




CLIMATE-SMART PRACTICES FOR INTENSIVE RICE-BASED SYSTEMS IN BANGLADESH, CAMBODIA, AND NEPAL

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International Rice Research Institute

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On the cover: Farmers are now exposed to various climate-smart agriculture practices.
(Photos by Asian Development Bank and International Rice Research Institute)

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Foreword

Rice is a staple crop in many countries in Asia, providing food, nutrition, and income to millions of resource-poor farmers. It is one of the top priority commodities in the agricultural development agenda in many Asian countries. However, dwindling agricultural resources, rising wages due to declining farm workers, competing use of waters, and climate change are emerging as the main problems to rice production in Asia. The Food Security Forum held in ADB Headquarters in 2016 identified these problems as the main hurdles to achieving Sustainable Development Goal 2 of ending hunger and malnutrition in Asia and the Pacific. Against this backdrop, the Asian Development Bank (ADB) partnered with the International Rice Research Institute (IRRI) and selected national research organizations to deliver knowledge solutions to these problems.

Water- and labor-saving technologies, alternating wetting and drying (AWD) in Bangladesh, and direct-seeded rice (DSR) in Cambodia and Nepal were field-experimented in rice cultivation under this project. Vegetables were cultivated in between two rice seasons in all countries. This report presents the benefits of these technologies, and policy recommendations to mainstream their use. The findings of the field experiment show that AWD and DSR, combined with better rice varieties and mechanization, can make rice production more profitable and sustainable even in the face of drought or flooding. The evidenced-based recommendations documented in this report offer viable solutions to the production of rice and accomplishment of food security in Asia. The proposed solutions act as a guidepost to scale up the use of resource-saving, climate-smart agricultural technologies and to make farming profitable in the region.

This report is the output of a partnership between ADB and IRRI. It brings together ADB 's knowledge and experience in agriculture and the natural resources sector, and IRRI's globally recognized expertise in advancing rice cultivation and protecting the rice-growing environment for future generations. This report is aligned with ADB's Strategy 2030, which aims to make Asia and the Pacific food-secure, free of malnutrition, and prosperous. This publication also responds to ADB's operational priority of promoting rural development and food security.

We are confident that this report will become a key resource for policymakers of developing member countries of ADB in undertaking evidence-based actions to promote sustainable rice production.

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Md. Abul Basher, Natural Resources and Agriculture Specialist, SDCC, led the implementation of the project, under the direction of Woochong Um, Director General, SDCC; Amy Leung, Director General, East Asia Department in her former capacity as Director General of SDCC; Chiara Bronchi, Chief Thematic Officer, SDCC; with the supervision of Akmal Siddiq, Chief of RDFS Thematic Group, SDCC; and Mahfuz Ahmed, former Technical Advisor, RDFS Thematic Group, SDCC (now retired). Other members of the implementation team include Leah P. Arboleda, Natural Resources and Agriculture Officer, SDCC and Maria Angela Pilar M. Banaria, Senior Operations Assistant, SDCC.

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The report is prepared based on the piloting of climate-smart practices and crop varieties for intensive rice-based systems, the policy workshops, interaction meetings with different stakeholders, and training imparted to farmers, extension workers, and Department of Agriculture officials in Bangladesh, Cambodia and Nepal during 2016-2018. The implementation of these activities was led by Arvind Kumar, Director of IRRI South Asia Regional Centre, Varanasi, India in collaboration with different national institutions in these countries. Field activities in Bangladesh, Cambodia, and Nepal were coordinated by the respective country representative of IRRI Humnath Bhandari, Buyung Hadi, and Krishna Dev Joshi.

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Abbreviations

ADB	Asian Development Bank
AWD	alternate wetting and drying
BARI	Bangladesh Agricultural Research Institute
BMP	best management practice
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
CARDI	Cambodian Agricultural Research and Development Institute
CSA	climate-smart agriculture
CSW	continuous standing water
DAE	Department of Agricultural Extension, Bangladesh
DDSR	dry direct-seeded rice
DOA	Department of Agriculture
DSR	direct-seeded rice
GHG	greenhouse gas
IRRI	International Rice Research Institute
KR	Cambodian riel
NARC	Nepal Agricultural Research Council
NRs	Nepalese rupees
PDAFF	Provincial Department of Agriculture, Forestry and Fisheries, Cambodia
RCM	Rice Crop Manager (decision support tool)
REY	rice equivalent yield
TA	technical assistance
Tk	Bangladesh taka

Weights and Measures

ha	hectare
kg	kilogram
t	ton

Executive Summary

The Asian Development Bank, in partnership with International Rice Research Institute, piloted two different climate-smart rice cultivation methods using different rice cultivars in order to demonstrate the benefits of climate-smart production practices. Results show that the climate-smart practices increased the income of the farmer compared to traditional or conventional production or cultivation methods. Mechanization increased the cost–benefit ratio compared to traditional methods of cultivation. The new rice cultivars also exhibited lower greenhouse gas emissions.

