.83	2.43
Floating garden	3.17	2.00	2.00	2.00	2.67	2.67	1.50	2.29
Rice-fish system	3.50	1.75	1.80	2.00	2.67	2.50	1.83	2.29
Ecological engineering for biological pest control	3.33	1.60	1.67	1.33	3.00	2.67	2.33	2.28
Sorjan system	3.17	2.00	1.80	1.60	2.5	2.33	1.33	2.10

The top three CRA interventions, which are most likely to be disseminated by key institutions and players were **the *Palayamanan* system**, with an average score of 3.01, followed by **crop diversification** (average score of 2.89), and **adjusting cropping pattern** (average score of 2.55) (Table 3.5b).

Table 3.5b. Summary of assessment score of key institutions/players in disseminating CRA for lowland rainfed ecosystems

CRA Intervention	Key institutions/players in disseminating CRA							
	Government	Custom Hiring Center	Youth Farmers Based Agro-Advisory Groups	Women Self-Help Groups	Farmers/ Producers/ People's Organizations	NGO/ CSO	Private Sector/ Retailers	Average Score
Palayamanan system	4.50	2.00	2.20	2.20	3.83	3.67	2.67	3.01
Crop diversification	4.33	2.00	2.40	2.00	3.50	3.17	2.83	2.89
Site-specific nutrient management for corn after rice	4.00	1.60	1.67	1.50	3.50	3.17	2.50	2.56
Adjusting cropping pattern	4.00	1.75	1.50	1.17	3.40	3.40	2.67	2.55
Bio-intensive gardens	2.83	1.75	2.00	2.00	3.20	3.20	2.67	2.52
Stress-tolerant varieties of corn in rainfed lowland	4.17	1.40	1.50	1.33	3.33	3.00	2.67	2.49
Hydroponics and aquaponics	3.20	2.75	1.60	1.40	2.75	2.80	2.80	2.47
Agroforestry in rainfed lowland	4.00	1.75	1.67	1.33	2.80	3.17	2.33	2.44
Alternate wetting and drying using pump irrigation	3.50	2.20	1.80	1.00	3.17	2.50	1.83	2.29
Basket composting as organic fertilizer source	2.67	1.75	1.83	1.83	3.00	2.80	2.17	2.29
Drip irrigation systems	3.50	2.75	0.67	0.50	2.50	2.60	2.67	2.17

Prioritization ranking of preferred CRA technologies and approaches. Based on the top three preferred CRA interventions in lowland irrigated and rainfed ecosystems, the following technologies and approaches have been selected according to their average scores (Tables 3.1–3.5):

Irrigated

1. laser-controlled land leveling;
2. grain drying, grain storage, grain cooling for postharvest; and
3. *Palay*Check system.

Rainfed

1. *Palayamanan* system;
2. crop diversification; and
3. adjusting cropping pattern.

UPLAND, HILLY LAND, AND HIGHLAND ECOSYSTEM

For upland, hilly land, and highland ecosystem, both **multi-storey cropping** and **agroforestry** got the highest average score of 2.54 (Table 3.6). Multi-storey cropping ensures high productivity and resilience as each crop component is profitable and remunerative within the system. Similar to multi-storey cropping, agroforestry

Table 3.6. Summary of assessment scores of CRA technologies and approaches for upland, hilly land, and highland ecosystems

CRA Intervention	CRA Assessment			
	Productivity	Resilience	Reduced Emission	Average Score
Multi-storey cropping	4.40	2.40	0.80	2.54
Agroforestry	4.40	2.00	1.30	2.54
Sloping agricultural land technology	3.50	2.30	1.20	2.34
Community-based forest management	2.90	1.90	1.80	2.18
Sustainable corn production in sloping areas	3.60	1.70	1.10	2.12
Conservation farming village	2.90	2.10	1.20	2.05
Livestock integration in upland farming system	2.80	1.90	1.10	1.93
Rainfed paddy rice terraces	3.20	1.90	0.40	1.84
Natural vegetative strips	2.50	1.90	1.10	1.81
Stone bunds and small basins	2.40	2.00	0.60	1.65
Soil conservation guided farming system	2.40	1.70	0.50	1.51
White corn for food and village-type white corn mill	2.70	0.60	0.50	1.28
Firebreaks and green breaks	1.40	1.20	0.80	1.16

integrates different components such as tree, crop, and livestock management to increase productivity and resilience of farmers to climate change. **Community-based forest management** got the second highest average score (2.18). Community-based forest management empowers forest communities to take on initiatives that improve forest cover, species diversity, and proliferation of forest and fruit trees, which help mitigates impacts of climate change.

Implementation feasibility determined whether the intervention is technically, fiscally, ethically, and administratively feasible. For the upland, highland, and hilly land ecosystems, **agroforestry** ranked the highest, with an average score of 4.17, followed by **community-based forest management** (4.03), and **conservation farming village** (3.87) (Table 3.7). These three interventions employ a participative approach in forest and farm management by directly involving communities and other stakeholders.

Adoption barriers referred to the external and internal constraints that can affect the adoption level of farmers and other stakeholders. The top three interventions in the upland, hilly land, and highland ecosystems were assessed according to availability of resources, access to extension service and market, and awareness of farmers. **Rainfed paddy rice terraces** ranked the highest, with an average score of 3.16, followed by **firebreaks and green breaks** (average score of 3.02), and **multi-storey cropping** (average score of 2.97) (Table 3.8).

Incentive mechanism is a measure that motivates or encourages farmers and other stakeholders to adopt and replicate the CRA technologies and approaches. The top three interventions garnered high scores in accessibility to subsidy, affordable credit, capacity building, and linkage to potential market. **Sustainable corn production in sloping areas** ranked the highest among the CRA interventions with an average score of 3.07, followed by **livestock integration in upland farming system** (average score of 3.00), and **rainfed paddy rice terraces** (average score of 2.98) (Table 3.9). These top three CRA interventions include corn, livestock, and rice production, which are highly subsidized and funded by different institutions and organizations usually through capacity building projects.

The summarized assessment score identified the top three CRA interventions that are most likely to be disseminated by key institutions and players. **Agroforestry** ranked the highest, with an average score of 3.29, followed by **livestock integration in upland farming system** (average score of 3.31), and **multi-storey cropping** (average score of 3.10) (Table 3.10).

Table 3.7. Summary of assessment scores of implementation feasibility for upland, hilly land, and highland ecosystems

CRA Intervention	Implementation Feasibility				
	Technical Feasibility	Cost of Implementation	Social Inclusivity and GAD Sensitive	Synergy with Stakeholders	Average Score
Agroforestry	4.30	4.20	4.00	4.30	4.17
Community-based forest management	4.20	4.30	3.60	4.70	4.03
Conservation farming village	3.80	4.20	3.70	4.00	3.87
Rainfed paddy rice terraces	4.20	4.30	3.40	3.80	3.83
Soil conservation guided farming system	4.00	3.70	3.50	4.20	3.77
Multi-storey cropping	4.20	4.00	3.70	3.00	3.70
Sloping agricultural land technology	3.50	3.50	3.60	4.30	3.70
Sustainable corn production in sloping areas	3.70	3.70	3.30	4.50	3.67
Firebreaks and green breaks	3.50	3.80	3.30	3.80	3.57
Livestock integration in upland farming system	3.70	2.70	3.50	3.80	3.43
Stone bunds and small basins	3.50	4.00	3.30	3.00	3.43
White corn for food and village-type white corn mill	2.80	3.00	3.10	3.80	3.17
Natural vegetative strips	3.30	2.00	3.10	3.30	2.97

Prioritization ranking of preferred CRA technologies and approaches. Based on the top three preferred CRA interventions in upland, hilly land, and highland ecosystems, the following technologies and approaches were selected according to their average scores (Tables 3.6–3.10):

1. agroforestry;
2. multi-storey cropping; and
3. rainfed paddy rice terraces.

Table 3.8. Summary of assessment scorers of adoption barriers for upland, hilly land, and highland ecosystems

CRA Intervention	Adoption Barrier								
	Availability of Finance	Availability of Machineries	Awareness of Farmers	Availability of Labor	Availability of Reliable Water	Availability of Government Support	Access to Market	Synergy with Stakeholders	Average Score
Rainfed paddy rice terraces	3.70	3.80	3.00	3.00	3.00	3.00	2.00	2.30	3.16
Firebreaks and green breaks	3.00	3.00	3.80	3.30	2.30	3.30	2.30	2.70	3.02
Multi-storey cropping	3.30	3.20	3.30	2.80	3.00	2.70	2.80	2.30	2.97
Stone bunds and small basins	3.20	4.20	3.00	3.20	2.00	3.20	2.80	2.30	2.97
Sustainable corn production in sloping areas	2.70	2.40	3.50	2.50	2.30	3.20	1.70	1.80	2.82
Sloping agricultural land technology	2.70	2.60	3.70	2.70	3.00	2.20	3.70	2.20	2.78
Soil conservation guided farming system	2.30	2.00	3.70	2.80	2.30	2.70	3.30	2.50	2.70
White corn for food and village-type white corn mill	2.70	3.00	3.50	3.00	2.30	2.20	3.00	2.50	2.70
Agroforestry	2.80	2.40	3.00	2.50	3.30	2.20	3.30	2.20	2.67
Conservation farming village	2.20	2.00	3.30	2.20	2.30	2.80	2.80	2.50	2.67
Livestock integration in upland farming system	2.80	2.20	2.80	2.30	2.50	2.50	3.20	2.20	2.65
Community-based forest management	3.30	3.00	3.20	2.50	2.70	2.00	2.30	2.70	2.65
Natural vegetative strips	2.30	1.60	3.00	1.80	2.30	2.50	2.70	2.70	2.26

Table 3.9. Summary of assessment scores of incentive mechanisms for upland, hilly land, and highland ecosystems

CRA Intervention	Incentive Mechanisms				
	Access to Subsidy	Access to Affordable Credit	Access to Capacity Building	Linkage with Market	Average Score
Sustainable corn production in sloping areas	2.60	2.80	3.30	3.50	3.07
Livestock integration in upland farming system	2.70	2.70	2.80	3.80	3.00
Rainfed paddy rice terraces	2.40	3.00	3.00	3.50	2.98
Agroforestry	2.70	2.50	2.80	3.30	2.83
Sloping agricultural land technology	2.30	2.30	3.00	2.80	2.63
White corn for food and village-type white corn mill	2.40	2.00	2.60	3.40	2.60
Conservation farming village	2.00	2.30	3.00	3.00	2.58
Community-based forest management	2.20	2.20	3.20	2.80	2.58
Soil conservation guided farming system	2.00	2.00	3.00	3.00	2.50
Multi-storey cropping	2.00	1.80	2.50	3.50	2.46
Firebreaks and green breaks	1.60	1.40	2.50	1.50	1.75
Natural vegetative strips	1.50	1.50	2.00	1.70	1.67
Stone bunds and small basins	1.20	1.20	2.20	1.80	1.60

Table 3.10. Summary of assessment scores of key institutions/players in disseminating CRA for upland, hilly land, and highland ecosystems

CRA Intervention	Key institutions/players in disseminating CRA						
	Government	Academe	Youth Farmers Based Agro-Advisory Group	Farmers/ Producers/ People's Organizations/ Women Groups	NGO/CSO	Private Sector/ Retail	Average Score
Livestock integration in upland farming system	3.40	3.00	2.80	3.70	3.60	3.40	3.31
Agroforestry	3.60	3.20	2.60	3.70	3.50	3.20	3.29
Sustainable corn production in sloping areas	3.40	2.80	2.80	3.50	3.30	2.80	3.11
Multi-storey cropping	3.00	3.20	2.60	3.50	3.30	3.00	3.10

Continued on next page

Table 3.10. continued

CRA Intervention	Key institutions/players in disseminating CRA						
	Government	Academe	Youth Farmers Based Agro-Advisory Group	Farmers/ Producers/ People's Organizations/ Women Groups	NGO/CSO	Private Sector/ Retail	Average Score
Sloping agricultural land technology	3.20	3.30	2.60	3.50	3.30	2.40	3.06
Community-based forest management	3.60	3.20	2.40	3.50	3.50	2.00	3.03
White corn for food and village-type white corn mill	3.40	2.70	2.20	3.20	2.80	3.60	2.97
Conservation farming village	3.20	3.30	2.00	3.30	3.70	1.60	2.89
Natural vegetative strips	2.20	3.00	2.80	3.30	3.20	2.00	2.75
Rainfed paddy rice terraces	2.80	2.50	2.20	3.20	3.30	2.40	2.73
Soil conservation guided farming system	3.20	3.00	2.00	3.30	3.20	1.60	2.72
Firebreaks and green breaks	3.40	2.80	2.20	3.20	3.20	1.00	2.63
Stone bunds and small basins	2.80	2.70	2.00	2.70	2.80	1.20	2.36

COASTAL ECOSYSTEM

Among the assessed CRA interventions, the **ridge-river-to-reef approach** ranked the highest, with an average score of 7.88 (Table 3.11). The ridge-river-to-reef approach aims to demonstrate sustainable river basins and coastal management practices that support livelihood, income, and ecotourism. The rationale behind this approach is to keep the river basins healthy in order to protect the wetlands and coastal environment

Table 3.11. Summary of assessment scores of CRA technologies and approaches for coastal ecosystems

CRA Intervention	CRA Assessment			
	Productivity	Resilience	Emission	Average Score
Ridge-river-to-reef approach: Reforestation, enhancement, and protection of wetlands and critical coastal ecosystems as buffers against natural hazards	7.50	7.50	8.25	7.88
Aquasilviculture	6.25	6.50	6.00	6.25
Community-based fish stock enhancement	6.25	4.75	3.75	5.25
Artificial reef	6.00	4.25	0	4.06
Provision of postharvest facilities and technologies (solar tunnel fish dryers)	5.25	4.75	2.00	3.88

from natural hazards. **Aquasilviculture** ranked second, with an average score of 6.25, followed by **community-based fish stock enhancement**, with an average score of 5.25. Aquasilviculture is an approach that integrates mangrove reforestation and livelihood provision to help address climate change and food security among coastal communities. Community-based fish stock enhancement has been recognized as an essential strategy that can sustain and increase coastal fishery resources.

Implementation feasibility determined whether the intervention is technically, fiscally, ethically, and administratively feasible. For the coastal ecosystem, **ridge-river-to reef approach** and **community-based fish stock enhancement** ranked the highest, with an average score of 4.13, **followed by aquasilviculture**, with an average score of 4.06 (Table 3.12).

Adoption barriers referred to the external and internal constraints that can affect the adoption level of farmers and other stakeholders. The top three interventions in the coastal ecosystem were assessed according to availability of resources, access to extension service and market, and awareness of and acceptability to farmers. **Ridge-river-to reef approach** ranked the highest, with an average score of 4.28, followed by **aquasilviculture** (average score of 4.03), and **community-based stock enhancement** (average score of 3.86) (Table 3.13).

Incentive mechanism is a measure that motivates or encourages farmers and other stakeholders to adopt and replicate the CRA technologies and approaches. The top three interventions garnered high scores in accessibility to subsidy, affordable credit, capacity building, and linkage to potential market. The **ridge-river-to-reef approach** ranked the highest, with an average score of 4.25, followed by **aquasilviculture** (average score of 4.14), and **community-based fish stock enhancement** (average score of 3.94) (Table 3.14).

Table 3.12. Summary of assessment scores of implementation feasibility for coastal ecosystems

CRA Intervention	Implementation Feasibility					
	Technical Feasibility	Cost of Implementing Intervention	Inclusivity		Synergy with government plan	Average Score
			Female Contribution	Male Contribution		
Ridge-river-to-reef approach: Reforestation, enhancement, and protection of wetlands and critical coastal ecosystems as buffers against natural hazards	4.75	2.25	4.75	4.75	4.75	4.13
Community-based fish stock enhancement	4.00	3.5	4.50	4.5	4.5	4.13
Aquasilviculture	4.25	2.5	4.75	4.75	4.75	4.06
Artificial reef	3.50	4.25	3.25	4.75	4.25	4.00
Provision of postharvest facilities and technologies (solar tunnel fish dryers)	4.00	3.25	4.00	4.75	4.25	3.97

Table 3.13. Summary of assessment scores of adoption barriers for coastal ecosystems

CRA Intervention	Adoption Barrier									
	Availability of Finance	Availability of inputs	Awareness among Farmers	Acceptability by Farmers	Availability of Labor	Availability of support resources	Availability of Government Support	Access to Extension Service	Access to Market	Average Score
Ridge-river-to-reef approach: Reforestation, enhancement, and protection of wetlands and critical coastal ecosystems as buffers against natural hazards	4.25	3.75	4.00	4.25	4.50	4.25	4.50	4.50	4.50	4.28
Aquasilviculture	4.00	3.25	3.75	3.50	4.25	3.75	4.75	4.25	4.75	4.03
Community-based fish stock enhancement	4.00	3.5	3.00	3.75	4.25	3.75	4.50	3.75	4.25	3.86
Provision of postharvest facilities and technologies (solar tunnel fish dryers)	3.25	2.75	3.00	3.00	4.00	3.75	4.00	3.25	3.75	3.42
Artificial reef	3.50	2.75	2.50	2.75	4.00	3.25	4.00	3.00	3.25	3.22

Table 3.14 Summary of assessment scores of incentive mechanisms for coastal ecosystems

CRA Intervention	Incentive Mechanism				
	Access to Subsidy	Access to Affordable Credit	Access to Capacity Building	Linkage with Market	Average Score
Ridge-river-to-reef approach: Reforestation, enhancement, and protection of wetlands and critical coastal ecosystems as buffers against natural hazards	4.25	3.50	4.5	4.75	4.25
Aquasilviculture	4.00	3.75	4.00	4.75	4.13
Community-based fish stock enhancement	4.00	3.75	4.00	4.00	3.94
Provision of postharvest facilities and technologies (solar tunnel fish dryers)	3.50	3.50	3.75	4.25	3.75
Artificial reef	3.00	2.50	3.25	3.50	3.06

The summarized assessment score identified the top three CRA interventions that are most likely to be disseminated by key institutions and players. In the coastal ecosystem, **aquasilviculture** ranked the highest, with an average score of 3.79, followed by the **ridge-river-to reef approach** (average score of 3.71), and **solar tunnel fish dryer** (average score of 3.64) (Table 3.15).

Prioritization ranking of preferred CRA technologies and approaches. Based on the top three preferred CRA interventions in the coastal ecosystem, the following technologies and approaches have been selected according to their average scores (Tables 3.11–3.15):

1. Ridge-river-to-reef approach: Reforestation, enhancement, and protection of wetlands and critical coastal ecosystems as buffers against natural hazards;
2. aquasilviculture; and
3. community-based fish stock enhancement.

INFORMATION TECHNOLOGY MANAGEMENT

For information technology management, **Smarter Approaches to Reinvigorate Agriculture as an Industry in the Philippines (SARAI)-Enhanced Agricultural Monitoring System (SEAMS), automatic weather station (AWS), and unmanned aerial vehicle (UAV)** ranked the highest, with an average score of 5.99 (Table 3.16). SEAMS, AWS, and UAV are information technology management tools that help increase resilience to drought, typhoon, and flooding incidences through wide-scale implementation since their target end-users are local government units (LGUs) and the Department of Agriculture (DA) regional offices.