In Bangladesh, the alternate wetting and drying (AWD) technology was applied for comparison with the continuous standing water irrigation system. A new rice variety, BRRI Dhan 75, was introduced in the transplanted *aman* (November–December) season in Korerhat and Nurpur areas in Bangladesh. This was followed by the cultivation of an off-season mustard variety (Bangladesh Agriculture Research Institute [BARI Sorisa 14]) before planting another rice variety (BRRI Dhan 28) in the next season (*boro*, April–May).

In Cambodia and Nepal, the direct-seeded rice (DSR) technology was applied to compare with the traditional transplanted puddled system. In Cambodia, stress-tolerant rice varieties were used with mechanized dry DSR in the Central Dry Zones of Kampong Thom and Takeo, followed by the production of vegetables, pulses, and cassava before planting rice again. The same mechanized dry and wet DSR method was applied in Nepal, which alternated rice cropping with cultivation of lentil sown using a drill machine.

The climate-smart practices increased the income of the farmer by 52%–61%. In Bangladesh, the AWD technology required about 22% less water compared to the continuous standing water irrigation system. Depending on the rice varieties and season of the rice cultivation, greenhouse gas emissions were 13%–41% less under AWD compared to continuous standing water. It was 13% during transplanted *aman* season and 41% during *boro* season. Among the rice varieties, the BRRI Dhan 75 had the lowest greenhouse gas emission at 44 kilograms per hectare (kg/ha) while BRRI Dhan 11 had the highest (50 kg/ha) greenhouse gas emission.

In terms of yield, the yield of the new BRRI Dhan 75 variety was 20% higher at 5.11 tons per hectare (t/ha) than the normal varieties used by farmers in the transplanted *aman* season (BRRI Dhan11 and BRRI Dhan 49), which yielded 4.26 t/ha.

In Cambodia, mechanized DSR technology decreased use of labor by 60%–79% compared to traditional transplanted puddled system. Mechanized cultivation of fruits and vegetables increased the cost–benefit ratio compared to the traditional method of cultivation by 2 to

3 times. In particular, mechanized cultivation of mung bean and watermelon resulted in labor saving of 23%–31% compared to traditional practices. The DSR technology also increased the yield of rice by 26%–50% compared to the traditional transplanted system; and saved water by about 19%–32%. Greenhouse gas emission was 68 kg/ha under DSR compared to 98 kg/ha under transplanted puddling system.

In Nepal, DSR technology combined with the machine-operated boom sprayer for plant protection and combine harvesting reduced the total cost of production of rice by 25% compared to the conventional method. DSR technology also reduced the use of labor by about 83% compared to the conventional transplantation. Seeds requirement decreased from 80 kg/ha under conventional methods to only 45 kg/ha under mechanized DSR. The benefit–cost ratio increased to 4.2 under DSR while it was 1.4 for conventional method of production.

Based on the findings of the field experiments and consultation with farmers and other stakeholders in the trial countries, the main recommendations follow:

(i) **Identify proper technology.** It is important to define the potential technology domain based on proper information or data on the ground first. The key is to have a clear picture of the field to determine the suitability of a technology and/or combination of technologies. There is a need to assess current practices, level of mechanization, and availability of services. Custom-tailored technologies should be developed through field experiments and should be validated involving farmers in the process.

(ii) **Build a support system.** A holistic approach should be followed to support the adoption of climate-smart technology with complete requirements including improvement in service delivery and knowledge transmission channels. There should be learning alliances or communities of practice that can help one another other. Similarly, a smart extension service system should be developed to improve farmers' access to information and knowledge. As a critical resource in rice production, good-quality seeds suitable for climate-smart practices should be made available.

(iii) **Strengthen delivery mechanism.** In Bangladesh, the Department of Agricultural Extension and Bangladesh Agricultural Development Corporation should be strengthened to play a better role in multiplication and distribution of climate-smart rice varieties and technologies. The government should also establish a community-based service center to provide support for climate-smart agriculture to farmers. A platform involving scientists, farmers, private sector, and academia working together in partnership to support climate-smart agriculture will be useful.