Table 3.15. Summary of assessment scores of assessment of key institutions/players in disseminating CRA for coastal ecosystems

CRA Intervention	Key institutions/players in disseminating CRA							
	Government	Custom Hiring Center/Service providers	Youth Farmers Based Agro-Advisory Groups	Women Self-Help Groups	Farmer Producer Organizations	NGO/ CSO	Private Sector/ Retailers	Average Score
Aquasilviculture	4.75	1.50	3.75	4.00	4.00	4.50	4.00	3.79
Ridge-river-to-reef approach: Reforestation, enhancement, and protection of wetlands and critical coastal ecosystems as buffers against natural hazards	5.00	1.25	3.25	4.00	4.00	4.75	3.75	3.71
Provision of postharvest facilities and technologies (solar tunnel fish dryers)	4.75	1.75	3.25	3.5	4.25	3.75	4.25	3.64
Community-based fish stock enhancement	4.50	0.75	3.25	4.00	4.00	4.50	3.75	3.54
Artificial reef	4.25	2.25	3.00	3.00	3.25	3.75	3.5	3.29

Table 3.16. Summary of assessment scores of CRA technologies and approaches for information technology management

CRA Intervention	CRA ASSESSMENT			
	Productivity	Resilience	Reduced Emission	Average Score
SEAMS, AWS, and UAV	5.56	7.20	5.20	5.99
SPIdTech	6.06	5.50	5.36	5.64
WAISS	5.44	6.43	4.00	5.29
Rice crop manager	5.56	5.31	4.06	4.98
Nutrient Expert® for Hybrid Maize	5.56	5.31	4.06	4.98

Smarter pest identification technology (SPiDTech) ranked second, with an average score of 5.64. SPiDTech is an information technology management tool that is cost-efficient and reduces climate risks, particularly insect and diseases. Concurrently, it minimizes usage of pesticides, which reduces GHG emissions. The **Water Advisory for Irrigation Scheduling System (WAISS)** ranked third, with an average score of 5.29. WAISS is an information technology management tool that is water- and cost-efficient. It provides resilience to drought while reducing use of inputs for irrigation purposes such as gasoline. Its target end-users are farmers with mobile phones.

Implementation feasibility determined if the intervention is technically, fiscally, ethically, and administratively feasible. For information technology system, both **SPiDTech** and **SEAMS**, **AWS**, and **UAV** ranked the highest, with an average score of 4.08. **Rice crop manager (RCM)** and the **Nutrient Expert® for Hybrid Maize** ranked second, both with an average score of 3.99 (Table 3.17). In terms of synergy with government's plans, all CRA interventions are government-funded projects whose target end-users are farmers, extension workers, and LGUs. All these interventions excluding rice crop manager, AWS, and UAV are free, internet-based applications that can be directly downloaded. WAISS, AWS, and UAV require hardware and equipment that incur high implementation costs.

Table 3.17. Summary of assessment scores of implementation feasibility for information technology management

CRA Intervention	Implementation Feasibility				
	Technical Feasibility	Cost of Implementation	Inclusivity	Synergy with government plan	Average Score
SPIdTech	3.50	3.63	4.50	4.71	4.08
SEAMS, AWS, and UAV	3.63	3.38	4.60	4.71	4.08
Rice crop manager	3.50	3.50	4.25	4.71	3.99
Nutrient Expert® for Hybrid Maize	3.50	3.50	4.25	4.71	3.99
WAISS	3.63	3.13	4.44	4.57	3.94

Adoption barriers determined the external and internal constraints that can affect the adoption level of farmers and other stakeholders. The top three interventions in information technology management were assessed according to availability of resources, access to extension service and market, and awareness of and acceptability to farmers. Both **RCM** and **Nutrient Expert® for Hybrid Maize** ranked the highest with a score of 3.92, followed by **SPiDTech** with an average score of 3.81, and **SEAMS**, **AWS**, and **UAV** with an average score of 3.59 (Table 3.18).

Incentive mechanism is a measure that motivates or encourages farmers and other stakeholders to adopt and replicate the CRA technologies and approaches. The top three interventions got high scores in accessibility to subsidy, affordable credit, capacity building, and linkage to potential market. **SPIdTech** ranked the highest, with an

Table 3.18. Summary of assessment scores of adoption barriers for information technology management

CRA Intervention	Adoption Barriers				
	Availability of Finance	**Availability of Machineries**	**Awareness among Farmers**	**Acceptability by Farmers**	**Availability of Labor**
Rice crop manager	3.86	3.86	3.43	3.29	4.14
Nutrient Expert® for Hybrid Maize	3.86	3.86	3.43	3.29	4.14
SPIdTech	4.00	3.71	2.71	3.71	3.86
WAISS	3.88	3.38	3.00	3.25	3.71
SEAMS, AWS, and UAV	3.75	3.00	2.88	3.38	3.43
	Availability of Reliable Water	**Availability of Government Support**	**Access to Extension Service**	**Access to Market (by the Potential Users)**	**Average Score**
Rice crop manager	4.00	4.33	4.00	4.33	3.92
Nutrient Expert® for Hybrid Maize	4.00	4.33	4.00	4.33	3.92
SPIdTech	5.00	3.67	3.33	4.33	3.81
SEAMS, AWS, and UAV	5.00	3.86	3.71	3.33	3.59
WAISS	3.80	3.33	3.43	3.00	3.42

average score of 3.57, followed by both **RCM** and **Nutrient Expert® for Hybrid Maize** (average score of 3.54), and followed by **WAISS** (average score of 3.50) (Table 3.19).

Table 3.19. Summary of assessment scores of incentive mechanisms for information technology management

CRA Intervention	Incentive Mechanisms				
	Access to Subsidy	Access to Affordable Credit	Access to Capacity Building	Linkage with End-User	Average Score
SPIdTech	4.86	0	4.71	4.71	3.57
Rice crop manager	4.86	0	4.57	4.71	3.54
Nutrient Expert® for Hybrid Maize	4.86	0	4.57	4.71	3.54
WAISS	4.13	1.00	4.57	4.29	3.50
SEAMS, AWS, and UAV	4.71	0	4.71	4.00	3.36

The summarized assessment scores for the CRA interventions showed that the ones most likely to be disseminated by key institutions and players in information technology management were SPIdTech, WAISS, and SEAMS, AWS, and UAV, with an average score of 2.82 (Table 3.20).

Prioritization ranking of preferred CRA technologies and approaches. Based on the top three preferred CRA interventions in information technology management, the following technologies and approaches have been selected according to their average scores (Tables 30–34):

1. SEAMS, AWS, and UAV;
2. SPIdTech; and
3. WAISS.

Table 3.20. Summary of assessment scores of key institutions/players in disseminating CRA for information technology management

CRA Intervention	Key Institutions/Players in Disseminating CRA			
	Government	Custom Hiring Center	Youth Farmers Based Agro-Advisory Groups	Women's Cooperatives
SPIdTech	3.75	1.00	2.88	1.83
WAISS	4.25	1.00	2.63	1.83
SEAMS, AWS, and UAV	4.25	1.00	2.88	1.83
Rice crop manager	4.00	1.00	2.38	1.50
Nutrient Expert® for Hybrid Maize	4.00	1.00	2.38	1.50
	Farmer Producer Organizations	NGO/ CSO	Private Sector/ Retailers	Average Score
SPIdTech	4.00	3.88	2.43	2.82
WAISS	3.75	3.88	2.38	2.82
SEAMS, AWS, and UAV	3.50	3.86	2.43	2.82
Rice crop manager	3.88	3.75	1.86	2.62
Nutrient Expert® for Hybrid Maize	3.88	3.75	1.86	2.62

Figure 3.1. Group 1 (Lowland Irrigated and Rainfed) discussing the indicators in assessing the CRA technologies and approaches for the lowland ecosystem

Figure 3.2. Group 2 (Upland, Hilly land, and Highland) during the break-out session of the workshop

Figure 3.3. Group 3 (Coastal) during the break-out session of the workshop

Figure 3.4. Group 4 (Information Technology Management) during the break-out session of the workshop

Figure 3.5. Group presentations of summary of assessments and prioritization

Figure 3.6. The participants and organizers of the stakeholder workshop on CRA in the Philippines

Table 3.21. List of workshop participants

Name	Organization	E-mail	Expertise
Agbisit, Elpidio Jr.	CA, UPLB	pidz84@gmail.com	Animal Science
Alberto, Eduardo	DA-BSWM	edalbie@yahoo.com	Soil Conservation
America, Leila	PCAARRD	leila_america@yahoo.com	Forestry and Environment Research
Alejar, Manny	former IRRI; SEARCA	-	Agriculture
Areglado, Rosemarie Laila	SESAM, UPLB	rdareglado@up.edu.ph	Development Communication
Armada, Adoracion	PCAARRD	a.armada@pcaarrd.dost.gov.ph	Crop Science
Bajit, Mahalene Kristine	DA-SWCCO	amiaphilippines@gmail.com	Program Management
Balingbing, Carlito	IRRI	c.balingbing@irri.org	Postharvest Engineering

Continued on next page

Table 3.21. continued

Name	Organization	E-mail	Expertise
Bantayan, Nathaniel	CFNR, UPLB	ncbantayan@up.edu.ph	GIS Application in Forestry, Forest Resources Management, and Geomatics
Bantayan, Rosario	SEARCA	rbb@searca.org	Natural Resources Management
Bejo, Mafeo	CA, UPLB	mbbejo@up.edu.ph	Animal Production
Bernardo, Eisen Bernard	CGIAR-CCAFS	e.bernardo@irri.org	Development Communication
Cabahug, Rowena	CFNR, UPLB	cabahug_weng@yahoo.com	Forestry/Agroforestry
Cabangbang, Patrick	SESAM, UPLB	rpmcabangbang@gmail.com	Agronomy
Celeridad, Renz	ICRAF	R.Celeridad@cgiar.org	Development Communication
Chivenge, Pauline	IRRI	p.chivenge@irri.org	Soil Science
del Bario, Arnel	DA-PCC	pcc-oed@mozcom.com	Animal Science
De Panis, Wilson	CA, UPLB	-	Agriculture and Food Science
Eslava, Decibel	SESAM, UPLB	dfeslava@up.edu.ph	Environmental Science
Espaldon, Ma. Victoria	SESAM, UPLB	moespaldon@up.edu.ph	Environmental Science
Estareja, Zara Mae	SEARCA	zmce@searca.org	Development Communication
Ferrer, Alice Joan	UP Visayas	agferrer@upv.edu.ph	Resource Economics/ Fisheries
Fumera, Jayson	PCAARRD	-	Forest Biological Sciences
Garcia, Jose Nestor	CA, UPLB	jnmg2001@yahoo.com	Environmental Science
Gonsalves, Julian	IIRR	juliangonsalves@yahoo.com	General Agriculture
Guiam, Angelo	UPLB	aguiam@gmail.com	Software Engineer
Labios, Jocelyn	CA, UPLB	jdlabios816@yahoo.com	Soil Science
Labios, Romeo	CGIAR-CCAFS	romeolabios@gmail.com	Agricultural Systems/ Agronomy
Lampayan, Rubenito	CEAT, UPLB	rmlampayan@up.edu.ph	Water Resource Management
Landicho, Leila	CFNR, UPLB	ldlandicho@gmail.com	Agroforestry
Malayang, Donna Bae	SEARCA	dbnm@searca.org	Community Development
Manigbas, Norvie	PhilRice	norviem@yahoo.com	Plant Breeding
Monsanto, Janah	UPLB	-	Mathematical Sciences and Physics
Nacorda, Hildie Maria	SESAM, UPLB	-	Marine Ecology, Environmental Science
Navarro, Rex	CCFAS-SEA	rex.navarro923@gmail.com	Development Catalyst

Continued on next page

Table 3.21. continued

Name	Organization	E-mail	Expertise
Noor, Faisal	ICRAF	f.noor@cgiar.org	Agroforestry
Orencio, Pedcris	SEARCA	pmo@searca.org	Coastal and Fisheries
Padin, Jim	DENR-ERDB	-	Marine Biology, Biodiversity Conservation and Systematics, and Natural Resources Management
Paris, Thelma	CGIAR-CCAFS	thelmaparis33@gmail.com	Gender Specialist
Pielago, Patricia Ann	SEARCA	-	Agricultural Economics
Rogel, Carmen Nyhria	SEARCA	ngr@searca.org	Environmental Studies
Salcedo, Toni-An Mae	UPLB	toniansalcedo@gmail.com	Agricultural Engineering
Sebastian, Leocadio	CGIAR-CCAFS	l.sebastian@irri.org	Plant Breeding/Research Management
Siladan, Marcelino	PCAARRD	m.siladan@pcaarrd.dost.gov.ph	Forestry and Environment
Suarez, Jerome	UPLB		Agricultural Engineering
Ticsay, Mariliza	SEARCA	mvticsay@gmail.com	Publication Management
Wassmann, Reiner	IRRI	r.wassmann@irri.org	Climate Change Adaptation and Mitigation

CHAPTER 4

Promotion and Dissemination of Appropriate CRA Technologies and Approaches in the Philippines

PROMOTION AND DISSEMINATION

Climate-resilient agriculture (CRA) can be defined as, "*agriculture that reduces poverty and hunger in the face of climate change, improving the resources it depends on for future generations*" (Christian Aid 2015). It transforms the current systems of climate adaptation and mitigation, as well as agricultural productivity. CRA has a wider and more inclusive vision than increased production alone. For CRA to be socially, economically, and environmentally sustainable, there should be unending support for local, regional, and global food production systems (Cordaid 2016).

The continuous expansion of work and good results from CRA are possible by investing political and financial support in development initiatives. Toward this end, CRA approach should be included in government policies and practices and should be created as platforms for further financial support from donor agencies. Likewise, knowledge development and peer-to-peer learning regarding CRA technologies and practices should be done alongside policy and financial reforms on agriculture and climate change. CRA initiatives need to be sustained, improved, and disseminated to solve the current challenges of food security, environmental degradation, and climate change.

To promote and disseminate available and appropriate CRA technologies and practices, concepts like regional cooperation, information, education, and communication (IEC) materials development, and resource mobilization should be considered in creating local agricultural and climate change adaptation policies and practices.

Regional cooperation

In archipelagic Philippines, regional experiences on using CRA technologies and practices vary; hence, cultural differences among regions should be considered in formation of partnerships, cooperation and linkages. Documentation of on-field experiences is important to create a knowledge database and facilitate exchange of data among regions. Shared knowledge and experiences can be used in modifying existing technologies and practices for efficient implementation and scaling-up of CRA. Collaboration between different stakeholders such as farmer organizations, civil society organizations, local government units (LGUs), private sector, and funding agencies, calls for further promotion of CRA and formation of partnerships and linkages across regions.

Regional sharing of knowledge can be more effective through structured information made available and accessible online from a database. In data management, documents should be sorted according to region or topic and should be searchable by keywords or other identifiers. National research institutions throughout the Philippines, given enough resource support, can document and publish their consolidated experiences with CRA technologies and approaches, school-on-the-air programs, and climate-smart villages (ASEAN 2017).

The sharing of curriculum and course materials, learning exchange visits, and facilitating of training workshops among regions have a high impact on a large-scale CRA promotion and dissemination. Through these activities, existing extension activities will be strengthened and expansion of successful and replicable programs to new farming communities will be initiated.

Development of IEC materials

The development of IEC materials for CRA technologies and practices is critical in knowledge transfer from experts to the public. The main drivers of agriculture are the farmers and fishermen who till the land and manage coastal resources; therefore, guidelines on implementing these technologies and practices should be packaged in a way that these people can easily comprehend and embrace as part of their daily life. The language used in packaging these technologies and practices is important in understanding technical information. Empowerment of the rural sector to work toward climate change resiliency is vital in improving their source of livelihood and encouraging them to take part in climate change discussions.

Government agencies and organizations have launched and disseminated several online and offline modules, website articles, mobile applications, posters, and training manuals intended for on-field application and circulation of recent research and development (R&D) technologies.

The rise of social media is a cutting-edge strategy in sharing CRA technologies and practices to a wider range of audience. In the digital age, interactive platforms combined with audio and visual elements can stimulate learning, focus, and memory retention. Using infographics is an efficient and creative way to present statistics and quick facts. This is most useful if the mode of distribution is printed media.

In marginalized areas where technology barrier exists, local and traditional media can be utilized as an alternative. Informative school-on-the-air programs are conducted by local radio stations. In the Philippines, some radio stations broadcast information on climate services and climate-smart agriculture to rural communities. Experts from various sectors are invited to discuss updates on agricultural technologies and management practices. Listeners, who are mostly farmers, can ask questions in real time, which are acknowledged and addressed by the experts (ASEAN 2017). Meanwhile, agricultural extension workers conduct site visitations and one-on-one workshops using pamphlets, manuals, and brochures.

A more effective way of promoting CRA is by combining different communication channels. Most of the time, farmers do not have access to IEC materials, especially those that are available in digital format only. Combining different available communication channels can help both agricultural extension workers and farmers to access updated information. In terms of content, it is recommended that the focus of CRA be expanded by integrating climate information and ecosystem management and restoration and disaster risk reduction and climate-resilient food production systems.

Resource mobilization

Resource mobilization helps in materializing plans for promoting and disseminating CRA. Financial, human, and material resources ensure the sustainability of CRA initiatives in different regions. To improve food security and work on climate adaptation and mitigation in developing countries, there should be financial support for CRA, at both national and regional levels across all sectors, especially for farmers' organizations.

CHALLENGES IN APPLICATION AND REPLICATION OF CRA TECHNOLOGIES AND APPROACHES

Geographical constraints

The geographic characteristics of a region determine the effectiveness of CRA technologies and practices. Replicating these methods in marginalized areas might pose problems and constraints during implementation. Variations in seasonality, crop choices, and cropping patterns are factors that should be considered. Hence, it is integral to identify the appropriate adaptation strategy for each region in any given context. Vulnerability and capacity assessments and analyses, followed by development planning and community adaptation, are ways to overcome geographical constraints (CARE 2018).

Limited availability and accessibility of needed resources

Smallholder farmers rely mostly on government programs and donor-funded projects to access sufficient farm inputs. Available seeds, fertilizers, and other inputs are generally not enough to meet required production demands for market distribution and personal consumption. On the other hand, some farming equipment needed for selected CRA technologies are not readily accessible to smallholder farmers despite existing government programs for the agriculture sector. Smallholder farmers often have limited options, making them at risk to disasters that may occur during critical seasons.

Limited financial assistance

Only a few agencies and organizations provide full financial assistance to farmers and fishermen. In most cases, financial assistance is part of programs or projects that are determined by scope and duration. Farmers and fishermen need capital for the next planting or fishing season, and some of them also resort to funding opportunities. The risk of losing their capital over disasters and climate change-induced events is always present, and without a reliable financial aid or insurance, this might not be good for long-term food production and income generation for both rural and urban communities.

Limited knowledge on CRA technologies and approaches

There are areas that have not yet been reached by research extension and government programs. Improper land, water, and overall resource management result from misinformation or the lack of it. If CRA is thoroughly promoted and disseminated for public and wider use, marginalized communities can learn and improve their existing knowledge on technologies and approaches.

STRATEGIES TO OVERCOME THE CHALLENGES

Regional consolidation of CRA technologies and approaches

It is important to connect disciplines in order to promote coherence and consistency between agricultural and climate change (adaptation and mitigation) policies, research, and programs. Regions should work toward increasing the predictive resolution of climate change models to make them more localized. Support for CRA projects and programs can be given through long-term planning at the national level and establishment of social safety net programs to improve regional resilience to climate change. Social networks, cohesion and gender equality for resilience, and knowledge and materials exchange should be enhanced in preparation for climate-induced crisis.

For local producers to make informed decisions, information systems that provide weather forecasting and tailored information on adaptation options should be developed. In addition, it is vital to build local knowledge and climate variability coping strategies for farmers. Regional consolidation should be the basis for future policy formulation and research initiatives (Pound et al. 2018).

Agricultural insurance

In the wake of climate change, farmers and fishermen are vulnerable to disasters. As an effective safety net to protect them against losses from drought, flooding, and erratic rainfall, agricultural insurance is offered by government programs.

Complementary approaches to build resilience and mitigating negative impacts of climate change are readily available for adoption and implementation. Agricultural insurance is seen as a promising strategy for building resiliency. Its goal is to transfer some of the production risks faced by farmers to the private insurance sector. The crop insurance compensates for the high losses incurred by farmers due to risks beyond their control. It is useful in reducing the negative coping adjustments of farmers, such as cost-cutting of farm inputs and decreased meal consumption. Farmers, or government agencies on their behalf, pay an amount at the start of the season to insurance company for this protection.

In the event of natural disasters affecting agricultural production, the Philippine Crop Insurance Corporation (PCIC) offers multi-risk cover, compensating for losses due to natural disasters, pest infestation, and plant diseases. All rice varieties accredited by National Seed Industry Council (NSIC) are insurable. Crop insurance coverage commences (granting that the certificate of insurance coverage is already issued) from direct seeding or upon transplanting to harvesting.

Ideally, agricultural insurance is just part of a holistic climate risk mitigation strategy that provides a safety net for events that are beyond the control of the farmer; the farmer must still take steps to mitigate risks.

In Southeast Asia, the most common practice is to compensate individual farmers or local groups at the micro-level. Individual farmers or small farmer groups take out insurance and receive payouts. Usually, farmers individually or in groups, sign with premiums paid per person to insure specific fields against defined risks. When a severe loss occurs (provided it is one of the covered risks), the insurance company compensates for the farmer or the group of farmers. However, this coverage level needs to be communicated well to farmers. It requires creating insurance awareness among farmers, training of farmers, registration efforts, and conduct of loss assessments, which accurately reflect and quantify losses at the individual field level.

Institutional sustainability

Strengthening stakeholders' capacity, land rights programming, and inclusive governance are progressive solutions in facilitating institutional sustainability. Engaging civil society organizations that support the same objectives as CRA's also contributes to sustainable development.

To achieve institutional sustainability in CRA, it is necessary to strengthen ongoing development initiatives, such as secured property rights, agricultural market development, agricultural policies, trade policies, environmental policies, social protection, and disaster preparedness (Pound et al. 2018).

From an agroecological perspective, strengthening these development initiatives, together with the appropriate CRA technologies and practices, can lead to agroecological sustainability and community resilience.

Farmer field and business schools as social learning platforms

Scaling-out climate-resilient practices requires providing avenues for stimulating farmer-led learning, such as the farmer field and business schools, which are cost-effective and when combined with savings and loans, can stimulate aggregation, local entrepreneurship, and market engagement. It is a long-term solution for financial sustainability, especially in times of fluctuating weather conditions.

Technology and asset management

Technology and asset management includes identifying risks and protecting agricultural assets from actual and possible climate hazards, identifying climate change resilient approaches to agricultural and natural resource management, improving condition of the ecosystem and its buffering and mitigating capacity, developing practices to utilize natural resources efficiently, developing means of agricultural production through improved extension that helps in reducing climate change risks, establishing climate-proof postharvest infrastructure, adjusting postharvest technology to new climate realities and creating harvest failure contingency system, and drafting of contingency actions against extreme climate risks (Pound et al. 2018).

Identifying regional- and farm-level adaptation action plans

In identifying regional- and farm-level adaptation plans, there is a need to identify bottlenecks and challenges to come up with adaptation strategies and action plans to ensure proper application of risk management. The action plan can be formulated based on different management and production systems considering applicable CRA technologies and approaches, as well as the type of ecosystem.

Interventions to provide greater access to the portfolio of technologies, information, support services, market linkage, and finance/credit are vital in resilience-building among smallholder farming and fishing communities. Interventions that will enable them to adjust, modify, or change their current production systems and practices are not only necessary but also urgent. This process is called community-based adaptation (CBA) (IIRR 2016).

The primary step in designing effective CBA efforts is understanding and assessing local risks and vulnerabilities of communities. To better understand location- and context-specific climate change impacts, vulnerability assessments through focus group discussions, key informant panels, surveys, and the study of secondary data are done. These assessments enable stakeholders to properly identify options for addressing risks and vulnerabilities.

Resilience-building in CBA is anchored on location- and context-specific vulnerabilities, which means that the main goal is to involve the grassroots in designing an adaptation plan. Community-based participatory action research and learning are essential to deriving effective solutions of the locality. For example, the effectiveness and scalability of options for addressing specific risks and vulnerabilities can be identified, planned, designed, tested, and learned by farming and fishing communities. The complexities of vulnerabilities and risks should be understood. Multiple scales and levels of strategies that can be utilized to address the multi-dimensional challenges of food, nutrition and livelihood insecurities should be developed.

Wide-scale adoption can be demonstrated in certain geographic areas that are designated as impact sites. These impact sites serve as basis for documentation and field-level advocacy. Adaptive models that provide practical guidance to local communities, organizations, and government agencies are means to scale-up CRA. Investments in CRA are opportunities to secure food production, reduce poverty, and overall achieve the sustainable development goals (SDGs). With that, CRA considerations must be assessed and included in LGU plans and future projects.

Integration of land into climate change adaptive planning

In adaptation planning, land policy is one key element that needs to be fully integrated with the National Adaptation Programs of Action at the national, regional, provincial and municipal levels. Other elements that should be included are integration of land inventories, tenure regularization, resettlement, and better land-use regulation in risk areas to improve climate proofing.

This integration calls for the effective mainstreaming of adaptive measures in national development policies and poverty reduction strategy frameworks, and in government and international agency planning. The latter is expected to deliver funding to priority adaptive actions tailored to farmers' needs (Quan and Dyer 2008).

Policy implications and recommendations for climate services design

Farmers should be involved in the design, production, and evaluation of climate services to give them an effective voice. Their engagement is critical for information products and services. Farmers' perspectives are valued and they should be given opportunities to work closely with experts. The essence of co-production is to work with rural communities to integrate their knowledge in the production of climate services. On a significant scale, engaging smallholder farmers requires efficient mechanisms to capture their evolving needs (Tall et al. 2014).

Establishing partnerships to bridge the gap between CRA research and farmers is necessary for climate services. New institutional arrangements for salience are ways to scale-up climate service production for both CRA research and farmers. Filling the gaps can transform routinely available information into information that is relevant and applicable to rural communities. Partnerships that enable sustained dialogues are important for climate services intended for farmers (Tall et al. 2014).

The continuous assessment of climate services improves the quality of service delivery by enabling it to respond to the changing needs of the end-users, and reflect the evolving science behind these technologies and practices. Projects and programs need to keep assessing the suitability of products and services to the local needs. Reassessing should be integrated into the process of climate services development. Farmers, in particular, should be given voice and communication channels to reach even those in the most vulnerable and marginalized areas. Having a formal mechanism to capture users' needs and feedbacks will encourage legitimacy and accountability. In addition, feedbacks can be used to tailor climate services according to the end-users' evolving needs. Lastly, the end results of the costs and benefits analysis of climate services can be utilized in drafting proposals to governments and donors for continued and increased investments in climate services (Tall et al. 2014).

CHAPTER 5

Transforming Philippine Agriculture Under Climate Change

Philippine agriculture must transform itself to do its share in the country's food and nutrition security, rural livelihood, and environmental sustainability. To achieve this transformation, the country needs to adopt a paradigm that can address the challenges that it is facing now and in the coming years. It needs transformative strategies that can support actions targeting the different socio-economic and agroecological contexts to which they will be applied.

Societal issues such as poverty and inequality should be linked with the country's agriculture sector. These issues will be aggravated by the impacts of climate change. Sources of livelihood and food of farmers will be destroyed, the ways of life of indigenous communities will be disrupted, and the divide between men and women in the society will widen. These issues could continue to pervade the country unless transformative strategies are crafted by all relevant stakeholders.

Specifically, transformative strategies that improve productivity, enhance climate resilience and reduce greenhouse gas emissions are keys to drive agricultural transformation in the Philippines (Vermeulen et al. 2018).

Climate change transcends the environmental, geographical, social, and political landscapes, and requires innovative approaches and long-term planning. Low agricultural productivity is a result of climate change impact. It pushes the poor deeper into poverty (Briones et al. 2014). Poverty, meanwhile, is exacerbated not only by low agricultural productivity but also by lack of access to basic social services. These issues further damage the reputation of agriculture, depicting it as an unattractive and impractical career, especially to the youth (Briones and Carlos 2013).

CHALLENGES TO THE PHILIPPINE AGRICULTURE

Philippine agriculture is affected by many factors such as poor access to market and information services, lack of investments in agricultural research, and limited finance mechanisms, which combine with a chain of other challenges that threaten livelihoods and food security in the country (Sajise et al. 2012). These challenges include climate change, which leads to massive losses and damages to agriculture and in turn affects agricultural productivity in farms.

Low agricultural productivity reduces the incomes of smallholder farmers, hampering their ability to meet their basic needs. Compounding this threat is stiff market competition, which is now influenced by in-country infrastructures and policies, as well as by regional and global level trade agreements. It is expected that the forthcoming Association of Southeast Asian Nations (ASEAN) economic integration will have far-reaching implications on the future of the Philippine agriculture sector (Llanto 2017).

Climate change and related natural disasters (e.g., changes in intensities or frequencies of floods, droughts, seawater intrusion, typhoons, and climate variability) are already causing damages to agriculture (CCC 2011; Cruz et al. 2017). The country is ranked 5th in the world in terms of extreme weather events (Eckstein et al. 2017)floods, heat waves etc.. The agriculture sector is highly vulnerable to climate change due to its reliance on favorable growing conditions (i.e., water resources, temperature, air humidity, wind velocities, precipitation intensity, and solar radiation)(RP 2014; Sajise et al. 2012).

Projections show that climate change impacts will cost the Philippines about PHP 145 billion annually (Rosegrant et al. 2016). The impacts of climate change can lead to an increase in the prices of agricultural commodities by 2030 and 2050, which can lead to less accessible food supplies for the poor, especially the smallholder rural farmers.

The agriculture sector is critical in reducing poverty and achieving inclusive growth and sustainable national development in the Philippines. The sector employs more than 10 million Filipinos, who account for 25 percent of the working population (PSA 2018a). Still, agricultural productivity continues to suffer due to dwindling resources, declining planting areas for cultivation, diverse agroecological production areas, poor transport infrastructures from farms to the markets across the archipelago or within island groups, and a decline in agricultural investments (Briones et al. 2014). This is despite the increased government budget allocated for agriculture in recent years.

In addition to low agricultural productivity, poverty is exacerbated by the lack of investments and financing and saving mechanisms for farmers and agricultural workers. The other drivers of poverty are educational attainment, availability, and quality of jobs in the country, high levels of inequality, and recurring stresses such as conflicts, climate-induced disasters, and economic crises (ADB 2009). The gaps in between the resource-poor farmers, the middle-income class (including many farmers and agripreneurs), and the rich class (including owners of big agri-conglomerates) also aggravate poverty condition with the resource-poor farmers left behind in many government and private intervention.

Another major challenge to Philippine agriculture is its competitiveness to regional and global agricultural producers. The competition can be challenging for the farmers, considering their low productivity is aggravated by the growing demand for food in the country. This demand for food will continue to grow as the Philippine population balloons to about 148 million by 2050 (UNDESAP 2015).

STRATEGIES TO TRANSFORM PHILIPPINE AGRICULTURE

Several transformative strategies[5] are already well known and recommended in the Philippines, but, for various reasons, had limited success in attaining the desired scale. We need to revisit them and apply them together with the other strategies, with support from the necessary policies, incentives, programs, and funding and financing schemes. These strategies are all connected with one another; each strategy allows the farmers—the end-users of climate-resilient technologies and approaches (Ts and As)—to participate in climate- and agriculture-related discussions, improve their productivity in the farms, enhance their adaptive capacity against current and impending risks, and reduce their greenhouse gas emissions into the atmosphere. Figure 5.1 illustrates these strategies.

Implementing suitable CRA technologies and approaches through integrated clusters and landscapes approaches

Climate-resilient initiatives should cater to the needs of the target community and to the overall agroecological context to which they can be applied. This can be achieved by mapping the various climate-related risks in the area. Key stakeholders in the agriculture sector should work together to combine various technical and local knowledge to determine the location-specific climate risks that threaten the sector. Climate risks vary in different locations due to the archipelagic geography of the Philippines (Cruz 2017). This geography creates different agroecological zones with various location-specific constraints and opportunities, which should be considered with climate risk and other information to enhance productivity and climate resilience.

Risk maps help determine the suitability of CRA Ts and As. For instance, a crop suitability database can be developed and integrated with color-coded maps that can show the suitability of a specific crop for a particular area (NEDA 2017). The current maps should be "ground-truthed" and localized to develop detailed maps that will be useful for local planning and operations. An example of such tools are the climate-resilient maps developed for the Mekong River Delta in Vietnam (Yen et al. 2019).

Such maps should integrate technical information from various sources, such as the Department of Agriculture-Bureau of Soils and Water Management (DA-BSWM)

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[5] Adopted from "A 6-part action plan to transform food systems under climate change: Creative actions to accelerate progress towards the SDGs" (Dinesh et al. 2018)

Figure 5.1. Strategies to transform Philippine agriculture

(soils and crop suitability), the Department of Environment and Natural Resources-National Mapping and Resource Information Authority (DENR-NAMRIA) (surveys on water-based and land area hazards), the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA) (web-based climate information and climate risks maps), the Bureau of Mines and Geoscience (geological hazards), and the Philippine Rice Research Institute (PhilRice) (rice variety suitability, rice pests and diseases maps). The information should be useful in developing various courses of action to make agriculture competitive and to cope with climate change.

The Ts and As listed in previous chapters were grouped based on their suitability to the different agroecological zones in the Philippines. Still, these Ts and As should be evaluated for location specificity to determine how they meet the needs of the communities vulnerable to the impacts of climate change. The evaluation phases should also assess the requirements for scaling these Ts and As in different household conditions within communities.

Various ways can be adopted to integrate these CRA technologies, approaches, and services into the communities. For instance, in the climate-smart village approach, farmers, researchers, policymakers, and other stakeholders collaborate to identify suitable Ts and As for the communities (Aggarwal et al. 2018).

Farmers can also combine their small areas into one large farm through the "small-farmers, large field" (SFLF)[6] scheme currently being upscaled in Vietnam and India (IRRI 2015; Financial Express 2018). In the Philippines, the SFLF scheme or the other similar successful schemes (e.g., corporate farming, cooperatives) can also be considered as a "clustering approach." In this scheme, farmers are organized as a group that can negotiate with input providers and because their farms are combined, they can share machines and other equipment, which can help reduce production costs (Briones 2014).

Farmers, in collaboration with researchers, extension workers, and other stakeholders, can transform their combined farms into climate-resilient landscapes. Such landscapes combine climate change adaptation and mitigation actions with other social, economic, and ecological targets. Since this approach integrates various actions at different levels, it also identifies trade-offs and synergies that reconcile with the targets of the farmers (Minang et al. 2015).

In climate-resilient landscapes, CRA options must be complemented with climate information services delivered by PAGASA which include monthly weather outlooks, seasonal rainfall forecasts, tropical cyclone warnings, and 10-day regional agri-weather forecasts and advisories for farmers (Cinco et al. 2018).

For other stakeholders such as policymakers, agricultural statisticians, among others, PAGASA releases climate impact assessments regularly (PAGASA 2018). Bringing together experts and practitioners can also lead to participatory activities that will provide opportunities for vulnerable communities to co-develop the climate services that they can adopt.

All these climate information services can improve the effectiveness and timeliness of CRA options. Media platforms must be tapped to deliver these services to their intended audiences. To improve their accessibility, they must be packaged into a database that can inform various audience groups about context-specific climate risks and suitable crops for the farms. Through these information-related services, CRA options such as farm mechanization and diversification can be utilized successfully in climate-

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[6] SFLF model in Vietnam allows small farmers to benefit from economies of scale by pooling their small farms into large fields of 50–500 ha to lower the per unit cost of using farm machinery, such as combine harvesters.

resilient landscapes, boosting farm productivity, improving food security and resource-use efficiency in the communities, and increasing farmers' income (PhilMech 2016; RP 2012).

The importance of farm mechanization is highlighted in the *Rice Tariffication Law of 2019*, which mandates government investments of PHP 5 billion annually in the next six years starting in 2019 (DA, NEDA, and DBM 2019; RP 2018b). Farm mechanization in the Philippine context should not be a stand-alone intervention, but an integral part of the transformative strategies to optimize the effectiveness and sustainability of farm mechanization.

Farm diversification, on the other hand, offers adaptation and mitigation benefits (Lasco et al. 2014; Rola et al. 2014). These benefits are manifested in diversified and intensified farming systems (DIFS), such as the *Palayamanan* system (also called integrated agro-eco farming) (Corales et al. 2004), coconut-based multi-storey system, farmer-led sustainable agriculture approach, bio-intensive gardening, sloping agricultural land technology, vegetable agroforestry system, and upland food production system (Parreno-de Guzman et al. 2015)such as underweight, underheight, and wasting. A viable agricultural solution to this problem is the practice of diversified and integrated farming systems (DIFS.

Farm diversification requires good market support, credit, and insurance. Good information on attractive and assured markets translates to diversification. Credit is meant to kickstart the adoption of diversified farms. Insurance secures farmers from different risks. Access to both credit and insurance combined with good market can encourage farmers to adopt new Ts and As.

A national program that encourages (provides incentives) and supports (provides funding and technical and marketing assistance) the organization of climate-resilient clustered farms or corporate farms (possibly under the *Rice Tariffication Law of 2019* or the *Sagip Saka Act of 2019*) should be developed. The program should encourage the participation of traders not only the agricultural production sector but also of relevant sectors such as finance, insurance, and export/import traders.

However, the integration of different targets is not limited at the farm level. The integrated area development (IAD) approach is considered a key strategy at the regional level in the Philippines (Mercado 2002). The approach combines different areas, depending on the complementing resources, language used, environmental issues, geopolitical boundaries, and physical proximity. In the context of agriculture, IAD can be followed to determine the areas where scalable Ts and As can be applied. The Philippines is already adopting IAD principles for its environment-related actions in river basins and watersheds (DENR 2017). It can explore IAD application in the agriculture sector as well.

Empowering farmers and farmers' organizations

Farmers, as well as consumers of agricultural products, can play crucial roles in transforming agriculture in the Philippines. It is important, however, to realize that farmers in the Philippines are differentiated because of growing socio-economic, technical, and demographic gaps. This requires innovative approaches to social mobilization.

The Philippines should build on its experiences in organizing farmer groups (e.g., *Samahang Nayon* and various farmers' cooperatives) (Araullo 2006). The Philippine experience has shown that farmer groups are ideal in small communities. By organizing themselves, farmers can voice out their concerns collectively and reach the decision makers who shape the agriculture sector (Campbell et al. 2018). Farmers can also facilitate a sustainable implementation and scaling-up of climate actions since farmers, through their organizations, can participate in and take ownership of these actions.

Farmer groups and organizations also foster farmer-to-farmer learning on the climate-resilient Ts and As that are being introduced to them (CGIAR CCAFS 2013). To capitalize on the earning potential of these Ts and As, farmers should enhance their decision-making skills and bargaining power. This requires enabling the farmers to access relevant information such as prices of agricultural inputs and outputs in the market.

Aside from information access, the entrepreneurial skills of farmers and farmer organizations' staff must be improved to enable them to run farming as a business (DOLE 2012). Farmers should realize that agriculture is not only a mere source of income but also a viable business that they can grow and sustain in the long run.

To cultivate this entrepreneurial mindset among the farmers, agricultural entrepreneurship should be developed in the country. Agricultural entrepreneurship, or "agripreneurship," teaches farmers how to sell value-added produce, manage risks, and commercialize their products. It is a shift from a labor-intensive mindset into a business-centric approach in agriculture. More than treating agriculture as a business, agripreneurship turns the farmers into trainers who work with fellow farmers, and teachers or lecturers who discuss agriculture with various audience groups (DA-ATI 2017). The new law "*Sagip Saka Act of 2019*," which establishes the *Farmers and Fisherfolk Enterprise Development Program*, can enhance the agripreneurship among farmers through partnerships with the private sector in agri-enterprise development, thereby enabling better access to technology, inputs, credit and financing, and market (RP 2018a).