(iv) **Create an enabling environment for private sector.** In Cambodia, the government needs to create an enabling environment for private companies to manufacture custom-designed machines and provide after-sales services. At the same time, the capacity of the extension service to train farmers on climate-smart technologies and work with the private sector in partnership should be enhanced.

(v) **Consolidate land.** In Nepal, in order to promote the mechanization required for climate-smart agriculture, land consolidation at the production level is important. Recent land consolidation under the Prime Minister's Agriculture Modernization Project has enhanced agricultural mechanization. Hence, government should take measures to promote more voluntary land consolidation at the production level.

(vi) **Promote private service providers.** Majority of smallholder farmers are unable to own machinery by themselves to practice climate-smart agriculture. The private sector should be incentivized to set up hiring centers from where farmers can rent machinery. Farmers' cooperatives should be promoted as well to set up hiring centers. However, such cooperatives should be run following corporate principles, i.e., with a clear demarcation between equity holders and management personnel, all of whom should be accountable for their decisions.

Capacity building. Farmers are now more familiar with technology-based solutions increasing their output with less input. (Photos by IRRI)

1 Mechanical transplanter
2 Mechanical dryer
3 Power sprayer
4 High-quality storage
5 Combine harvester
6 Automated rice milling machinery

1 INTRODUCTION

A global population on the rise, amid climate change and dwindling natural resources, is exerting continued pressure on food production, availability, and access in many countries. In Asia, the major rice-producing countries are reported to be severely affected rising temperature, varying rainfall, inconstant water availability, and various biotic and abiotic stresses that disrupt productivity. More than 90% of rice is produced and consumed in Asia,[1] making it an economically important commodity ranking high on the region's development agenda. Science-based solutions such as the use of appropriate stress-tolerant varieties, matched with good agronomic or management practices, could double yield. The Asian Development Bank (ADB) and the International Rice Research Institute (IRRI) are just two of the many institutions that champion the plight of rice-farming communities, with the ultimate aim of raising productivity and strengthening food security on a sustainable basis, thus contributing to improved human welfare. Development efforts are directed at the delivery of well-targeted knowledge products, resources, and other strategies to address the complexity of sustainable development.

Project Background and Context

Decades of research and development have already produced many technological innovations, yet farming communities stay mired in deep poverty and hunger. Huge research investments have already given rise to sustainable technologies, such as the essentials of conservation agriculture—reduced or zero tillage, machine seeding or transplanting, water-efficient alternate wetting and drying (AWD), crop residue retention, and crop rotation. The efficacy, economic benefits, and social acceptability of these technologies have been tested and evaluated in single- and double-cropping rice systems. IRRI and its partners have already developed and supported the release of a significant number of stress-tolerant varieties suitable for rice areas and marginal upland areas affected by submergence, drought, and salinity. Yet these rice varieties are not quickly and widely disseminated to the intended users—the farmers who stand to reap higher income and improved overall welfare from scientific endeavors.

Several related ADB-funded projects have been implemented in the past, producing results that have shown the efficacy and remarkable performance of the appropriate technologies.

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1 Ricepedia. Asia. http://ricepedia.org/rice-around-the-world/asia.

Under the Dissemination of AWD Varieties and Management Practices in Muhuri Irrigation Project in Chittagong division, Bangladesh, implemented in 2016–2017, 508 farmers were trained in the use of AWD technology on a popular and suitable variety of high-yielding rice developed by the Bangladesh Rice Research Institute, BRRI Dhan 28, during the *boro* season. After just one season of AWD adoption, its benefits had been clearly shown on about 100 hectares (ha) in the Muhuri project region, paving the way for the farmers' adoption of AWD and farm mechanization in general, in light of their demonstrated value. The ADB technical assistance (TA) project Climate-Smart Practices and Varieties for Intensive Rice-Based Systems in Bangladesh, Cambodia, and Nepal, implemented in 2017–2018, was intended to further the gains from the earlier project. Another ADB TA project, Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific, expanded the dissemination of climate-smart practices through demonstration on 60 ha of farmland in Bangladesh and Cambodia, and later also in Nepal.[2] The project was expected to promote the adoption of water- and labor-saving varieties and practices as well as methods of reducing greenhouse gas (GHG) emissions, introduce mechanization in agriculture, and in the process help increase rice yield and farming profits.

This final report captures the learning, technologies, and outcome from the completed projects, and is intended to set the stage for succeeding efforts to bring science-based and participatory solutions to the needs of resource-poor rice-farming communities in the three countries.