Agripreneurship is then a transformative approach in agriculture. It transforms farms into firms that aim to produce high-value outputs from available inputs. Likewise, farmers are turned into farmer-entrepreneurs who know how to capitalize on their products while overcoming the challenges faced by their firms (DOLE 2012). With the impact of climate change threatening food security and the livelihoods of farmers, the shift to agripreneurship can facilitate the adoption of climate-resilient Ts and As. Farmer-entrepreneurs are open to innovations and consequently, to risks, more than the farmers who choose to follow their traditional practices (Santiago and Roxas 2015).

Changing mindsets and behaviors can be difficult due to the deep-rooted perception that agriculture is a “poor man’s job.” Education can be the contributory factor to foster agripreneurship among farmers (Manalo IV et al. 2016; Santiago and Roxas 2015). An alternative learning system called the farm business school (FBS) trains farmers to develop profitable farms.

The FBS follows a three-step business model based on agriculture context: (1) diagnosis and planning, (2) implementation, and (3) evaluation and re-planning (Tumbali and Alo 2015). It compensates for the lack of a structured agricultural program in the Philippine education system. More alternative learning systems should be explored to bring the school to farmers whose time is mostly spent on farming activities.

Go digital

The Philippines should take advantage of the digital revolution to improve its competitiveness, adapt to climate change, access markets and services, attract more investments, and improve access to finance. Under this revolution are several phenomena that feature technologies applied to the agriculture sector.

Big Data refers to the phenomenon where massive quantities of data are collected, analyzed, and interpreted depending on certain purposes (Wolfert et al. 2017). In the context of agriculture, Big Data provides integrated data-driven insights to policymakers and educates vulnerable sectors about the impacts of climate change in their communities (Campbell et al. 2018).

The Big Data phenomenon can be complemented with “Internet of Things” technologies such as wireless sensor networks, network-connected weather stations, cameras, and even smartphones (Jayaraman et al. 2016). Such technologies can collect and analyze the data gathered for the farmers and instantly provide relevant information they can use for their farms. Handling massive loads of data, however, will require a system that promotes efficiency, transparency, and traceability, as well as enhanced data management, within a shared database (Ge et al. 2017).

Blockchain technology, initially an accounting system for the cryptocurrency, has already entered the agriculture sector. It serves as a shared digital journal that allows its users to record and encrypt transactions on a computer network (Tripoli and Schmidhuber 2018). The technology can be used to track the flow of agricultural commodities and food items from farm to market.

All these technologies fall under the upcoming revolution in agriculture known as Agriculture 4.0. This revolution signals a new era for agriculture, wherein technological innovations can take a prominent role in turning agriculture into a viable business and climate-responsive and -responsible endeavor (Clercq et al. 2018). The responsiveness and responsibility of agriculture to climate change are determined by the sector's ability to adapt to and mitigate its impacts.

Mainstreaming low-emission development

Mitigating the impacts of climate change involves promoting low-emission development (LED) in the country. Low-emission Ts and As should be tested, evaluated, and if possible, scaled to teach the farmers how to reduce greenhouse gas emissions in their farms. Several of these Ts and As are already being applied on limited scale in different parts of the Philippines.

For instance, solar-powered irrigation systems, which supply water to agricultural lands through solar energy (Smith et al. 2014) is being implemented by DA in rice lands and for high-value crops (DA 2017). Meanwhile, underground taming of floods for irrigation stores floodwater underground and uses it for irrigating agricultural lands during the dry season, reducing the costs of farmers (Reddy and Rout 2017).

In other farms, site-specific nutrient management (SSNM) and alternate wetting and drying (AWD) technique are practiced. Through the SSNM, farmers use fertilizers systematically to address the nutrient needs of a high-yield crop and maximize the available nutrients from the soil, manures, and irrigation water (Ocampo et al. 2015). AWD allows farmers to save irrigation water and use it for other purposes. AWD not only reduces the use of water but also the cost of irrigation (Siopongco et al. 2013). SSNM and AWD are part of *PalayCheck*, the recommended integrated crop management practice for rice.

In the uplands, agroforestry systems—integration of trees on farms—can be adopted to conserve biodiversity, enhance carbon sequestration, improve forest products and services, and diversify farms and incomes (Landicho et al. 2016). An example of this system is the sloping agricultural land technology. In this system, annual and perennial crops are grown between contoured rows of leguminous trees and shrubs (Sajise et al. 2012).

Incentives and other benefits can further motivate farmers to adopt LED (Phil REDD+ST 2010). The Philippines can also explore the Clean Development Mechanism (CDM) as means to implement more mitigation projects (Sajise et al. 2012). Since the country's mitigation efforts are dependent on fund support, different climate financing schemes at all levels should be explored (RP 2015).

Improving access to finance

At the national level, the country should utilize the People's Survival Fund, which supports adaptation projects under the *National Framework Strategy on Climate Change* (PSF 2015). At the international level, the Philippines has yet to tap the Green Climate Fund, a billion-dollar fund support specifically for developing countries (GCF 2015). Even with these funding opportunities, the country must find other means to finance the farmers directly, not only the projects.

The lack of financial resources, as well as the current and emerging risks in agriculture, keep farmers from investing in CRA options (Campbell et al. 2018). The same risks and financial constraints discourage financial institutions from lending to farmers. To eliminate this reluctance among the farmers and financial institutions and to encourage them to adopt and scale CRA options, innovative financing mechanisms should be explored. Financial innovations should enable the farmers to access credit and insurance platforms, which not only protect them from climate-induced losses but also support them in initiating agricultural investments.

Expanded private sector activity and public-private partnerships are keys to unlocking the potential of such innovative financing. Private institutions can customize their collateral requirements to suit the farmers' needs and situation (Geron et al. 2016). In doing so, they can work with experts to develop location- or situation-specific loans that farmers can readily pay.

Private institutions can then collaborate with farmer organizations and cooperatives in distributing loans and collecting payments. They can hire agents to conduct loan distribution and collect relevant data from farmers. If possible, these institutions can introduce electronic banking to make it easy for farmers to pay the loans.

Farmers can be enrolled in financial literacy programs and agricultural skills training to enable them to utilize their funds (Reyes et al. 2015). Donor organizations can facilitate such activities, together with collaborations with private institutions to assess the risks of investing in climate-resilient options.

Another aspect of agricultural finance that should be improved is access to credit and insurance. Enabling policies and institutions can unlock the potential of credit and insurance in agricultural finance in the Philippines. The Philippine Crop Insurance Corporation and the Agricultural Credit Policy Council protect the farmers from losses brought about by various risks. Relevant policies are also in place, one of which is the *Republic Act No. 1000* or the *Agri-Agra Reform Credit Act of 2009*. This act aims to improve the productivity of the agriculture sector by providing loans for agricultural production, agricultural businesses, establishment of relevant agricultural infrastructures, and other agricultural initiatives (RP 2009).

The loans come from the banks, which are mandated to allocate 25 percent of their loanable funds to the agriculture and fisheries sector. However, the risks posed by investing in agriculture discourage banks and other institutions to follow this law. They choose to pay the penalties instead of lending funds to farmers who, in their view, lack the capacity to pay (Geron et al. 2016).

The government should work with these financial institutions to develop credit and insurance products that cater to the needs of farmers and agripreneurs. Innovative credit and insurance programs should also be explored to support agriculture and rural development, encouraging farmers to adopt climate-resilient technologies and supporting financial institutions that extend loans to farmers and agripreneurs. The government should assure financial institutions that if the farmers default on their loans due to *force majeure,* it will help the financial institutions absorb their losses.

Despite the potential of working with these non-government entities, the Philippine Government can still play a crucial role in improving farmers' access to credit and insurance (Geron et al. 2016). The government can start with building and strengthening the capacities of farmers to manage funds. At the organizational level, it can train farmer organizations to turn them into reliable channels of credit and insurance in rural areas. The government can build relevant infrastructures, such as farm-to-market roads, to make these areas more accessible to financial institutions (Mina et al. 2015). These infrastructures can then pave the way to connect the other vulnerable sectors of society.

Enhancing social inclusion

Indigenous people (IP) groups, the women, and the youth are considered highly vulnerable to climate change due to their societal roles and socio-economic statuses (FAO 2017). In the IP communities, environmental degradation brought about by climate change compounds the issues of land grabbing and displacement which they face every day (AIPP 2015). Women are trapped inside their sociocultural roles and are burdened by lack of access to resources (PCW 2014). Meanwhile, the youth lack the knowledge, skills, and capacity to join initiatives against climate change (UNICEF 2017).

These sectoral and gender-specific challenges should be considered in crafting socially inclusive plans and strategies against climate change. The potential contributions of these vulnerable sectors should also be identified and integrated into climate-change initiatives. Specifically, IP communities can adapt to climate change with their traditional knowledge and practices (TF 2017). Women can participate in climate-change initiatives through access to relevant resources (Rosimo et al. 2018; Villavicencio et al. 2018). The youth may serve as infomediaries of climate information in their communities (Manalo IV et al. 2016).

The youth sector can also be trained on agripreneurship. Agriculture as a viable business should be discussed in households and in schools. Currently, the youth view agriculture as an unattractive and impractical career (Briones and Carlos 2013). This view should change, especially because the farmers in the Philippines are aging and, eventually, should be replaced by succeeding generations. (Manalo IV et al. 2016). Promoting the concept and potential of agripreneurship as a business could change this view.

The government can mold young agripreneurs by educating them about agripreneurship (AFASRD 2015). The youth should realize that agripreneurship involves not only labor-intensive activities in the farms, but also farm operations, risk management, and financial planning. Through trainings and extension activities, they can acquire the necessary entrepreneurial skills and apply the knowledge that they learned to actual agripreneurship endeavors.

To achieve these goals, participatory approaches, as well as dialogues, should be implemented during the development of climate change initiatives. Such approaches must foster an environment where IP groups, women, and the youth are treated on an equal footing. This environment can encourage these sectors to voice out their concerns, which can help in addressing their needs and situations. Their needs and situations should serve as bases in crafting climate change initiatives. Policies and institutions should provide access to relevant resources and information to equip them with knowledge, skills, and capacities necessary to join actions against climate change in their communities. Such an enabling environment can motivate them to demand safe and nutritious food, reduce food wastes, and promote alternative food in a changing climate.

Educating the consumers and producers

Information, education, and communication (IEC) materials can inform consumers about the safe and nutritious food available to them. IEC materials can also promote specific behaviors such as responsible consumption and production. Social marketing strategies should then target both consumers and producers for them to assume roles in reducing food wastes in the country. Responsible consumption and production can be complemented with the promotion of alternative food. With climate change impacts causing critical losses and damages to major crops in the Philippines, consumers should learn what alternatives they can buy to expand their food choices. From the perspective of the producers, looking for alternatives can help them earn income even if staple products are not available.

IEC materials should be delivered through various communication channels, utilizing both old and new media and identifying specific target audiences. IEC materials should be easy to understand. Specifically, the target audience should be able to respond to the messages of these materials. The messages should also follow specific sociocultural standards for them to be acceptable to the intended audience.

CONCLUSION

The challenge in transforming Philippine agriculture to cope with climate change is not just about developing new ideas, approaches, technologies, and practices. The challenge is how to attain a scale that can create an impact on the lives of the Filipino farmers and the economy. It will require both bold and practical actions described in this paper. The interrelated and complementary actions must be harnessed to achieve agricultural transformation.

We need to work on the details of our plans. Many of our plans lack details that can provide clear operational guidance. There is a need to integrate data and information on the location- and context-specificity of climate risks, to come up with practical tools that can be used by planners, implementers, and farmers in deciding appropriate actions and CRA Ts and As. The risk maps generated need to be verified on the ground and the concerned entities should be properly informed and engaged. Recommendation for CRA Ts and As should be specific in terms of location, season, and target farmers and their households. Recommendations, planning, and decentralized implementation should start at the provincial level.

Strengthen farmer groups, private sector, and government partnership. Strengthening farmer groups and building strong partnerships among farmers, private sector, and the government can enhance the competitiveness and resilience of the agriculture sector to climate change. We need to optimize the implementation of laws such as the *Sagip Saka Act of 2019* and *the Rice Tariffication Law of 2019*, to strengthen farmer groups and their partnership with the private sector. The private sector can support the government in training farmers to transform into farmer-entrepreneurs. The private sector possesses knowledge and expertise, as well as the financial capacity, to deliver other relevant services to farmers. Among these services are agricultural infrastructures that can link farmers with the markets. They can also provide the platform to establish even non-farming businesses, which can contribute to the economic growth of communities. All sectors of society should aim for economic growth. For instance, the youth sector can contribute to agriculture by getting involved in agripreneurship.

We need innovative approaches to engage farmers and the private sector. The location and time specificity of many Ts and As and the differentiation of farmers, markets, and consumers require more innovative approaches. At the same time, conventional and new technologies require good blending and transition so as not to further widen the technological and technical divide. We need to consider this as we aim to go digital, to mechanize, and to diversify farming to reduce costs, increase income, and improve farm productivity. Shifting to mechanized farming and diversifying the farms could be quite drastic to farmers. They should be able to access innovative forms of credit and insurance to afford these changes. Farmers may have to acquire entrepreneurial skills and develop an entrepreneurial mindset to better manage their farms. Transforming farms into firms requires a business-centric attitude instead of a labor-intensive approach.

We need to mainstream transformation efforts into the country's policies, programs, and investment plans. The transformation of Philippine agriculture needs to be mainstreamed and contextualized into the country's programs and investment plans. It must be aligned in the context of the government's other policies, programs, and investments in infrastructure, health, education, energy, environment, natural resources, and finance. Transforming Philippine agriculture requires action beyond the farms.

References and Further Readings

ADB (Asian Development Bank). 2009a. *Building climate resilience in the agriculture sector in Asia and the Pacific*. International Food Policy Research Institute.

----------. 2009b. *Poverty in the Philippines: Causes, constraints, and opportunities (*Vol. 136). Retrieved from https://www.adb.org/sites/default/files/publication/27529/poverty-philippines-causes-constraints-opportunities.pdf

Adriano, M.S. 1989. “Implications for policy of the studies on profitability of irrigated non-rice crop production: A synthesis.” *Proc. National workshop on Crop Diversification in Irrigated Agriculture in the Philippines*. IIMI, Sri Lanka, 134–142.

Adriano, M.S., and V.E. Cabezon. 1993. “Economic policies affecting crop diversification in the Philippines.” *Proc. National Workshop on Crop Diversification in the Philippines.* IIMI, Sri Lanka, 134–142.

AFASRD (Asian Farmers’ Association for Sustainable Rural Development). 2015. “A viable future: Attracting the youth to agriculture.” *AFA Issue Paper* 7-1 (June). Retrieved from http://asianfarmers.org/wp-content/uploads/2015/07/AFA-Issue-Paper_-for-web.pdf

Aggarwal, P.K., A. Jarvis, B.M. Campbell, R.B. Zougmoré, A. Khatri-chhetri, S.J. Vermeulen, and B.T. Yen. 2018. “The climate-smart village approach: Framework of an integrative strategy for scaling up adaptation options in agriculture.” *Ecology and Society*, *23*(1). https://doi.org/10.5751/ES-09844-230114

Agrios, G.N. 2005. *Plant Pathology (*5th Edition). Elsevier Academic Press, New York. Retrieved from https://www.elsevier.com/books/plant-pathology/agrios/978-0-08-047378-9

AIPP (Asia Indigenous Peoples Pact). 2015. *Asia report on climate change and indigenous people*. Chiang Mai, Thailand. Retrieved from http://www.ccmin.aippnet.org/attachments/article/1338/Asia Report.pdf

Alam, M.M., J.K. Ladha, K.S. Rahman, Harun-ur-Rashid Foyjunnessa, A.H. Khan, and R.J. Buresh. 2005. “Leaf color chart for managing nitrogen fertilizer in lowland rice in Bangladesh.” *Agronomy Journal* 97:949–959.

Alave, K. 2011. “DA to promote white corn to ease demand for rice.” *Philippine Daily Inquirer,* 22 May 2011. Retrieved from http://newsinfo.inquirer.net/8121/da-to-promote-white-corn-to-ease-demand-for-rice

Alcantara, A.J. 1991. *Environmental management of the hilly-land farming system*. Philippines: Institute of Environmental Science and Management. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=PH9310192

Arais, A.P., and P. Caraga. 2018. “Caring for the environment the SCoPSA Way.” *Philippine Information Agency*, 5 May 2018. Retrieved from http://pia.gov.ph/news/articles/1007302

Araullo, D.B. 2006. “Agricultural Cooperatives in the Philippines.” Paper presented at the International Seminar on Agricultural Cooperatives in Asia: Innovations and Opportunities in the 21st Century, Seoul, Korea, 11–15 September 2006. National Agricultural Cooperative Federation (NACF), Korea, and Food and Fertilizer Technology Center for the Asian and Pacific Region (FFTC/ASPAC). Retrieved from http://www.fftc.agnet.org/htmlarea_file/activities/20110719103351/paper-859000900.pdf

Arraudeau, M.A., and B.S. Vergara. 1998. *A farmer’s primer on growing upland rice*. International Rice Research Institute. Retrieved from http://books.irri.org/9711041707_content.pdf

ASEAN (Association of Southeast Asian Nation). 2017. *ASEAN guidelines for promoting climate smart agriculture (CSA) practices* (Vol 2). Retrieved from https://ccafs.cgiar.org/publications/asean-regional-guidelines-promoting-climate-smart-agriculture-csa-practices-volume-ii#.Xdeb-4MzbMw

----------.2015. *ASEAN guidelines for promoting climate smart agriculture (CSA) practice*. Retrieved from https://www.asean.org/storage/images/2015/October/ASEAN-Regional-Guidelines-on-Promoting-CSA-Practices/ASEAN%20Regional%20Guidelines%20on%20Promoting%20CSA%20Practices-endorsed%2037th%20AMAF.pdf

Baas, S., S. Ramasamy, J.D. De Pryck, and F. Battista. 2008. *Disaster risk management systems analysis: A guidebook*. Environment and natural resources management series. Retrieved from http://www.fao.org/3/a-i0304e.pdf

Babson, E. 2018. “Strained stability: Climate change and regional security in Southeast Asia.” Washington, D.C. Retrieved from https://meetings.pices.int/publications/presentations/2018-Climate-Change/S16-1500-Babson_R.pdf

Balingbing, C., N.V. Hung, and M. Gummert. 2017. “Laser leveling in small scale rice production – benefits from advanced technologies for resource poor farmers.” An oral presentation at Rice Seminar of AGRITECHNICA Asia. Bangkok, 15–17 March 2017.

Barnett, A., L. Pyle, and S.K. Subramanian. 1978. *Biogas technology in the third-world: a multidisciplinary review*. Canada: International Development Research Centre. Retrieved from http://sciencedirect.com/science/article/pii/S0734242X86800623

Bartley, D. 2007. *Responsible stock enhancement, restocking, and sea ranching: rational and terminology*. Italy: Food and Agriculture Organization. Retrieved from http://www.vliz.be/docs/events/restocking/eustocking_bartley.pdf

Bautista, N. 2017. “Delivering local resilience through adaptation and mitigation in Agri-fisheries: A roving workshop for AMIA regional focal persons and LGU partners.” Climate Smart Villages. 25–29 September 2017. Retrieved from https://climatesmartvillagess.wordpress.com/2017/11/04/delivering-local-resilience-through-adaptation-and-mitigation-in-agri-fisheries-a-roving-workshop-for-amia-regional-focal-persons-lgu-partners/

Bell, J., D. Bartley, K. Lorenzen, and N. Loneragan. 2006. "Restocking and stock enhancement of coastal fisheries: Potential, problems and progress." *Fisheries Research* 80(1):1-8 (August 2006). Retrieved from https://www.researchgate.net/publication/255575562_Restocking_and_stock_enhancement_of_coastal_fisheries_Potential_problems_and_progress

Bhor, P.P., Y.P. Khandetod, A.G. Mohod, and H. Sengar. 2010. "Performance study of solar tunnel dryer for drying of fish variety Dhoma." *International Journal of Agricultural and Biological Engineering*, 2 (2): 222–227.

BIND (Broad Initiatives for Negros Development). 2004. *Mainstreaming SRI in Negros Occidental*. Retrieved from https://pm22100.net/docs/pdf/agriculture/01_SRI/sri-pssst-verzola.pdf

Bosshart, U., 1997. "Catchment Discharge and Suspended Sediment Transport as Indicators of Physical Soil and Water Conservation in the Mayketin Catchment, Afdeyu Research Unit. A Case Study in the Northern Highlands of Eritrea." Bern, SCRP. *Research Report* 39.

Briones, R.M. 2014. *Compilation and synthesis of major agricultural value chain analysis in the Philippines* (No. 35). Makati City, Philippines. Retrieved from http://www.value-chains.org/dyn/bds/docs/889/pidsdps1435.pdf

Briones, R.M., and M.B. Carlos (Eds.). 2013. *Higher education in agriculture: Trends, prospects, and policy directions*. Philippine Institute for Development Studies (PIDS) and the Philippine Council for Agriculture, Aquatic and Natural Resources Research and Development (PCAARRD). Retrieved from https://dirp3.pids.gov.ph/webportal/CDN/PUBLICATIONS/pidsbk14-afnr.pdf

Briones, R.M., M.A. Sombilla, and A.M. Balisacan. 2014. *Productivity growth in Philippine agriculture*. Southeast Asian Regional Center for Graduate Study and Research in Agriculture. Retrieved from http://www.searca.org/knowledge-resources/1603-pre-download?pid=266

Brown, L. 2013. "How to make a floating garden." *The Borgen Project*. Retrieved from https://borgenproject.org/how-to-make-a-floating-garden

Bugayong, L., and W. Carandang. 2003. "Agroforestry practices in a community-based forest management site." Food and Agriculture Organization. Retrieved from http://www.fao.org/docrep/ARTICLE/WFC/XII/0447-B5.HTM

Buresh, R.J. 2015. "Rice crop manager: innovative ICT approach for food security." Presented during the 2015 AFNR Symposium , AIM Makati City, Philippines, 30 September 30 2015. Retrieved from https://www.slideshare.net/atiinteractive/rice-crop-manager-innovative-ict-approach-for-food-security?from_action=save

Buresh, R.J., R.L. Castillo, C.J. Dela Torre, E.V. Laureles, M.I. Samson, P.J. Sinohin, and M. Guerra. 2019. "Site-specific nutrient management for rice in the Philippines: Calculation of field-specific fertilizer requirements by rice crop manager." *Field Crops Research,* 239(1):56–70.

Cabangbang, R.P.M., M.V.O. Espaldon, H.D. Mendoza, J.A.M. Lacson, R.J.C. Ducusin, D.F. Eslava, M.A. Dorado, V.G. Ballaran, M.D. Ebuenga, C.L. Khan, B.M. Salazar, C.M. Protacio, E.A. Aguilar, and V.A. Bato. 2019. *Paving the pathway for climate smart agriculture among small scale farmers in the Philippines.* Retrieved from http://www.fftc.agnet.org/files/lib_articles/20190321153806/EB%20716.pdf

Cabangon, R., S. Yadav, and R. Lampayan. 2016. "Water saving technologies under water scarce conditions." In *Water in Agriculture,* edited by Banta S.J. Laguna, Philippines: The Asia Rice Foundation.

Campbell, B.M., J. Hansen, J. Rioux, C.M. Stirling, S. Twomlow, and E. Wollenberg. 2018. "Urgent action to combat climate change and its impacts (SDG 13): transforming agriculture and food systems." *Current Opinion in Environmental Sustainability,* 34:13–20. https://doi.org/10.1016/j.cosust.2018.06.005

Cao, Y.Y., H. Duan, L. N. Yang, Z.Q. Wang, S.C. Zhou, and J.C. Yang. 2008. "Effect of heat stress during meiosis on grain yield of rice cultivars differing in heat tolerance and its physiological mechanism." *Acta Agronomica Sinica,* 34:2134–2142. Retrieved from https://www.sciencedirect.com/science/article/pii/S1875278009600225

Cao, Y.Y., H. Duan, L.N. Yang, Z.Q. Wang, L.J. Liu, and J.C. Yang. 2009. "Effect of high temperature during heading and early filling on grain yield and physiological characteristics in indica rice." *Acta Agronomica Sinica,* 35(3) 512–521. doi.org/10.1016/S1875-2780(08)60071-1. https://www.sciencedirect.com/science/article/pii/S1875278008600711

Carrijo, D.R., M.E. Lundy, and B.A. Linquist. 2017. "Rice yields and water use under alternate wetting and drying irrigation: A meta-analysis." *Field Crops Research*, 203: 173–180. https://doi.org/10.1016/j.fcr.2016.12.002

Castaños, M. 1997. "An aquasilvifarm in the Philippines." *SEAFDEC Asian Aquaculture*, 19(5): 18–20.

CCC (Climate Change Commission). 2011. *National climate change action plan*. Retrieved from http://extwprlegs1.fao.org/docs/pdf/phi152934.pdf

CGIAR. 2014. *Annual report 2014: Featuring Nutrition and Health.* CGIAR. Montpellier, France. Retrieved from http://www.g20ys.org/upload/files/CGIAR%20ANNUAL%20REPORT%202014.pdf

CGIAR-CCAFS (Climate Change Agriculture and Food Security). 2013. *Unlocking the potential of social learning for climate change and food security: Wicked problems and non-traditional solutions.* Copenhagen, Denmark: CGIAR Research Program on CCAFS. Retrieved from http://cgspace.cgiar.org/rest/bitstreams/19883/retrieve

Chandiramani, M., P. Kosina, and K. Jones. 2007. "Laser land leveling—a precursor technology for resource conservation." *Fact Sheet*. International Rice Research Institute-CIMMYT alliance Cereal Knowledge Bank. Retrieved from http://www.knowledgebank.irri.org/images/docs/irri-cimmyt-laser-land-leveling.pdf

Chauhan, P.S., and A. Kumar. 2016. "Performance analysis of greenhouse dryer by using insulated north-wall under natural convection mode." *Energy Reports,* 2 (2016), 107–116. Retrieved from https://www.sciencedirect.com/science/article/pii/S2352484716300178

CIFFAD (Cornell International Institute for Food, Agriculture, and Development). n.d. *SRI and climate change mitigation.* Retrieved from http://sri.ciifad.cornell.edu/index_files/ClimateChangeMitigation.pdf

Cinco, T.A., M.Q. Villafuerte II, E.D. Ares, J.A. Manalo, W.A. Agustin, K.A.M. Aquino, and R.Q. Gaspar. 2018. "Observed climate trends and projected climate change in the Philippines." In *Observed and Projected Climate Change in the Philippines*, edited by F.D. Hilario, E.L. Juanillo, and R.G. de Guzman. Diliman, Quezon City, 1100 Philippines: Philippine Atmospheric Geophysical and Astronomical Services Administration. Retrieved from https://icsc.ngo/portfolio-items/pagasa-observed-climate-trends-and-projected-climate-change-in-the-philippines-2018/

Clements, R., J. Haggar, A. Quezada, and J. Torres. 2011. *Technologies for climate change adaptation – agriculture sector*. Edited by X. Zhu. Retrieved from https://orbit.dtu.dk/files/5706575/Technologies_for_Climate_Change_Adaptation_Agriculture_sector.pdf

Clercq, M.D., A. Vats, and A. Biel. 2018. *Agriculture 4.0: The future of farming technology.* World Government Summit. Retrieved from https://www.worldgovernmentsummit.org/api/publications/document?id=95df8ac4-e97c-6578-b2f8-ff0000a7ddb6

Climate Reality Project. 2016. "How is climate change affecting the Philippines?" *Climate Reality Project Blog Post,* 19 January 2016. Retrieved from https://www.climaterealityproject.org/blog/how-climate-change-affecting-philippines

Coche, A.G. 1967. "Fish culture in rice fields. A worldwide synthesis." *Hydrobiologia,* 30:11–44. Retrieved from https://cals.arizona.edu/azaqua/AquacultureTIES/publications/English%20WHAP/GT8%20Rice_Fish.pdf

Concern Worldwide. 2016. "Rebuilding the Philippine reefs: Reversing the damage from Typhoon Haiyan." *Exposure.* Retrieved from https://concernworldwide.exposure.co/rebuilding-the-philippines-reefs

Contreras, S. 2012. "The soil conservation and management division plays a key role in the promotion and implementation of sustainable land management (SLM)." BSWM Online. Retrieved from http://bswm.da.gov.ph/article/002/the-soil-conservation-and-management-division-plays-a-key-role-in-the-promotion-and-implementation-of-sustainable-land-management-slm (site discontinued)

Corales, R.G., L.M. Juliano, A.O.V. Capistrano, H.S. Tobias, N. Dasalla, S.D. Canete, M.C. Casimero, and L.S. Sebastian. 2004. "*Palayamanan*: A sustainable rice-based farming systems model for small-scale farmers." *The Philippine Journal of Crop Sciences,* 29(1):21–27.

Critchley, W. 1991. *Looking after our land: Soil and water conservation in dryland Africa.* Edited by Olivia Graham. Oxford, UK: Oxfam Publications Oxfam on behalf of the Arid Lands Information Network and the International Institute for Environment and Development. Retrieved from http://www.fao.org/3/x5301e/x5301e00.htm#Contents

Croplife Philippines, DA, and BSWM. 2018. "Training manual on sustainable corn production in sloping area." Retrieved from https://issuu.com/croplifeph/docs/trainingmanualonscopsa

Cruz, A. 2016. "Philippine community adopts climate-smart agriculture with greater involvement." *CGIAR-CCAFS*, 5 August 2016. Retrieved from https://ccafs.cgiar.org/blog/philippine-community-adopts-climate-smart-agriculture-greater-involvement#.XO-NmYgzbIU

Cruz, B.P., E.F. Dacumos, and M.F. Martinez. 2012, December. "Making our lands more efficient for production." BSWM Online. Retrieved from http://bswm.da.gov.ph/article/0010/making-our-lands-more-efficient-for-production

Cruz, C.J., I. Zosa-Feranil, and C.L. Goce. 1988. "Population pressure and migration: Implications for upland development in the Philippines." *Journal of Philippine Development*, pp. 15–26.

Cruz, R.V.O. 2017. *Philippine climate change assessment: Impacts, vulnerabilities and adaptation.* The Oscar M. Lopez Center for Climate Change Adaptation and Disaster Risk Management Foundation, Inc. Pasig City 1605 Philippines..

Cruz, R.V.O., P.M. Aliño, O.C. Cabrera, C.P.C. David, L.T. David, F.P. Lansigan, and C.L. Villanoy. 2017. *Philippine climate change assessment: Impacts, vulnerabilities and adaptation.* Retrieved from http://www.omlopezcenter.org/new-release-philcca-working-group-2-impacts-vulnerabilities-and-adaptation

DA (Department of Agriculture). 2017. "General guidelines on the implementation of solar-powered irrigation system of the Department of Agriculture." Memorandum Order No. 13 Series of 2017, 6 March 2017. Retrieved from http://bpi.da.gov.ph/bpi/images/PDF_file/m.o no.13.pdf

DA-ATI (Agricultural Training Institute). 2017. *Corporate plan FY 2017–2022*. Quezon City, Philippines. Retrieved from http://ati.da.gov.ph/ati-main/sites/default/files/publications/ATI CORPORATE PLAN 2017 2022 b.pdf

DA-BFAR (Bureau of Fisheries and Aquatic Resources). 2018. *Fisheries situation report.* Retrieved from https://www.bfar.da.gov.ph/2019/FSR2018Jan-DecRevisedV5.0.pdf

DA-BSWM (Bureau of Soil and Water Management). 1993. *Crop development and soil conservation framework for Luzon Island*. Diliman, Quezon City: BSWM.

DA, DA-BSWM, and DA-BAR (Bureau of Agricultural Research). 2017. *Philippine case studies on sustainable land management approaches and technologies*. Quezon City, Philippines. Department of Agriculture-Bureau of Soils and Water Management.

DA, NEDA (National Economic and Development Authority), and DBM (Department of Budget and Management). 2019. "The Implementing Rules and Regulations of Republic Act No. 11203, An Act Liberalizing the Importation, Exportation and Trading of Rice, Lifting for the Purpose the Quantitative Import Restriction on Rice, and for Other Purposes." Joint Memorandum Circular No. 01-2019 Series of 2019. Retrieved from http://www.neda.gov.

ph/wp-content/uploads/2019/04/IRR-of-RA-No.-11203-or-the-Rice-Liberalization-Act-RLA_signed.pdf

Dagne, R.R. 1968. "Application of digestion theory of digestor control." *Journal of the Water Pollution Control Federation*, 40:2021–2032.

Das, S., P. Krishnan, M. Nayak, and B. Ramakrishnan. 2014. "High temperature stress effects on pollens of rice (*Oryza sativa* L.) genotypes." *Environmental Experimental Botany,* 101:36–46. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0098847214000100

DENR (Department of Environment and Natural Resources). 2017. *Guidelines on the implementation of sustainable integrated area development (SIAD) strategy*. Philippines: Retrieved from https://server2.denr.gov.ph/uploads/rmdd/dao-2017-02.pdf

DENR-ERDB (Ecosystems Research and Development Bureau). 2010. *A research compendium for marginal upland*. Retrieved from http://erdb.denr.gov.ph/2015/06/01/other-a-research-compendium-for-marginal-uplands/

DENR, DA-BFAR, and DILG (Department of Interior and Local Government). 2001. *Philippines Coastal Management Guidebook No. 1: Coastal Management Orientation and Overview.* Coastal resource management project of the Department of Environment and Natural Resources, Cebu City, Philippines. Retrieved from http://faspselib.denr.gov.ph/sites/default/files//Publication%20Files/crmguidebook1.pdf

DENR and IIRR (International Institute for Rural Reconstruction). 1992. "Soil and water conservation (SWC) technologies and Agroforestry Systems." *Agroforestry Technology Information Kit (ATIK) 1*. Retrieved from http://faspselib.denr.gov.ph/sites/default/files//Publication%20Files/crmguidebook1.pdf

Denton, F., T.J. Wilbanks, A.C. Abeysinghe, I. Burton, Q. Gao, M.C. Lemos, T. Masui, K.L. O'Brien, and K. Warner. 2014. "Climate-resilient pathways: Adaptation, mitigation, and sustainable development." In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by C.B. Field, V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1101–1131.

Devendra, C., and D. Thomas. 2002. "Crop-animal interactions in mixed farming systems in Asia." *Agricultural Systems*. 71:27–40.

Dieta, R.E., and F.C. Dieta. 2015. "The Philippine National Aquasilviculture Program." In *Resource Enhancement and Sustainable Aquaculture Practices in Southeast Asia: Challenges in Responsible Production of Aquatic Species: Proceedings of the International Workshop on Resource Enhancement and Sustainable Aquaculture Practices in Southeast Asia 2014 (RESA)*, edited by M.R.R. Romana-Eguia, F.D. Parado-Estepa, N.D. Salayo, and M.J.H. Lebata-Ramos. Tigbauan, Iloilo, Philippines: Aquaculture Dept., Southeast Asian Fisheries Development Center.

Dikitanan, R., G. Grosjean, A. Nowak, and J. Leyte. 2017. *Climate-resilient agriculture in Philippines. CSA Country Profiles for Asia Series.* International Center for Tropical Agriculture (CIAT) and Department of Agriculture-Adaptation and Mitigation Initiative in Agriculture. Government of the Philippines. Manila, Philippines.

DILG (Department of the Interior and Local Government). 2011. *Climate change in the Philippines.* Retrieved from https://dilg.gov.ph/PDF_File/reports_resources/DILG-Resources-2012130-2ef223f591.pdf

Dinesh, D., A.M.L. Rodríguez, A. Millan, T. Rawe, L. Stringer, P. Thornton, and B. Campbell. 2018. *A 6-part action plan to transform food systems under climate change creative actions to accelerate progress towards the SDGs*. Retrieved from https://ccafs.cgiar.org/publications/6-part-action-plan-transform-food-systems-under-climate-change-creative-actions#.XVFQMOgzbIU

Dizon, J. 2018. "Promoting rice and white corn combination as a staple for Filipinos." *UP Office of the Vice President for Academic Affairs (OVPAA) website,* 5 January 2018. Retrieved from https://ovpaa.up.edu.ph/promoting-rice-and-white-corn-combination-as-a-staple-for-filipinos/

Dobermann, A., and T.H. Fairhurst. 2002. "Rice straw management." *Better Crops International*, Vol. 16, Special Supplement (May 2002). http://www.ipni.net/publication/bci.nsf/0/163087B956D0EFF485257BBA006531E8/$FILE/Better%20Crops%20International%202002-3%20p07.pdf

DOLE (Department of Labor and Employment). 2012. *Industry career guide: Agribusiness*. Manila, Philippines. Retrieved from http://www.ble.dole.gov.ph/downloads/Publications/ICG/ICG-Agribusiness.pdf

Drake, D., G. Nader, and L. Forero. 2002. *Feeding rice straw to cattle*. University of California-Division of Agriculture and Natural Resources. Retrieved from https://anrcatalog.ucanr.edu/Details.aspx?itemNo=8079

Eckstein, D., V. Künzel, and L. Schäfer. 2017. "Global climate risk index 2018: Who duffers most from extreme weather events? Weather-related loss events in 2016 and 1997 to 2016." *German Watch Briefing Paper.* Retrieved from https://germanwatch.org/sites/germanwatch.org/files/publication/20432.pdf

EI (Equator Initiative). 2013. "Integrated rice-duck farming and value chain." Equator Initiative. Retrieved from https://www.equatorinitiative.org/2017/08/08/integrated-rice-duck-farming-and-value-chain

Escobin, R. 2001. "Integrated rice-duck farming systems." In *Food Security: Integrated Farming Systems (With Environment Friendly Approaches*, edited by J. A. Eusebio and R. V. Published by JMC Press, Inc. Quezon City, Philippines. Distributed by Goodwill Bookstore, Philippines. pp 119–126.

Espino, R., and C. Atienza. 2016. "Crop diversification in the Philippines." Food and Agriculture Organization. Retrieved from http://www.fao.org/3/x6906e/x6906e0a.htm

Eusebio, J.A. and R.V. Labios. 2001. *Food security: Integrated farming systems (With environment friendly approaches)*. Published by JMC Press, Inc. Quezon City, Philippines. Distributed by Goodwill Bookstore, Philippines. 312 p. (ISBN 971-11-1126-8)

Fabi, G., A. Spagnolo, A. Scarcella, A. Spagnolo, S.A. Bortone, E. Charbonnel, J.J. Goutayer, N. Haddad, A. Lök, and M. Trommelen. 2015. "Practical guideline for artificial reefs in the Mediterranean and Black Sea." *Studies and Reviews* No. 96. Food and Agriculture Organization and General Fisheries Commission for the Mediterranean. Rome. Retrieved from http://www.fao.org/3/a-i4879e.pdf

FAO (Food and Agriculture Organization of the United Nations). 2018. "Climate-smart crop production practices and technologies." In *Climate Smart Agriculture Sourcebook: Production and Resources*. Retrieved from http://www.fao.org/climate-smart-agriculture-sourcebook/production-resources/module-b1-crops/chapter-b1-2/en/

----------. 2017a. *FAO strategy on climate change*. Food and Agriculture Organization of the United Nations. Rome. Retrieved from http://www.fao.org/3/a-i7175e.pdf

----------. 2017b. *Report of the regional symposium on agroecology for sustainable agriculture and food systems for Europe and Central Asia*. Food and Agriculture Organization of the United Nations. Budapest, Hungary, 23–25 November 2016. Rome. Retrieved from http://www.fao.org/3/a-i7604e.pdf

----------. 2006. "Country pasture/forage resource profiles." Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/ag/agp/agpc/doc/counprof/PDF%20files/Philippines.pdf (site discontinued)

----------. n.d. "FAO Penman-Monteith equation." Food and Agriculture Organization of the United Nations. Retrieved from http://www.fao.org/3/X0490E/x0490e06.htm

FAO and ADB. 2015. Crop monitoring for improved food security. In *Proceedings of the Expert Meeting Vientiane, Lao People's Democratic Republic,* edited by M.K. Srivastava. Retrieved from http://www.fao.org/3/a-i4273e.pdf

FAO-WOCAT (World Overview of Conservation Approaches and Technologies). 2016. "Decision support for mainstreaming and scaling out sustainable land management." Retrieved from https://www.wocat.net/library/media/46/

FAO, WFP (World Food Program), and IFAD (International Fund for Agricultural Development). 2012. *The state of food insecurity in the world: Economic growth is necessary but not sufficient to accelerate reduction of hunger and malnutrition*. Rome, FAO.