Country Context

In the Eastern Indo-Gangetic Plain, including much of Bangladesh, intensive rice-based farming practices match productivity to population growth. Bangladesh is a rice-producing country where irrigation is available in 45% of the cultivated areas. These cultivated areas are vulnerable to climate change, with flood and submergence adversely affecting more than 66% of the land; drought, 25%; and salinity, 13%. In this setting, sustainability is a concern, especially given the relatively small size of landholdings, meager resources, limited technological know-how, and low or insufficient use of appropriate farm input. All of these characteristics generally apply to farmland in Bangladesh.

Typically, rice cultivation in Bangladesh faces critical problems such as inadequate knowledge of crop management practices, inappropriate input use, land-use conflicts, and improper crop planning and implementation. Farmers have been lukewarm about improvements in rice and non-rice production, and continue to grow traditional varieties. They lack knowledge of ideal seedbed preparation and management, proper uprooting of seedlings for transplanting, fertilizer management, and supplemental

2 ADB. 2016. *Technical Assistance for Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific.* Manila. https://www.adb.org/projects/50058-001/main.

irrigation under rainfed lowland rice cultivation. The biological control of insects, using perching as an environment-friendly control method, is not extensively practiced. Farmers cultivate long-duration *T. aman* varieties (paddy harvested in November–December) such as BRRI Dhan 11, BRRI Dhan 22, BRRI Dhan 49, Nayapajam, and Sharnobasuri (140–150 days' duration). They are not aware of the availability of short-duration *T. aman* varieties such as BRRI Dhan 71. Seeds are of low quality and are bought from agricultural input agents, and access to new and more appropriate varieties is limited. Despite the small size of their landholdings, farmers maintain a high seeding rate; this contributes to higher production costs. Many other countries, farming communities in Bangladesh endure the effects of climate change such as drought, flooding, salinity, and pests and diseases, which lower productivity and keep smallholder farmers mired in poverty. Coupled with these difficulties are the perennial problems of limited availability of farm input, weak links to markets, lack of credit, and, in many cases, lack of technical know-how and access to more appropriate, higher-quality varieties.

Rice makes up a considerable part of the Cambodian diet. It supplies 65%–75% of the people's energy needs, and accounts for 21% of their daily calorie intake and 13% of their daily protein intake.[3] As a major agricultural crop, rice is cultivated on more than 90% of the country's land area. Rice is grown mainly in the monsoon season; the harvest accounts for 75% of annual paddy production. Since 1980, the area devoted to rice cultivation has been increasing by 2.4% yearly, and rice production by 4.7%. This growth in rice production has been attributed to the spread of improved technologies such as modern varieties and good-quality seeds, the expansion of the dry-season rice area, and increased extension efforts.[4]

In Nepal, arable land is only 17% of the total land area. Rice is the dominant crop, cultivated on 59% of the total agricultural of 2.64 million ha. Almost 70% of the rice is cultivated on irrigated land, generally in two seasons: the main rice crop during the monsoon season (June–October) and *boro* (summer) rice in January–June. Cultivation usually involves transplanting, with a bullock for tillage and farm laborers for the uprooting of nursery plants, transplanting, weeding, and harvesting. These activities require 90–100 person-days of labor, adding up to NRs85,000 to the production cost. The alternate production method of direct seeding—either machine-drilled dry direct seeding or drum seeding or drum seeder–operated wet seeding in puddled soil—followed by machine-operated and technology-based management practices (such as machine-operated herbicide application for weed management, insecticide and pesticide application, split and appropriate application of chemical fertilizers, the use of a harvester for harvesting and threshing) can reduce the total cost of production by 30%–40%. The reduced need for tillage and for water under the

[3] International Rice Research Institute. 2013. *Global Rice Science Partnership*. Los Baños ,Philippines: IRRI http://books.irri.org/9789712203008_content.pdf.

[4] S. Pandey and H. Bhandari. 2010. Rice Production in Cambodia: Will Exports Continue to Grow? In D. Dawe, ed. *Rice Crisis: Markets, Policies and Food Security*. London: Food and Agriculture Organization of the United Nations and Earthscan. pp. 233–254. http://www.fao.org/3/a-an794e.pdf.

direct-seeded rice (DSR) method (20%–25% less water than the requirement under the traditional method) can also increase the benefit–cost ratio to 1.5–2.0.

To grow rice in Bangladesh, Cambodia, and Nepal, 21-day-old to 1-month-old seedlings are commonly transplanted in puddled and continuously flooded soil. This system contributes to higher water losses through puddling, surface evaporation, and percolation. Repeated puddling disturbs the soil's physical properties, thus impairing drainage and having a negative effect on subsequent plant growth in non-rice crop rotations.