Farming First. 2012. "Stone bunds as soil and water conservation measures in Sahelian countries" *Blog Post,* 10 September 2012. Retrieved from: https://farmingfirst.org/2012/09/stone-bunds-as-soil-and-water-conservation-measures-in-sahelian-countries/

Financial Express Online. 2018. "Doubling farmers' income: It's possible! How much-needed policy can work; all you need to know in 5 points." *Financial Express Online*, 1 November 2018. Retrieved from https://www.financialexpress.com/economy/doubling-farmers-income-its-possible-how-much-needed-policy-can-work-all-you-need-to-know-in-5-points/1368947/?fbclid=IwAR17WWEVB-kjDr7IVpk3NjJs0fW9L5pb0Lhxni-A8sbX6D0GbTSt7Rjsnu4

Flor, R.J., G.R. Singleton, M. Casimero, Z. Abidin, N. Razak, H. Maat, and C. Leeuwis. 2016. "Farmers, institutions and technology in agricultural change processes: Outcomes from adaptive research on rice production in Sulawesi, Indonesia." *International Journal of Agricultural Sustainability*, 14:166–186.

Flores, C., M. Corpuz, and J. Salas. 2016. "Adoption of aquasilviculture technology: a positive approach for sustainable fisheries and mangrove wetland rehabilitation in Bataan, Philippines." *International Journal of Food Engineering*, 2:1. Retrieved from http://www.ijfe.org/uploadfile/2016/0512/20160512064711789.pdf

FPE (Foundation for the Philippine Environment). 2018. "The lay of the land: Ecosystem diversity in the Philippines." FPE-Biodiversity. Retrieved from https://fpe.ph/biodiversity.html/view/the-lay-of-the-land-ecosystem-diversity-in-the-philippines

Francisco, H., and A. Rola. 2004. "Realities of watershed management in the Philippines: Synthesis of case studies." *PIDS Discussion Paper Series* No. 2004-24. Retrieved from https://dirp3.pids.gov.ph/ris/dps/pidsdps0424.pdf

Fukai, S., and H. Boonjung. 1996. "Effects of soil water deficit at different growth stages on rice growth and yield under upland conditions." *Phenology, biomass production and yield,* 48 (1):47–55. Retrieved from https://www.sciencedirect.com/science/article/pii/0378429096000391

Gaihre, Y.K., U. Singh, S. M. MofijulIslam, A. Huda, M.R. Islam, M.A. Satter, J. Sanabria, Md.R. Islam, and A.L. Shah. 2015. "Impacts of urea deep placement on nitrous oxide and nitric oxide emissions from rice fields in Bangladesh." *Geoderma* 259:370–379.

Gamuyao, R., H.C. Joong, J.P. Tanaka, and S. Heuer. 2012. "The protein kinase 0sPSTOL1 from traditional rice confers tolerance of phosphorous deficiency." *Nature* 488(7412):535-9. Retrieved from https://www.researchgate.net/publication/230722033_The_protein_kinase_OsPSTOL1_from_traditional_rice_confers_tolerance_of_phosphorus_deficiency/stats

Gasum. n.d. "How is biogas produced?" Gasum. Retrieved from https://www.gasum.com/en/About-gas/biogas/Biogas/how-is-biogas-produced/

GCF (Green Climate Fund). 2015. "Engaging with the Green Climate Fund: A resource guide for national designated authorities and focal points of recipient countries." *Elements* 01, 2nd Edition (November 2015). Green Climate Fund. Retrieved from https://www.greenclimate.fund/documents/20182/194568/GCF_ELEMENTS_01.pdf/542c1610-81b4-40df-be62-025cef3d26d8

Ge, L., C. Brewster, J. Spek, A. Smeenk, and J. Top. 2017. *Blockchain for agriculture and food: Findings from the pilot study.* Wageningen University and Research. Retrieved from https://www.wur.nl/upload_mm/d/c/0/b429c891-ab94-49c8-a309-beb9b6bba4df_2017-112 Ge_def.pdf

German Watch. 2018. *Global climate risk index 2018*. German Watch. Retrieved from https://germanwatch.org/de/14638

Geron, M. P. S., G.M. Llanto, and J.A.R. Badiola. 2016. “Comprehensive study on credit programs to smallholders.” *PIDS Discussion Paper Series* No. 2016-48. Retrieved from https://dirp4.pids.gov.ph/websitecms/CDN/PUBLICATIONS/pidsdps1648.pdf

Gerpacio, R.V., J.D. Labios, R.V. Labios, and E.J. Diangkinay. 2004. *Corn in the Philippines: Production systems, constraints and research priorities*. Mexico, D.F.: CIMMYT. Retrieved from http://ageconsearch.umn.edu/bitstream/7650/1/mp04ge01.pdf. https://books.google.com.ph/books?isbn=9706481230

Gonzales, L.A. 1989. “The economics of diversifying into irrigated non-rice crops in the Philippines.” *Proc. National workshop on Crop Diversification in the Philippines*. IIMI, Sri Lanka, 203–208.

Gonsalves, J., D. Campilan, G. Smith, V. L. Bui, and F. M. Jimenez. (Eds.). 2015. *Towards climate resilience in agriculture for Southeast Asia: an overview for decision-makers.* Hanoi, Vietnam: International Center for Tropical Agriculture (CIAT). CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). 450 p. Retrieved from https://cgspace.cgiar.org/handle/10568/71100

Gonsalves, J., E.M. Oro, and I. Baguilat. 2017. *Bio-intensive gardening (BIG): a climate and nutrition smart agriculture approach*. Cavite, Philippines: International Institute of Rural Reconstruction (IIRR). International Development Research Centre (IDRC). 23 p. Retrieved from https://schoolnutritionphils.files.wordpress.com/2017/04/big-primer.pdf

Greenland, D. 1997. *Rice land ecosystems*. Retrieved from https://www.researchgate.net/figure/Rice-land-ecosystems-after-Greenland-1997-as-adapted-from-IRRI-1993_fig1_23550931

Gregory, R. 1997. *Rice fisheries handbook*. Cambodia-IRRI-Australia Project, Cambodia, 38p.

Gregorio, G.B. 2010. “Progress in breeding for trace minerals in staple crops.” *The Journal of nutrition* 132 (3):500S–502S.

Gregorio, G.B., D. Senadhira, R.D. Mendoza, N.L. Manigbas, J.P. Roxas, and C.Q. Guerta. 2002. “Progress in breeding for salinity tolerance and associated abiotic stresses in rice.” *Field Crops Research*. 76:91–101.

GRiSP (Global Rice Science Partnership). 2013. *Rice almanac (*4th edition). Los Baños (Philippines): International Rice Research Institute. 283 p. Retrieved from http://books.irri.org/9789712203008_content.pdf

Grospe, J.L., E.A. Abella, and N.L. Manigbas. 2016. “Quantitative trait loci for high-temperature tolerance in rice (*Oryza sativa* L.).” *Philippine Agricultural Scientist*, 99:1 7–18.

Guiang, E., S. Borlagdan, and J. Pulhin. 2001. *Community-based forest management in the Philippines: a preliminary assessment.* Quezon City: Institute of Philippine Culture, Ateneo de Manila University. Retrieved from http://dlc.dlib.indiana.edu/dlc/bitstream/handle/10535/7541/CBFM%20Preliminary%20Assessment.pdf?sequence=1

Gummert, M., and C. Balingbing. 2018. *Laser-assisted land leveling*. International Rice Research Institute, pp. 26.

Gunasena, H.P. 2001. *Intensification of crop diversification in the Asia-Pacific region*. Food and Agriculture Organization. http://www.fao.org/docrep/003/x6906e/x6906e0e.html (site discontinued)

Gurr, G.M. 2009. “Prospects for ecological engineering for planthoppers and other arthropod pests in rice.” In *Planthoppers: new threats to the sustainability of intensive rice production systems in Asia,* edited by K. L. Heong and B. Hardy. Los Baños (Philippines): International Rice Research Institute.

Gurr, G.M., H. van Emden, and S.D. Wratten. 1998. “Habitat manipulation and natural enemy efficiency: implications for the control of pests.” In *Conservation Biological Control,* edited by Barbosa P. Academic Press, San Diego. pp 155–183.

Gurr, G.M., S.D. Wratten, and M.A. Altieri. 2004. *Ecological engineering: advances in habitat manipulation for arthropods*. Collingwood (Australia): CSIRO Publishing. 232 p.

Hasanuzzaman, M., K. Nahar, and M. Fujita. 2013. “Extreme temperature responses, oxidative stress, and antioxidant defense in plants.” In *Chapter 6 on Abiotic stress--plant responses and application in agriculture*. Retrieved from http://dx.doi.org/10.5772/54833Available from https://www.intechopen.com/books/abiotic-stress-plant-responses-and-applications-in-agriculture/extreme-temperature-responses-oxidative-stress-and-antioxidant-defense-in-plants

Heong, K.L., M.M. Escalada, H.V. Chien, and L.Q. Cuong. 2014. “Restoration of rice landscape biodiversity by farmers in Vietnam through education and motivation using media.” *SAPIENS*, 7.2, 2014. Retrieved from http://journals.openedition.org/sapiens/1578.

Huang, Y., H. Wang, H. Huang, F. Zhaozhong, Z.H. Yang, and Y.C.C. Luo. 2005. “Characteristics of methane emission from wetland rice–duck complex ecosystem.” *Agriculture Ecosystems & Environment* 105(1–2):181–193. doi:10.1016/j.agee.2004.04.004. Retrieved from https://www.researchgate.net/publication/222965521_Characteristics_of_methane_emission_from_wetland_rice-duck_complex_ecosystem/citations

Huet, M. 1972. “Textbook of fish culture: breeding and cultivation of fish.” *Fishing News*, London. Retrieved from http://aquaticcommons.org/792/1/No_5.CV.pdf

Hung, N.V. 2016. *Laser controlled land leveling: Principles and hydraulic system. Laser leveling course for Syngenta*. International Rice Research Institute. Philippines, 5–9 December 2016.

IFAD (International Fund for Agricultural Development). 2013. *2012 IFAD annual report*. Retrieved from https://maintenance.ifad.org/documents/38714170/39625681/annual+report+2012+english+final+print.pdf/664e5cf9-8166-4d43-9db2-f5d4b6a9eb03

IIRR (International Institute of Rural Reconstruction). 2016. *Climate resilience in agriculture: key concepts for community-based adaptation*. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). 17 p. Retrieved from https://cgspace.cgiar.org/rest/bitstreams/90427/retrieve

IIRR and IDRC (International Development research Centre). 2008. *Community-based forest management at 10: A Multi-stakeholder Forum Proceedings*. Retrieved from https://www.academia.edu/34777010/Benefits_and_Constraints_of_Community-Based_Forest_Management_in_the_Philippines

Ingh, Y., and H.S. Sidhu. 2014. "Management of cereal crop residues for sustainable rice-wheat production system in the Indo-gangetic plains of India." *Proc. Indian National Science Academy*, 80(1):95–114.

IPB-CA-UPLB (Institute of Plant Breeding, College of Agriculture, U.P. Los Baños). 2019. *Open pollinated white corn varieties released in the Philippines*.

IPCC (Intergovernmental Panel on Climate Change). 2012. *Special report on managing the risks of extreme events and disasters to advance climate change adaptation.* In *A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change,* edited by C.B.V. Field, T.F. Barros, D. Stocker, D.J. Qin, K.L. Dokken, M.D. Ebi, K.J. Mastrandrea, G.K. Mach, S.K. Plattner, M.T. Allen, and P.M. Midgley. Cambridge University Press, Cambridge, UK and New York, NY, USA, 582 pp.

IRRI (International Rice Research Institute). 2017. *Rice crop manager providing field-specific crop and nutrient management for increased yield and income*. Retrieved from http://www.agritechnica-asia.com/wp-content/uploads/2017/03/Nutrient-Management-in-RCM_13March17.pdf

----------. 2016a. *Rice straw collection fact sheet.* International Rice Research Institute-Postharvest and Mechanization Unit.

----------. 2016b. *Solar bubble dryer fact sheet.* International Rice Research Institute-Postharvest and Mechanization Unit.

----------. 2015. "Small farmers, large field scheme gaining success in Vietnam." *IRRI News,* 15 May 2015. Retrieved from http://news.irri.org/2015/05/small-farmers-large-field-scheme.html

IRRI-RKB (Rice Knowledge Bank). n.d. "Rice straw." International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/step-by-step-production/postharvest/rice-by-products/rice-straw

----------. 2009. "Irrigated lowland rice ecosystem." International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/submergedsoils/index.php/rice-growing-environments/lesson-1

----------. 2007a. "Nutrient Management." International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/ericeproduction/IV.4_SSNM.htm

----------. 2007b. “N-application.” International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/ericeproduction/pop_up_Nitrogen_application.htm

----------. n.d. “Phosphorus (P).” International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/training/fact-sheets/nutrient-management/item/phosphorus

----------. 2007d. “K-application.” International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/ericeproduction/pop_up_Potassium_application.htm

----------. n.d. “Step-by-step rice production.” International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/step-by-step-production

----------. n.d. “In-field rice straw management.” International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/step-by-step-production/postharvest/rice-by-products/rice-straw/in-field-rice-straw-management

----------. n.d. “Saving water with alternate wetting drying (AWD).” International Rice Research Institute. Retrieved from http://www.knowledgebank.irri.org/training/fact-sheets/water-management/saving-water-alternate-wetting-drying-awd

Islam, M.T., and M. Nursey-Bray. 2017. “Adaptation to climate change in agriculture in Bangladesh: The role of formal institutions.” *J Environ Manage* 200:347–358 (15 Sep 2017). doi: 10.1016/j.jenvman.2017.05.092. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/28599218

Ismail, A.M., D.E. Johnson, E.S. Ella, G.V. Vergara, and A.M. Baltazar. 2012. “Adaptation to flooding during emergence and seedling growth in rice and weeds, and implications for crop establishment.” *AoB PLANTS* 2012, pls019. doi:10.1093/aobpla/pls019

Ismail, A.M., M.J. Thomson, G.V. Vergara, M.A. Rahman, and R.K. Singh. 2010. “Designing resilient rice varieties for coastal deltas using modern breeding tools.” In *Tropical Deltas and Coastal Zones: Food Production, Communities and Environment at the Land-Water Interface*, CABI. 154 p.

IUCN (International Union for Conservation of Nature). 2018**. “**Land degradation and climate change.” *IUCN Issues Brief.* Retrieved from https://www.iucn.org/resources/issues-briefs/land-degradation-and-climate-change

IWMI (International Water Management Institute). *In-field rainwater harvesting: A climate-smart sustainable production practice.* CGIAR Challenge Program on Water and Food. Retrieved from http://www.iwmi.cgiar.org/wp-content/uploads/2011/11/infield.pdf

JASRI (Japan Association of the System of Rice Intensification). 2012. *Guideline on SRI practice for tropical countries*. Retrieved from http://sri.ciifad.cornell.edu/countries/japan/extmats/JSRI_Guideline0312.pdf

Jat, M.L., P. Chandna, R. Gupta, S. K. Sharma, and M. A. Gill. 2006. “Laser land leveling: A precursor technology for resource conservation.” *Rice-Wheat Consortium Technical Bulletin Series* 7. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains. p. 48.

Jayaraman, P.P., A. Yavari, D. Georgakopoulos, A. Morshed, and A. Zaslavsky. 2016. “Internet of things platform for smart farming: Experiences and lessons learnt.” *Sensors* 2016, 16(11), 1884. https://doi.org/10.3390/s16111884

Keys, N., D.C. Thomsen, and T.F. Smith. 2016. “Adaptive capacity and climate change: the role of community opinion leaders.” *Local Environment*, 21(4): 432–450. DOI: 10.1080/13549839.2014.967758

Kong, L., and B. Yuen. 2009. “Climate change and urban planning in Southeast Asia.” *SAPIENS* pp. 11.

Labios, R.V., J.D. Labios, L.L. Jr. Tamisin, M.Q. Esguerra, E.A. Balbarino, F.T. Dayap, R.C. Cambaya, and E.C. Nacario. 2004. “Conservation tillage systems and farmer’s practice in corn production in the Philippines.” *Philippine Journal of Crop Sciences* 29(1):11–20.

Labios, R.V., and D.B.N Malayang. 2015. *Promotion of climate resilience in corn and rice: Philippines national study. A joint undertaking by the ASEAN Technical Working Group on Agricultural Research and Development (ATWGARD) and the Deutsche Gesellshaft fur, Internationale Zusammenarbeit (GIZ) Gmbh through the ASEAN-German Programme on Response to Climate Change*. Deutsche Gesellshaft fur, Internationale Zusammenarbeit (GIZ) Gmbh, Germany. 46 p. Retrieved from https://asean-crn.org/?media_dl=761

Labios, R.V., P.H. Manguiat, J.D. Labios, and D.B. Malayang. 2016. “Considering farmers’ preferences in breeding and dissemination of white corn varieties as staple food.” *Philippine Agricultural Scientist*, 99 (4): 379–390.

Labios, R.V., J.G. Montesur, and R.O. Retales. 1994. “Alley cropping in sloping upland rice areas of Cavite, Philippines.” *Philippine Journal of Crop Sciences*, 19 (1):33–37.

Labios, R.V., V.T. Villancio, J.D. Labios, A.M. Salazar, and R.E. de los Santos. 1997. “Development of alternative cropping pattern in rainfed lowland areas with small farm reservoir.” *The Philippine Agricultural Scientist*, 80 (3 and 4):187–199.

Labios, R.V., and R. Wassmann. 2018. *Climate-smart rice production manual: Myanmar context*. Los Baños (Philippines), International Rice Research Institute. 171 p.

Lampayan, R.M., R.M. Rejesus, G.R. Singleton, and A.M. Bouman. 2015. “Adoption and economics of alternate wetting and drying water management for irrigated lowland rice.” *Field Crops Research*, 170: 95–108. https://doi.org/10.1016/j.fcr.2014.10.013

Landicho, L.D., R.F. Paelmo, R.D. Cabahug, C.C. de Luna, R.G. Visco, and L.L. Tolentino. 2016. “Climate change adaptation strategies of smallholder agroforestry farmers in the Philippines.” *Journal of Environmental Science and Management*, 19(1): 37–45. Retrieved from https://journals.uplb.edu.ph/index.php/JESAM/article/download/1484/pdf_41

Landicho, L., and J. Fernandez. 2009. *Agroforestry education in the Philippines: Status report from the Southeast Asian network for agroforestry education (SEANAFE). Working paper 96*. World Agroforestry Centre. Bogor, Indonesia. 23p(PDF). Retrieved from https://www.researchgate.net/publication/228587410_Agroforestry_Education_in_the_Philippines_Status_Report_from_the_Southeast_Asian_Network_for_Agroforestry_Education_SEANAFE

Lawas, N.R., and B.M. Calub. 1991. *Productivity of hilly-land farming systems*. University of the Philippines, Los Baños, College, Laguna (Philippines). Dept. of Agronomy [Corporate Author.]. Retrieved from http://agris.fao.org/agris-search/search.do?recordID=PH19930034479

Lasco, R.D., R.J.P. Delfino, D.C. Catacutan, E.S. Simelton, and D.M. Wilson. 2014. "Climate risk adaptation by smallholder farmers: The roles of trees and agroforestry." *Current Opinion in Environmental Sustainability*, 6:83–88. https://doi.org/10.1016/j.cosust.2013.11.013

Leber, K. n.d. "The expanding role of marine aquaculture and fisheries enhancement in sustainable fisheries." Retrieved from http://www.stockenhancement.org/admin/UF%20Spring%20Symposium%20-%20Leber%203.pdf

Leghari, S.J., M. Buriro, M.A. Khaskheli, G.M. Laghari, U.A. Leghari, and F.A. Soomro. 2016. "Modern leaf colour chart successfully prepared and used in crop production of Sindh, Pakistan." *European Acad Res*. 4(2). Retrieved from https://www.researchgate.net/publication/303074042_Modern_Leaf_Color_Chart_Successfully_Prepared_and_Used_in_Crop_Production_of_Sindh_Pakistan

Licuanan, A.M., M.Z. Reyes, K.S. Luzon, M.A.A. Chan, and W.Y. Licuanan. 2017. "Initial findings of the nationwide assessment of Philippine coral reefs." *Philippine Journal of Science.* Retrieved from http://philjournalsci.dost.gov.ph/53-vol-146-no-2-june-2017/640-initial-findings-of-the-nationwide-assessment-of-philippine-coral-reefs

Lin B.B. 2011. "Resilience in agriculture through crop diversification: Adaptive management for environmental change." *BioScience*, 61(3):183–193.

Llanto, G.M. 2017. Philippines. In *ASEAN and Member States: Transformation and Integration*, edited by P. Intaland and L. Chen. Indonesia: Economic Research Institute for ASEAN and East Asia and the Department of Foreign Affairs, pp. 180–198.

Lohan, S.K., S.S. Harminder, and S. Manpreet. 2014. "Laser-controlled land leveling and grading for precision farming." In *Precision Farming: A New Approach*. First Astral International Pvt Ltd. New Delhi.148–158. doi: 10.13140/2.1.1103.9689

Mackill, D.J., W.R. Coffman, and D.P. Garrity. 1996. *Rainfed lowland rice improvement*. Philippines: International Rice Research Institute.

Mackill, D.J., A.M. Ismail, U.S. Singh, R.V. Labios, and T.R. Paris. 2012. "Development and rapid adoption of submergence tolerant (Sub1) rice varieties." *Advances in Agronomy*, 115:299–352.

Makkar, H.P.S. 2016. "Smart livestock feeding strategies for harvesting triple gain—the desired outcomes in planet, people and profit dimensions: A developing country perspective." *Animal Production Science*, 56: 519–534.

Malak, I. 2016. *Pumping water using solar energy for irrigation*. School of Science and Engineering, AAkhawayn University.

Manalo IV, J.A., K.P. Balmeo, J.C. Berto, and F.M. Saludez. 2016. *Youth and agriculture: The infomediary campaign in the Philippines*. Science City of Muñoz, 3119 Nueva Ecija: DA-PhilRice and DA-Bureau of Agricultural Research. Retrieved from http://www.ble.dole.gov.ph/downloads/Publications/ICG/ICG-Agribusiness.pdf

Manigbas, N.L., and L.S. Sebastian 2007. "Breeding rice for high temperature tolerance in the Philippines." Paper presented during the International Workshop on Cool Rice for a Warmer World. 26–30 March 2007. Wuhan, Hubei, China.

Manigbas, N.L., L.A. Lambio, L.B. Madrid, and C.C. Cardenas. 2014. "Germplasm innovation of heat tolerance in rice for irrigated lowland conditions in the Philippines." *Rice Science*, 21(3): 162–169.

Manguiat P. H., J.D. Labios, R.V. Labios, and D.B.N. Malayang. 2018. *A guidebook on participatory varietal selection of white corn as grits for food*. Agricultural Systems Institute, College of Agriculture, University of the Philippines Los Baños, Laguna, Philippines. 73 p.

Manzanilla, D.O., J.D. Janiya, and D.E. Johnson. 2014. *Establishing community-based seed systems: a training manual*. Philippines: International Rice Research Institute. 215 p.

Manzanilla, D.O., T.R. Paris, G.V. Vergara, A.M. Ismail, S. Pandey, R.V. Labios, G.T. Tatlonghari, R.D. Acda, T.T.N. Chi, K. Duoangsila, I. Siliphouthone, M.O.A. Manikmas, and D.J. Mackill. 2011. "Submergence risks and farmers' preferences: implications for breeding Sub1 Rice in Southeast Asia." *Agricultural Systems* 104:335–347.

Mercado, R.G. 2002. "Regional development in the Philippines: A review of experience, state of the art and agenda for research and action." *PIDS Discussion Paper Series* No. 2002-3. Makati City, Philippines. Retrieved from https://dirp3.pids.gov.ph/ris/dps/pidsdps0203.pdf

Mina, C.D., C.M. Reyes, and R.A.B. Gloria. 2015. "Targeting the agricultural poor: The case of PCIC's special programs." *PIDS Discussion Paper Series* No. 2015-8. Makati City, Philippines. Retrieved from https://www.econstor.eu/bitstream/10419/127031/1/pidsdps1508.pdf

Minang, P.A., M. van Noordwijk, O.E. Freeman, C. De Mbow, J. De Leeuw, and D.C. Catacutan. (Eds.). 2015. *Climate-smart landscapes: Multifunctionality in practice.* Nairobi, Kenya: World Agroforestry Centre. Retrieved from http://www.worldagroforestry.org/sea/Publications/files/book/BK0179-14.pdf

MO (Manila Observatory). 2012. "Mapping Philippine agroecological zones (AEZS): Technical notes." *HDN Discussion Paper Series* 2012/2013-14. Retrieved from https://www.scribd.com/document/231221385/Mapping-Philippines-Agro-Ecologizal-Zones

Mohod, A.G., Y. P.Khandetod, and H.Y. Shrirame. 2014. "Development and evaluation of solar tunnel dryer for commercial fish drying." *Journal of the Institution of Engineers* (India): Series A 95: 1. https://doi.org/10.1007/s40030-014-0070-2

Morgan, R.P.C. 1995. *Soil erosion and conservation* (second ed.) Silsoe College, Cranfield University. Retrieved from https://biblio.ugent.be/publication/378900/file/738003

NAPC (National Anti-Poverty Commission) and IIRR 2016. *Integrated community food production. a compendium of climate-resilient agriculture options.* Retrieved from https://ccafs.cgiar.org/publications/integrated-community-food-production-compendium-climate-resilient-agriculture-options#.XdcxUoMzbMw

NEDA. 2017. *Philippine development plan 2017–2022 Abridged Version*. Pasig City 1605 Philippines. Retrieved from http://www.neda.gov.ph/wp-content/uploads/2018/01/Abridged-PDP-2017-2022_Updated-as-of-01052018.pdf

----------. 2013. *Annual report: Restructuring NEDA, transforming the Philippine economy*. Retrieved from http://www.neda.gov.ph/wp-content/uploads/2014/06/Annual-REport-2013_FINAL-ARTWORK_for-print.pdf

Nepomuceno, P. 2018. "Agri damage due to 'Ompong' hits P14.3-b mark." *Philippine News Agency,* 18 September 2018. Retrieved from https://www.pna.gov.ph/articles/1048360

Ngo, T. 2011. *Comparative assessment of using rice straw for rapid composting and straw mushroom production in mitigating greenhouse gas emissions in Mekong Delta, Vietnam and Central Luzon, Philippines*. Unpublished dissertation for PhD in Environmental Science. School of Environmental Science and Management, University of the Philippines Los Banos.

Nidhi, P.V. 2016. "A review paper on solar greenhouse dryer." *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, e-ISSN: 2278-1684, p-ISSN: 2320-334X. Retrieved from http://www.iosrjournals.org/iosr-jmce/papers/Conf15010/Vol-2/8.%2043-48.pdf

Nyssen, J., J. Poesen, D. Gebremichael, K. Vancampenhout, M. D'aes, G. Yihdego, G. Govers, H. Leirs, J. Moeyersons, J. Naudts, N. Haregeweyn, M. Haile, and J. Deckers. 2006. *Interdisciplinary on-site evaluation of stone bunds to control soil erosion on cropland in Northern Ethiopia.* Retrieved from https://biblio.ugent.be/publication/378900/file/738003

Obcemea, W.N., M.P. Lucas, S.R. Pascua Jr., E.O. Agustin, T.F. Marcos, J.K. Ladha, and S.R. Obien. 1996. "Rainfed lowland rice-based cropping systems in the Philippines: A review." *ACIAR Proc. No.* 70, 197–231. Retrieved from www.fao.org/3/x6906e/x6906e0a.htm

Ocampo, A.M., R.V. Labios, J.D. Labios, C.M. Medina, C.R. Lapoot, S.C. Tumamang, H.C. Gines, J. Descalsota, J.M. Pasuquin, and C. Witt. 2015. "Site-specific nutrient management for corn production in favorable environments of the Philippines." *Philippine Journal of Crop Sciences* 40(3):40–48.

Oerke, E.C. 2006. "Crop losses to pests." *Journal of Agricultural Science*, 144:31–43. http://dx.doi.org/10.1017/S0021859605005708. Retrieved from https://www.cambridge.org/core/journals/journal-of-agricultural-science/article/crop-losses-to-pests/AD61661AD6D503577B3E73F2787FE7B2

One Ocean. n.d. "Understanding the Philippine coastal environment: An endangered coastal environment." Retrieved from http://www.oneocean.org/textver/about_crmp/coastal.html

Ortiz-Monasterio, I., and W. Raun. 2007. "Reduced nitrogen and improved farm income for irrigated spring wheat in the Yaqui Valley, Mexico, using sensor-based nitrogen management." *Journal of Agricultural Science* (Cambridge), 145: 215–222.

PAGASA (Philippine Atmospheric Geophysical and Astronomical Services Administration). 2018. *Climate impact assessment for Philippine agriculture (rice and corn)* (7-34). PAGASA-Department of Science and Technology. Retrieved from http://pubfiles.pagasa.dost.gov.ph/iaas/assessment.pdf

Page, W. 2014. *Crop diversification and nutrition*. Australian Centre for International Agricultural Research (ACIAR). Retrieved from https://www.aciar.gov.au/file/81726/download?token=1uo2q7Ew

Pampolino, M.F., C. Witt, J. M. Pasuquin, A. Johnston, and M.J. Fisher. 2012. "Development approach and evaluation of the Nutrient Expert software for nutrient management in cereal crops." *Computers and Electronics in Agriculture*, (88):103–110.

Paningbatan, E.P., R.A. Comia, and L. Håkansson. 1994. "Erosion and crop yield response to soil conditions under alley cropping systems in the Philippines." *Soil and Tillage Research* 31(2):249–261 Retrieved from https://www.researchgate.net/publication/223559424_Erosion_and_crop_yield_response_to_soil_conditions_under_alley_cropping_systems_in_the_Philippines

Parreno-de Guzman, L.E., O.B. Zamora, and D.F.H. Bernardo. 2015. "Diversified and integrated farming systems (DIFS): Philippine experiences for improved livelihood and nutrition." *Journal of Developments in Sustainable Agriculture*, 10(1), 19–33. https://doi.org/10.11178/jdsa.10.19

Paris, T.R., D.O. Manzanilla, G. Tatlonghari, R. Labios, A. Cueno, and D. Villanueva. 2011. *Guide to participatory varietal selection for submergence-tolerant rice.* International Rice Research Institute. Los Baños, Philippines. 111p. (ISBN 978-971-22-262-9). Retrieved from http://books.irri.org/9789712202629_content.pdf

Pasuquin, J. M., M. F. Pampolino, C. Witt, A. Dobermann, T. Oberthür, M. Fisher, and K. Inubushi. 2014. "Closing yield gaps in corn production in South-east Asia through site-specific nutrient management." *Field Crops Research*, (156):219–230.

Pasuquin, J.M., S. Saenong, P.S. Tan, C. Witt, and M.J. Fisher. 2012. “Evaluating N management strategies for hybrid corn in Southeast Asia.” *Field Crops Research*, (134):153–157.

Pasuquin, J.M., C. Witt, and M. Pampolino. 2010. “A new site-specific nutrient management approach for corn in the favorable tropical environments of Southeast Asia.” Paper presented at the 19th World Congress of Soil Science, Soil Solutions for a Changing World, Brisbane, Australia, 1–6 August 2010, Published on DVD. Retrieved from https://iuss.org/19th%20WCSS/Symposium/pdf/0811.pdf

Patil, R., and R. Gawande. 2015. “A review on solar tunnel greenhouse drying system.” *Renewable and Sustainable Energy Reviews*, Volume 56, April 2016, Pages 196–214. http://dx.doi.org/10.1016/j.rser.2015.11.057

Patle, G.T., D.K. Singh, A. Sarangi, and M. Khanna. 2016. “Managing CO_2 emission from groundwater pumping for irrigating major crops in trans indo-gangetic plains of India.” *Climatic Change* 136(2). DOI10.1007/s10584-016-1624-2

PCAARRD. 2003. *PCARRD recommends for reforestation and tree farming*. Los Baños, Laguna.

----------. 2016. “Boosting commercialization of agricultural innovations.” *The PCAARRD Monitor* 1 (2). ISSN 0116-3140. Retrieved from http://www.pcaarrd.dost.gov.ph/home/portal/index.php/pcaarrd-monitor/book/93

PCW (Philippine Commission on Women). 2014. *Women’s empowerment, development and gender equality Plan 2013–2016*. Manila, Philippines. Retrieved from https://www.pcw.gov.ph/sites/default/files/documents/resources/womens_edge_plan.pdf

Peng, S., F.V. Garcia, R.C. Laza, A.L. Sanico, R.M. Visperas, and K.G. Cassman. 1996. “Increased N-use efficiency using a chlorophyll meter on high-yielding irrigated rice.” *Field Crops Research*. 47:243–252.

Prakash, O., A. Kumar, and V. Laguri. 2016. “Performance of modified greenhouse dryer with thermal energy storage.” *Energy Reports 2 (2016)*, pp. 155–162. Retrieved from https://www.sciencedirect.com/science/article/pii/S2352484716300233

Prakash, O., and A. Kumar. 2014. “Solar greenhouse drying: A review.” *Renewable and Sustainable Energy Reviews*, Volume 29 (January 2014), pp. 905–910. Retrieved from https://www.researchgate.net/publication/265249321_Solar_Greenhouse_Drying_A_Review

PhilCAT SLM (Philippine Conservation Approaches and Technologies-Sustainable Land Management). 2016. “Sustainable Land Management (SLM) Practices.” PhilCAT SLM. Retrieved from http://www.bswm.da.gov.ph/philcat-slm/slm/index

PhilMech (Philippine Center for Postharvest Development and Mechanization). 2016. PhilMech annual report 2015: *Making waves in research, development and extension*. Science City of Muñoz, Nueva Ecija, Philippines. Retrieved from http://old.philmech.gov.ph/upload/PUBLICATIONS/annual_reports/2015/PhilMech Annual Report 2016.pdf

PhilREDD+ST (The Philippines REDD-plus Strategy Team). 2010. “The Philippine national REDD-plus strategy.” DENR– Forest Management Bureau and CoDe REDD-plus Philippines Retrieved from https://www.elaw.org/system/files/PhilippineNationalREDDplusStrategy.pdf

PhilRice (Philippine Rice Research Institute). 2018. *Released stress-tolerant rice varieties in the Philippines*.

----------. 2017. *PhilRice Los Baños climate-smart agriculture projects*. Retrieved from https://www.philrice.gov.ph/philrice-los-banos-launches-climate-smart-agriculture-projects

Picard, J. 2011. *Stone bunds: Methods and tools [Factsheet]*. Abeche, Chad: Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. Retrieved from https://wocatpedia.net/images/e/eb/GIZ_(2011)_Stone_Bunds.pdf

Pound, B., R. Lamboll, S. Croxton, G. Naman, and A. Bahadur. 2018. “Climate-resilient agriculture in South Asia: An analytical framework and insights from practice.” *Action on Climate Today Learning Paper*. Retrieved from http://www.adaptationlearning.net/sites/default/files/resource-files/OPM_Agriculture_Pr2Final_WEB.pdf

Practical Action. n.d. *Floating gardens in Bangladesh. Water Hyacinth Technical Brief Practical Action*. Retrieved from http://www.fao.org/climatechange/17849-0e277b46b31f98942e6bc81bb22319243.pdf

PSA (Philippine Statistics Authority). 2016. “PSA Releases 2016 Philippines in Figures,” Press Release No. 2016-141, 16 September 2016. Retrieved from https://psa.gov.ph/sites/default/files/attachments/ird/pressrelease/PIF%202016_Press%20Release.pdf

----------. 2018a. *Philippines in Figures 2018*. PSA. Retrieved from https://psa.gov.ph/sites/default/files/PIF%202018.pdf

----------. 2018b. *Selected statistics agriculture on 2018*. PSA. Retrieved from https://psa.gov.ph/sites/default/files/Selected Statistics on Agriculture 2018.pdf

PSF (People’s Survival Fund). 2015. *Proponent’s handbook: A guide on how to access the People’s Survival Fund*. PSF. Retrieved from http://psf.climate.gov.ph/wp-content/uploads/2016/12/PSF-AmendedHandbook.pdf

Quan, J., and N. Dyer. 2008. “Climate change and land tenure: the implications of climate change for land tenure and land policy.” *Land tenure working paper 2*. International Institute for Environment and Development (IIED). Natural Resources Institute, University of Greenwich. Retrieved from https://cgspace.cgiar.org/handle/10568/71100

Reddy, V. R., and S. Rout. 2017. “Underground taming of floods in the Ganges Basin: Technologies, institutions and policies.” Paper presented at the 10th World Congress of European Water Resources Association (EWRA), Athens, Greece, 5–9 July 2017. Retrieved from https://www.researchgate.net/publication/318376698_Underground_Taming_of_Floods_in_the_Ganges_Basin_Technologies_Institutions_and_Policies

Republic of the Philippines. 2009. Republic Act (R.A.) 10000-The Agri-Agra Reform Credit Act of 2009, 14th Cong, Republic of the Philippines. (2009). Retrieved from http://www.bsp.gov.ph/regulations/laws/RA10000.pdf

----------. 2012. R.A. 10601-Agricultural and Fisheries Mechanization (AFMech) Law of 2012, 15th Cong, Republic of the Philippines. (2012). Retrieved from https://www.senate.gov.ph/republic_acts/ra 10601.pdf

----------. 2014. *Second national communication to the United Nations framework convention on climate change: Philippines*. Geneva. Retrieved from http://unfccc.int/resource/docs/natc/phlnc2.pdf

----------. 2015. *Intended nationally determined contributions*. Retrieved from http://www4.unfccc.int/submissions/INDC/Published Documents/Philippines/1/Philippines - Final INDC submission.pdf

----------. 2018a. R.A. 11321-Sagip Saka Act, 17th Cong, Republic of the Philippines. (2018). Retrieved from https://www.officialgazette.gov.ph/downloads/2019/04apr/20190417-RA-11321-RRD.pdf

----------. 2018b. R.A. 11203-Rice Tarrification Law, 17th Cong, Republic of the Philippines. (2018). Retrieved from https://www.officialgazette.gov.ph/downloads/2019/02feb/20190214-RA-11203-RRD.pdf

Reyes, C.M., C.D. Mina, R.A.B. Gloria, and S.J.P. Mercado. 2015. "Review of design and implementation of the agricultural insurance programs of the Philippine crop insurance corporation." *PIDS Discussion Paper Series* No. 2015-07. Retrieved from https://dirp3.pids.gov.ph/webportal/CDN/PUBLICATIONS/pidsdps1507_rev2.pdf

Richards, M., K. Butterbach-Bahl, M. Jat, B. LIpinski, I. Ortiz-Monasterio, and T. Sapkota. 2016. *Site-specific nutrient management: Implementation guidance for policymakers and investors. practice brief on CSA*. doi: 10.13140/RG.2.1.1573.5448. Retrieved from https://www.researchgate.net/publication/297543444_Site-Specific_Nutrient_Management_Implementation_guidance_for_policymakers_and_investors_Practice_brief_on_CSA

Rickman, J.F. 2002. "Manual for laser land leveling. Rice-Wheat Consortium." *Technical Bulletin* Series 5. New Delhi-110 012, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

Rola, A., J.P. De Mesa, and I. Bagares. "Agricultural economy of an upland community: Twelve-year (1994–2006) trend in Bukidnon, Philippines." *ISPPS Working Paper* 07-1.