Agricultural practices must change, to deal with climate- and resource-related challenges. Water-saving technologies for crop diversification, labor-saving mechanization, and improved management practices must be introduced. AWD and DSR are deemed better options for attaining optimal plant density and high water productivity in water-scarce areas. Besides enabling the attainment of higher economic returns, AWD and the DSR system are less labor-intensive, consume less water, are more conducive to mechanization, and result in less methane emissions than the transplanting method. These combinations of technologies therefore offer better opportunities to farmers to improve the productivity of rice and non-rice crop production and achieve better income diversification, while also helping to reduce their carbon footprint. Efforts to promote technology-based rice farming should highlight the reduced cost of production that comes with mechanization and the increases in yield that can be achieved through the adoption of best management practices. Rice-based farming systems can thus be ultimately sustained and food security can be strengthened. The spread of cost-effective and climate-smart production technologies in rice-based farming systems in Bangladesh, Cambodia, and Nepal will go a long way toward solving sustainable development issues.

2
USE OF HIGH-LEVEL TECHNOLOGIES IN RICE PRODUCTION

Current Situation

An assessment study of the use of high-level technologies for food security in Asia and the Pacific, conducted by IRRI and its partners, listed several prevalent biophysical, socioeconomic, institutional, and policy factors that constrain the large-scale adoption of high-level rice-based technologies in Asia.[5] Among these constraints is the predominance of small and fragmented farms, which makes it difficult for farmers to take advantage of economies of scale in farm mechanization. In many cases, farm machinery is developed or initially adapted from more developed countries, where landholdings are bigger and farm integration or consolidation is possible and is supported by the government. Machinery introduced in developing countries does not have the characteristics that farmers look for in machinery and equipment suitable for small-farm conditions—durability, lightness, compactness, low power consumption, multipurpose use, and low cost. In some cases, even if the machines are adaptable, the lack of skilled personnel to operate, maintain, and repair them leads to problems with spare parts and after-sales service. Machinery supply chain management is weak. Low-volume, seasonal demand from farms does not make the machinery supply business profitable and attractive to investors, especially with arbitrary taxes and duties on raw materials and fabricated machinery adding to the already high costs of production.

On the institutional front, farmers face difficulties gaining access to finance and markets because short- and long-term credit facilities are limited. The lack of support services to ensure the acceptability of the machines to farmers, ineffective marketing, too few cooperatives and associations, and lack of entrepreneurial coordination with farmers have been persistent constraints on the commercialization of agriculture (footnote 5). Coupled with these are constraints brought about by low access to extension services, due mainly to the insufficiency of extension staff to serve the significant number of farmer-clients, and the lack of personnel with the required technical expertise and communication skills. Technology adoption is also hindered by the limited knowledge of improved agricultural technologies among extension workers and farmers, and the apparent risk aversion of farmers, with their deep-seated resistance to change.

[5] IRRI. 2017. *Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific.* IRRI Ref. No. A-2016-167 Technical Report. Los Baños: Philippines.

To analyze further the constraints on technology dissemination, the technical assistance project funded by ADB organized a policy dialogue on constraints on the large-scale adoption of farm mechanization AWD irrigation technology as well as defining policy measures in eastern Bangladesh on 10 October 2017. It aimed to discuss the constraints and opportunities and define the way forward for scaling of the AWD irrigation method, laser land leveling, rice transplanter, and rice harvesting machines (reaper and combine harvester) in rice-based production systems in eastern Bangladesh. Different stakeholders—agricultural scientists and development workers, policy makers, development partners, private companies, and farmers—convened under one platform to share their knowledge and experience. Panelists provided their view on the biophysical, technological, socioeconomic, and institutional and policy constraints on scaling up various technologies. They also suggested technological, institutional, and policy interventions that would speed up the dissemination of these climate-smart agriculture (CSA) technologies.

The following additional information about the constraints on technology adoption in rice cultivation was distilled from the discussions and presentations of key officials and participants.

Biophysical considerations. Technologies must suit the landscape at the target sites. Soil and water and the microenvironment are critical resources, and their characteristics are important factors to be considered in decisions related to crop production systems. For instance, fields that are not properly leveled will impede the flow of water and will therefore not be suitable for AWD application.