Rola, A.C., A.J.U. Sajise, D.S. Harder, and J.M. Alpuerto. 2014. "Natural capital." In *Productivity growth in Philippine agriculture,* edited by R. Briones, M. Sombilla, and A. Balisacan, A. Republic of the Philippines: Southeast Asian Regional Center for Graduate Study and Research in Agriculture, Bureau of Agricultural Research, and Philippine Rice Research Institute, pp. 225–247.

Romana-Eguia, M.R.R., F.D. Parado-Estepa, N.D. Salayo, and M.J.H. Lebata-Ramos (Eds.) 2014. *Resource enhancement and sustainable aquaculture practices in Southeast Asia: Challenges in responsible production of aquatic species: Proceedings of the international workshop on resource enhancement and sustainable aquaculture practices in Southeast Asia (RESA).* (pp. 77–83). Tigbauan, Iloilo, Philippines: Aquaculture Dept., Southeast Asian Fisheries Development Center.

Romasanta, R.R., O.B. Sander, Y.K. Gaihre, M.C. Alberto, M. Gummert, J. Quilty, N. Van Hung, A.G. Castalone, C. Balingbing, J. Sandro, T. Correa, Jr., and R. Wassmann. 2017. “How does burning of rice straw affect CH_4 and N_2O emissions? A comparative experiment of different on-field straw management practices.” *Agriculture, Ecosystems and Environment*, 239:143–153.

Rosegrant, M.W., N. Perez, A. Pradesha, and T.S. Thomas. 2016. “The economy wide impacts of climate change on Philippine agriculture.” *Climate Change Policy Note* 1 (November 2016). International Food Policy Research Institute. Retrieved from http://www.ifpri.org/cdmref/p15738coll2/id/130837/filename/131048.pdf

Rosegrant, M.W., A. De Pinto, and K. Wiebe. 2016. “Climate change and agricultural policy options: A global-to-local approach.” *IFPRI Policy Brief.* Retrieved from http://ebrary.ifpri.org/utils/getfile/collection/p15738coll2/id/130790/filename/131001.pdf

Rosimo, M., J. Gonsalves, J. Gammelgard, R. Vidallo, and E. Oro. 2018. “Addressing gender-based impacts of climate change: A case study of Guinayangan, Philippines.” *CCAFS Info note.* Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Sace, C. F. 2018. “Hydroponics and aquaponics: Improving food security, nutrition, and livelihood for sustainable and competitive cities.” Presentation during the Bureau of Agricultural Research (BAR) Seminar Series, RDMIC Bldg., cor. Visayas Ave., Elliptical Rd., Diliman, Quezon City, 28 November 2017. Retrieved from https://www.slideshare.net/bardotgov/production-technology-using-hydroponics-and-aquaponics

Sadodin, S. and T.T. Kashani. 2011. *Numerical investigation of a solar greenhouse tunnel drier for drying of copra.* Retrieved from https://arxiv.org/ftp/arxiv/papers/1102/1102.4522.pdf

Sajise, P., and A. Sajise. 2017. “The ecological and economic aspects of the multifunctional role of agroecosystems.” *Asian Journal of Agriculture and Development*, Vol. 3, Nos. 1 & 2. Bioversity International, Malaysia, and SEARCA. Retrieved from https://ageconsearch.umn.edu/record/165788/files/AJAD_2006_3_1_2_4Sajise_Sajise.pdf?version=1

Sajise, A.J., M. Sombilla, and R. Ancog. 2012. *Socioeconomics of climate change in the Philippines: A literature synthesis (1990–2010)*. Los Baños, Laguna, Philippines: SEARCA and PCAARRD.

Salvatierra, A., M. Nagle, M. Gummert, T. De Bruin, and J. Muller. 2014. “Development and performance evaluation of a new solar dryer with force convection for paddy rice in the Philippines.” A poster presented at the International Rice Congress, Bangkok, Thailand, 27–31 October 2014. Retrieved from https://ijabe.org/index.php/ijabe/article/view/2444

Santiago, A. and F. Roxas. 2015. “Reviving farming interest in the Philippines through agricultural entrepreneurship education.” *Journal of Agriculture, Food Systems, and Community Development*, pp 1–13. https://doi.org/10.5304/jafscd.2015.054.016

Satake, T. and S. Yoshida. 1978. “High temperature induced sterility in Indica rice at flowering.” *Japan Journal of Crop Science*, 47: 6–17. Retrieved from https://www.jstage.jst.go.jp/article/jcs1927/47/1/47_1_6/_article/-char/ja/

Seetharam, K., M.T. Vinayan, and P.H. Zaidi. 2014. “Stress-resilient maize hybrids developed for Asian tropics.” *CIMMYT,* 20 March 2014. International Maize and Wheat Improvement Center. Retrieved from https://www.cimmyt.org/news/stress-resilient-maize-hybrids-developed-for-asian-tropics/

Shapiro, B.I., M. Winslow, P.S. Traore, V. Balaji, P. Cooper, K.P.G. Rao, S. Wani, and S. Koala. 2007. *Climate applications and agriculture: CGIAR efforts, capacities, and partner opportunities*.

Shreeja, D. n.d. “Site specific nutrient management (SSNM)–explained!” *Soil Management India*. Retrieved from http://www.soilmanagementindia.com/soil-fertility/site-specific-nutrient-management-ssnm-explained/3192,

Sinclair, F. 1999. “A general classification of agroforestry practice.” *Agroforestry Systems* 46(2):161–180 doi: 10.1023/A:1006278928088. Retrieved from https://www.researchgate.net/publication/225920854_A_general_classification_of_agroforestry_practice

Singh, S., D.J. Mackill, and A.M. Ismail. 2009. “Responses of SUB1 rice introgression lines to submergence in the field: Yield and grain quality.” *Field Crops Research*. 113:12–23.

Singh, Y., and H.S. Sidhu. 2014. “Management of cereal crop residues for sustainable rice-wheat production system in the Indo-gangetic plains of India.” *Proc. Indian National Science Academy*. 80(1):95–114. Retrieved from http://www.knowledgebank.irri.org/step-by-step-production/postharvest/rice-by-products/rice-straw/off-field-rice-straw-management

Singleton, G., and R.V. Labios. 2018. *Diversification and intensification of rice-based cropping systems in lower Myanmar (MyRice)*. Project Number SMCN/2011/046. ACIAR GPO Box 1571, Canberra ACT 2601, Australia.

Siopongco, J.D.L.C., R. Wassmann, and B.O. Sander. 2013. “Alternate wetting and drying in Philippine rice production: Feasibility study for a clean development mechanism.” *IRRI Technical Bulletin* No. 17. Philippines: International Rice Research Institute. 14 p. Retrieved from http://books.irri.org/TechnicalBulletin17_content.pdf

Smit, B., and J. Wandel. 2006. “Adaptation, adaptive capacity and vulnerability.” *Global Environmental Change,* 16:282–292. http://dx.doi.org/10.1016/j.gloenvcha.2006.03.008

Smith, M., G. Muñoz, and J.S. Alvarez. 2014. “Irrigation techniques for small-scale farmers: Key practices for DRR implementers.” *A Field Guide for Disaster Risk Reduction in Southern Africa: Key Practices for DRR Implementers.* FAO and European Commission’s Humanitarian Aid. Retrieved from http://www.fao.org/3/a-i3765e.pdf

Cornell University-College of Agriculture and Life Sciences. 2015. “SRI methodologies.” International Programs, Cornell University. Retrieved from http://sri.ciifad.cornell.edu/aboutsri/methods/index.html

Su, D., F. Sultan, N.C. Zhao, B.T. Lei, F.B. Wang, G. Pan, and F.M. Cheng. 2014. “Positional variation in grain and mineral nutrients within a rice panicle and its relation to phytic acid concentration.” *J Zheijang University of Sciences* 15(11): 986–996. Retrieved from https://www.researchgate.net/publication/322415349_Manipulating_the_Phytic_Acid_Content_of_Rice_Grain_Toward_Improving_Micronutrient_Bioavailability

Tall, A., J. Hansen, A. Jay, B. Campbell, J. Kinyangi, P.K. Aggarwal, and R. Zougmoré. 2014. “Scaling up climate services for farmers: mission possible. Learning from good practice in Africa and South Asia.” *CCAFS Report* No. 13. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). Retrieved from https://cgspace.cgiar.org/handle/10568/71100

TF (Tebtebba Foundation). 2017. *Indigenous peoples and the green climate fund*. Baguio City, Philippines: Tebtebba Foundation.

The Economist Intelligence Unit. 2019. *Global Food Security Index 2019: Strengthening food systems and the environment.* The Economist Intelligence Unit Limited. Retrieved from https://foodsecurityindex.eiu.com/Resources

Thomsen, D.C., T.F. Smith, and N. Keys. 2012. “Adaptation or manipulation? Unpacking climate change response strategies.” *Ecology and Society*, 17 (3):20. Retrieved from http://www.ecologyandsociety.org/vol17/iss3/art2

Thomson, M.J., M. de Ocampo, J. Egdane, M.A. Rahman, A.G. Sajise, D.L. Adorada, E. Tumimbang-Raiz, E. Blumwald, Z. I. Seraj, R. K. Singh, G. B. Gregorio, and A. M. Ismail. 2010. “Characterizing the Saltol quantitative trait locus for salinity tolerance in rice.” *Rice*, 3:148–160.

Toma, L., G. Voicu, M. Ferdes, and M. Dinca. 2016. “What Is A Biogas Digester?” GLW Energy. Retrieved from https://glwenergy.com/what-is-a-biogas-digester/

Tomacruz, S. 2018. “Typhoon Ompong affects over 800,000.” *Rappler,* 18 September 2018. Retrieved from https://www.rappler.com/nation/212231-affected-persons-typhoon-ompong-september-18-2018

Tripoli, M., and J. Schmidhuber. 2018. “Emerging opportunities for the application of blockchain in the agri-food industry.” *Agriculture Issue Paper.* Food and Agriculture Organization of the United Nations and the International Centre for Trade and Sustainable Development. Retrieved from http://www.fao.org/3/CA1335EN/ca1335en.pdf

Tumbali, G., and J.R. Alo. (Eds.). 2015. *Farm business school for the Filipino farmer: A facilitator’s manual*. Retrieved from http://ati.da.gov.ph/sites/default/files/FBS/FBS-full-manual.pdf

UNDESAP (United Nations Department of Economic and Social Affairs Population Division). 2015. “World population prospects: Key findings and advance tables.” *Animal Genetics*. Retrieved from https://esa.un.org/unpd/wpp/Publications/Files/Key_Findings_WPP_2015.pdf

UNH (United Nations Habitat). 2019. “UN-Habitat presents guide on addressing human settlements in national adaptation plans at NAP expo 2019.” UN Habitat. Retrieved from https://unhabitat.org/un-habitat-re-launches-guides-on-addressing-human-settlements-in-national-adaptation-plans-at-nap-expo-2019/

UNICEF (United Nations International Children’s Emergency Fund). 2017. *UNICEF annual report 2017: Philippines* (Vol. 2017). Retrieved from https://www.unicef.org/about/annualreport/files/Philippines_2017_COAR.pdf

UPD MPRO (University of the Philippines Diliman Media and Public Relations Office). 2018. “Promoting rice and white corn combination as a staple for Filipinos.” University of the Philippines Diliman. Retrieved from https://www.up.edu.ph/index.php/promoting-rice-and-white-corn-combination-as-a-staple-for-filipinos/

Verges, J. 2014. “Preliminary study of the potential for the development of “Macroalgae reefs” in the Limfjorden.” *PLoS ONE* 7(9):e45543, pp. 5–10. Retrieved from https://www.researchgate.net/publication/231815427_Diversity_among_Macroalgae-Consuming_Fishes_on_Coral_Reefs_A_Transcontinental_Comparison/references

Vermeulen, S.J., D. Dinesh, S.M. Howden, and L. Cramer. 2018. “Transformation in practice: A review of empirical cases of transformational adaptation in agriculture under climate change.” *Front. Sustain. Food Syst.*, (10 October 2018) https://doi.org/10.3389/fsufs.2018.00065

Verzola, R. n.d. “System of Rice Intensification (SRI):Practices and results in the Philippines.” Paper presented at the conference of the Philippine Society of Soil Science and Technology (PSSST). Retrieved from https://pm22100.net/docs/pdf/agriculture/01_SRI/sri-pssst-verzola.pdf

Villavicencio, F., M. Rosimo, R. Vidallo, R. E. Oro, and J. Gonsalves. 2018. “Equity, empowerment and gender relations: A literature review of special relevance for climate-smart agriculture programming.” *CCAFS Info note*. Wageningen, Netherlands: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Vincke, M.M.J. 1979. “Fish culture in rice fields: Its status and future role”. In *Advances in Aquaculture,* edited by Pillay, T.V.A. and Dill, W.A. Fishing Needs Book Ltd. Farnham. Surrey, England, pp. 208–223. Retrieved from http://www.fao.org/3/AC180E/AC180E01.htm#ch1

Wangpakapattanawong, P., R. Finlayson, I. Öborn, J. Roshetko, F. Sinclair, K. Shono, S. Borelli, A. Hillbrand, and M. Conigliaro. 2017. *Agroforestry in rice-production landscapes in Southeast Asia: A practical manual*. Retrieved from http://www.fao.org/3/a-i7137e.pdf

Wassmann, R., S.V.K. Jagadish, K. Sumfleth, H. Pathak, G. Howell, A.M. Ismail, R. Serraj, E. Redona, R.K. Singh, and S. Heuer. 2009a. "Regional vulnerability of climate change impacts on Asian rice production and scope for adaptation." *Advances in Agronomy* 102:91–133.

Wassmann, R., S. V. K. Jagadish, S. Heuer, A. Ismail, E. Redona, R. Serraj, R. K. Singh, G. Howell, H. Pathak, and K. Sumfleth. 2009b. "Climate change affecting rice production: the physiological and agronomic basis for possible adaptation strategies." *Advances in Agronomy,* 101:59–122.

Watson, H. 1995. *The development of sloping agricultural land technology (SALT) in the Philippines*. Mindanao Baptist Rural Life Center (MBRLC).

Wiemers, M., D. Streiff, and D. Niggli. 2016. "Ecological engineering for biological pest control in lowland rice agroecosystems [Philippines]." WOCAT SLM Database. Retrieved from https://qcat.wocat.net/en/wocat/technologies/view/technologies_1720/

Witt, C., V. Balasubramanian, A. Dobermann, and R.J. Buresh. 2002. "Nutrient management." In *Rice: A practical guide to nutrient management*, edited by Fairhurst, T.H. and Witt, C. Potash and Phosphate Institute (PPI), Potash and Phosphate Institute of Canada (PPIC), and International Rice Research Institute (IRRI). pp 1–45.

Witt, C., J.M. Pasuquin, R. Mutters, and R.J. Buresh. 2005. "New leaf color chart for effective nitrogen management in rice." *Better Crops*, 89(1):36–39.

Witt, C., J.M. Pasuquin, M.F. Pampolino, R.J. Buresh, and A. Dobermann. 2009. *A manual for the development and participatory evaluation of site-specific nutrient management for corn in tropical, favorable environments*. International Plant Nutrition Institute, Penang, Malaysia. Retrieved from http://seap.ipni.net/ipniweb/region/seap.nsf/0/C087BB94A7A0C8C748257B67002B53A8/$FILE/2009%20IPNI%20SSNM%20Manual%20Maize.pdf

Wolfert, S., L. Ge, C. Verdouw, and M. Bogaardt. 2017. "Big data in smart farming—A review." *Agricultural Systems,* 153:69–80. https://doi.org/10.1016/j.agsy.2017.01.023

Wu, Y.C., S.J. Chang, and H.S. Lura. 2016. "Effects of field high temperature on grain yield and quality of a subtropical type *japonica* rice - Pon-Lai rice." *Plant Production Science* 19 (1): 145–153. Retrieved from https://www.tandfonline.com/doi/full/10.1080/1343943X.2015.1128091

Wu, C., K. Cui, W. Wang, Q. Li, S. Fahad, Q. Hu, J. Huang, L. Nie, and S. Peng. 2016. "Heat-induced phytohormone changes are associated with disrupted early reproductive development and reduced yield in rice." *Scientific Reports* 6, 34–978. doi.org/10.1038/srep34978. Retrieved from https://www.nature.com/articles/srep34978

Yadav, S., and M.J.C. Regalado. n.d. *Water Rice project fact sheet*. International Rice Research Institute.

Yasar, A., R. Saba, T. Rizwan, and N. Amtul. 2017. “Economic review of different designs of biogas plants at household level in Pakistan.” *Renewable and Sustainable Energy Reviews*. 74. 221–229. 10.1016/j.rser.2017.01.128.

Yen, B.T., S.H. Nguyen, T.T. Le, T.S. Amjath-Babu, and L.S. Sebastian. 2019. “Development of a participatory approach for mapping climate risks and adaptive interventions (CS-MAP) in Vietnam’s Mekong River Delta.” *Climate Risk Management*. 24: 59–70 https://doi.org/10.1016/j.crm.2019.04.004

Yuen, B., and L. Kong. 2009. “Climate change and urban planning in Southeast Asia.” *SAPIENS*. Retrieved from http://journals.openedition.org/sapiens/881

Yusuf, A.A. and H. Francisco. 2009. *Climate change vulnerability mapping for Southeast Asia*. p. 26. EEPSEA. Retrieved from https://www.idrc.ca/sites/default/files/sp/Documents%20EN/climate-change-vulnerability-mapping-sa.pdf

Zaidi, P.H. 2014. *Abiotic stress-tolerant corn for increasing income and food security among the poor in South and Southeast Asia*. International Corn and Wheat Improvement Center (CIMMYT).

Zhang, R., X. Li, and J.G. Fadel. 2002. “Oyster mushroom cultivation with rice and wheat straw.” *Bioresource Tecnology*, 82:277–284.

Zhao, Y., C. Wang, S. Wang, and L.V. Tibig. 2005. *Impacts of present and future climate variability on agriculture and forestry in the humid and sub-humid tropics.* In *Increasing climate variability and change: Reducing the vulnerability of agriculture and forestry*, edited by Salinger, J., Sivakumar, M.V.K., and Motha, R.P. Dordrecht. The Netherlands.

Zhiqiang, F., H. Huang, X. Liao, Y. Hu, W. Xie, and B. He. 2008. “Effect of ducks on CH_4 emission from paddy soils and its mechanism research in the rice-duck ecosystem.” *Acta Ecologica Sinica*. 28:2107–2114. Retrieved from: 10.1016/S1872-2032(08)60045-1

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This Compendium presents agricultural technologies and approaches (Ts & As) that can enhance resilience to climate change in lowland, upland, hilly land, highland, and coastal agroecological systems in the Philippines. The Ts & As are designed for sustained productivity, adaptation, and/or mitigation to climate change. This Compendium also highlights the use of a tool to assess these Ts & As in terms of their effect on productivity, resilience, and contribution to GHG emissions. The Compendium enumerates seven transformative strategies, each of which allows the farmers—the end-users of climate-resilient technologies and approaches—to participate in climate- and agriculture-related discussions, improve their productivity in the farms, enhance their adaptive capacity against current and impending risks, and reduce their GHG emissions into the atmosphere.

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