Production systems. Inadequate access to crop production technologies and limited CSA information knowledge and skills are constraints in this category. In many countries, the future of agriculture lies in mechanization and knowledge-intensive systems. The new approaches are resource-saving, use green technology, point to higher profits, and have entrepreneurial support, as opposed to traditional rice cultivation, which is labor- and resource-intensive, and dependent on on-farm input.[6] Other countries are already benefiting from the extensive use of technologies such as drones, field sensors, and satellites for water balance calculations, spraying and other farm operations, and collection and use of meteorological parameters.

Economic benefits. Existing technologies provide scant additional benefits in terms of yield, income, and livelihood. Higher investment costs (input, weed control) and deficiencies in capital, incentives, and infrastructure limit productivity. Marketing systems are ineffective and entrepreneurship is not emphasized. Farmers' cooperatives and associations are not accorded enough importance as pillars of agricultural development, and in many areas do not exist at all.

Sociocultural benefits. Food self-sufficiency is a top priority, and traditional practices (community, labor, gender, norms, and values) sometimes impede the acceptance

[6] M. A. Basher. 2017. *Potentials and Challenges of Knowledge-Intensive Agriculture: The Bangladesh Context.* Presentation at the Knowledge-Intensive Agriculture Workshop. ADB, Manila. 15–16 June.

of new knowledge. Human behavior (resistance to change, risk aversion, limited women's participation) poses a challenge for technology delivery. Mechanization and its benefits are not well understood or appreciated by farmers. There is an overall lack of awareness of the availability of high-level technologies, and of how these work and can be most suitable for farming conditions. The farmers' mind-set is averse to change and they would rather stick to their traditional ways than risk adopting new ways in farming or suffering great losses.

Enabling environment. Constraints in this category are limited access to credit and markets, weak institutions (extension, information, credit, land tenure), and poor governance (policy, rules and regulations, support, coordination). Mechanization, for instance, is a low priority for government, discouraging investment in technological and logistic support. Other logistical problems are prohibitive trucking and shipping costs, and duties imposed on raw materials and imported machinery. Public–private partnership is lacking in many aspects of the rice supply chain, from production to marketing, and in research and development.

Potential Role of Technologies

Several high-level rice-based technologies that can increase rice production on a sustainable basis are available. The ADBI–IRRI assessment of potential rice-based systems, technologies, and practices or their importance, potential benefits, current level of use (low, medium, and high), and suitability for Bangladesh, Cambodia, and Nepal was based on the opinions of an expert panel working in Asia (Table 1). Among the listed high-level rice-based technologies, the following are deemed likely to have higher potential for adoption and return on investment in Asia:

- Better rice varieties (high yield, short duration, and better grain quality):
  - rice varieties suitable for AWD conditions in Bangladesh (e.g., BRRI Dhan 28, BRRI Dhan 67, BRRI Dhan 69, BRRI Dhan 71, and BRRI Dhan 75);
  - rice varieties suitable for direct-seeded rice (DSR) conditions in Cambodia (e.g., CAR14 and CAR15); and
  - rice varieties suitable for DSR conditions in Nepal (Sukha Dhan 1, Sukha Dhan 2, Sukha Dhan 3, and Hardinath 2).
- Rice Crop Manager (agronomy and nutrient management) for all three countries.
- Water-saving technologies (e.g., AWD for Bangladesh and DSR for Nepal).
- Mechanization of crop establishment (e.g., seed-sowing machines and rice transplanting) in all three countries.
- Mechanization of rice harvesting and proper storage and milling facilities (e.g., reaper and mini combine harvester) in all three countries.
- Development of a farm machinery custom-hiring service economy in all three countries.

- Intensification and diversification of rice-based cropping systems in the project target areas:
  - rice–mustard–rice, rice–potato–rice, rice–pulses–rice, and rice–soybean–rice in Bangladesh;
  - rice–mung bean–rice, rice–vegetable–rice, and rice–cassava–rice in Cambodia; and
  - rice–wheat, rice–pulses, rice–mustard, and rice–maize in Nepal.
- Use of information and communication technology to disseminate agrometeorological advisory and market information to farmers.
- Establishment of a crop insurance program for rice farmers in the project target areas.

In addition to the listed technologies, ranked from 1 to 10 (Table 1) on the basis of suitability for the conditions in each country, the short survey also included eliciting information on the potential high-level rice-based technologies and their benefits which could easily be adapted by the target farmers (Table 2). Twenty IRRI scientists were asked to rank the sustainability of the listed technologies and practices as low, medium, or high on the basis of their importance, potential benefits, current level of technology use. The list could be a good source of information about the potential of each technology for improving the value chain in each country (footnote 5). These technologies listed have been tested, validated, and proven to contribute significantly to the objectives of increasing the productivity of rice-based cropping, saving water, and providing other benefits as adaptation mechanisms for rice cultivation under climate change.

IRRI's experience in many countries indicates rapidly growing interest increasing in direct-drill seeding or mechanical transplanting under puddled or non-flooded conditions because of the increasing scarcity of labor, energy constraints, and rising input costs. In addition, crop rotations with non-cereal crops such as vegetables and short-duration legumes are becoming popular as nutrition and well-balanced meals, along with conservation of soil resources, take center stage in development efforts. These technological innovations, including high-yielding and stress-tolerant varieties, appropriate agronomic practices, and better irrigation management, have been tested and validated under different physical and biological stress conditions in farmers' fields. Labor input-reducing practices include direct seeding, weed management, and mechanization that can also reduce environmental footprint. Technologies such as AWD irrigation and DSR cultivation are simple and easy to apply, yet these are not widely disseminated. Using these resource-efficient technologies can lower production costs. In addition, innovative and mechanized postharvest technologies and practices related to drying, milling, and storage can reduce losses and increase product quality and the price premium for farmers.

Table 1: Existing Technologies for Rice-Based Systems and Their Sustainability Ranking

Existing Technologies in Rice-Based Systems	Ranking		
	Bangladesh	Cambodia	Nepal
Short-duration rice varieties suited to water saving	10	10	10
Shorter-duration varieties for other crops	10	10	10
Premium-quality rice varieties	8	8	6
New breeding techniques	9	8	8
Rice varieties tolerant of abiotic stresses (flood, drought, salinity, and cold)	10	10	8
Production and use of good-quality rice seeds	10	10	10
AWD irrigation	10	6	9
Direct-seeded rice crop establishment	8	9	8
Mechanical rice transplanter	9	9	9
Laser land leveling	8	5	5
Rice Crop Manager	8	8	8
Mechanical rice harvester	10	10	10
Rice Super Bag and Cocoon for rice seed storage	9	9	9
Rice-based cropping patterns for introducing pulses, oilseeds, and vegetables	9	9	9
Systematic and quick varietal release system	8	8	8
Strengthened seed systems with ability to produce good-quality seed in larger volumes	10	10	10
Small farmers–large farm strategy for implementing mechanization and improved management practices	8	8	8
Policy support to encourage water saving, labor saving, and adoption of mechanization	10	10	10
Use of ICT in providing agrometeorological advisory and market information	9	8	8
Digital financial services	9	8	8
Crop insurance	9	9	9

AWD = alternate wetting and drying, ICT = information and communication technology.
Note: The questionnaire was sent to 20 scientists from the International Rice Research Institute with in-depth knowledge of rice-based cropping systems in Bangladesh, Cambodia, and Nepal. The scientists were asked to rank the sustainability of the listed technologies and practices from 1 (not suitable) to 10 (highly suitable).
Source: International Rice Research Institute. 2017. *Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific*. IRRI Ref. No. A-2016-167.

Table 2: Potential High-Level Rice-Based Technologies and Their Benefits

Available High-Level Technologies for Rice-Based Systems	Potential Benefits of These Technologies	Current Level of Technology Use
Short-duration rice varieties suited to water saving	Water savings Protection from late-season drought Early planting of second-season crop	Medium
Shorter-duration varieties of non-rice crops	Low water requirement; water savings Drought protection Growing of extra crop after early harvest Early planting of other-season crop	Low
Premium-quality rice varieties	Higher prices obtained by farmers Higher income for farmers Export potential	Low
New breeding techniques	Quick and precise development of new varieties Shorter breeding cycle and hence accelerated plant breeding Less need for resources	Low
Rice varieties tolerant of abiotic stresses (flood, drought, salinity, and cold)	Improved tolerance of multiple stresses Higher grain yield under stress Net economic benefits Improved economy and well-being of farmers Enhanced food security Employment generation during crop season Adaptation to climate change Resilience to climate change	Low
Production and use of good-quality rice seeds	Higher yield Reduction of weeds, off-types, and susceptibility to diseases Input savings Improved farm income	Low
AWD irrigation	20%–30% water savings Higher yield even under water shortage Enhanced resource-use efficiency Energy and financial savings Environmental protection through reduction of greenhouse gas emissions	Low
Direct-seeded rice crop establishment	Water, labor, energy, and money savings Enhanced efficiency of resource use Higher yield even under water shortage Early planting of next-season crop Environmental protection through reduction of greenhouse gas emissions Reduced health risks	Low
Mechanical rice transplanter	Timely planting and harvesting of crop Labor savings Reduced stress, workload, and health risks Uniform spacing and plant density Fats-recovering seedlings, vigorous tillers, and uniform maturation Reduced health risks	Low
Laser land leveling	Better crop establishment Reduced irrigation time Water savings in land preparation Less effort in crop management Reduced consumption of seeds, fertilizers, and pesticides and insecticides Fewer weed problems Uniformity in crop maturity Time efficiency in completion of task Higher grain yield	Low

continued on next page

Table 2 *continued*

Available High-Level Technologies for Rice-Based Systems	Potential Benefits of These Technologies	Current Level of Technology Use
Rice Crop Manager	Improved fertilizer-use efficiency Increased income Higher yield Extension services reaching more farmers Less adverse effects on environment	Low
Mechanical rice harvester	Time and labor savings Reduced production cost Reduced postharvest losses and better grain quality Increased yield Reduced losses from floods	Low
Rice Super Bag and Cocoon for rice seed storage	Extended germination life of seeds Control of grain insect pests without chemicals Improved head rice recovery of stored grain Better product quality	Low
Rice-based cropping patterns for introducing pulses, oilseeds, and vegetables	Improved soil fertility Increased resource-use efficiency Soil-moisture conservation Increased land productivity Increased farm income Reduced risk of crop failure Reduced weed risks Better human nutrition	Low
Use of ICT in providing agrometeorological advisory and market information	Timely and updated information about farming practices, weather forecasts, and markets Increased agricultural productivity Stronger agriculture sector Increased farmer access to markets Higher income for farmers	Low
Digital financial services	Easy and quick access to credit, especially for smallholder farmers Wider adoption of improved technologies Higher income	Low

AWD = alternate wetting and drying, ICT = information and communication technology.
Note: Low, medium, and high rank assigned to technology is based on survey ranking.
Source: International Rice Research Institute. 2017. Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific. IRRI Ref. No. A-2016-167. November. https://www.adb.org/projects/50058-001/main

In Asia, irrigation systems are generally complex systems, where major decisions are not made by the farmers themselves. Often, the intricate web of primary, secondary, or even tertiary canals depends on biophysical conditions such as farm location, soil and water resources, and available infrastructure, and on existing water governance within a small hydrologic unit. Farmers are not likely to be receptive to the use of mechanized AWD and other water-saving technologies because they perceive these technologies as laborious and time-consuming. Although knowledge-intensive, knowledge sharing can enhance the farmers' technical know-how while reaping the short- and long-term rewards of technological development. In addition to having higher economic returns, AWD as well as DSR crop systems are less labor-intensive, consume less water, are more conducive to mechanization, have lower methane emissions, and hence offer more opportunity for farmers to earn from carbon credits than rice-transplanting systems.

Based on a careful assessment of agricultural situations specifically on rice, integrated and holistic approaches, such as combinations of best agronomic management practices and appropriate varieties, are thus recommended. These innovative technologies can be combined into what is now commonly termed climate-smart agriculture, depending on the needs and resources available in a particular area. CSA is an approach that guides actions and decisions on the farm aimed at sustainably increasing agricultural productivity and income, adapting and building resilience to climatic fluctuations, and reducing the carbon footprint or decreasing or totally eliminating greenhouse gas emissions.

However, without the needed awareness, knowledge, and training, most farmers are still unable to gain access to these technologies and use them effectively. The adoption of suitable technologies and practices is a major opportunity to change production practices and attain farming efficiency, higher productivity, and higher incomes in resource-scarce rice-growing areas. Technological change will help transform farming communities into viable enterprises that can tap into the benefits of improved links along the value chains for rice and other grains. Farming communities can help conserve natural resources and mitigate the impact of climate change. Farmers' agricultural practices will need to adjust to emerging climate change–related constraints, adopt different water-saving technologies for efficient diversification, and introduce labor-saving mechanization and improved management practices. Problems regarding the low rate of adoption will have to be addressed. Interventions in terms of understanding technology adoption constraints, increasing farmers' access to improved technologies, building extension workers' knowledge on improved technologies, building farmers' capability to use technologies, and providing policy and logistic support are needed to widely scale up and adopt these high-level rice-based technologies. Apart from building farmers' capability to use available technologies that originated mainly from developed countries, the farmers' capability to innovate technologies more suited to their farm and agroclimatic situations was also emphasized during interaction meetings with farmers so that they remain providers and important players in agriculture rather than mere consumers. An adequate investment to develop, test, validate, and scale up these high-level rice technologies will produce large returns through social, economic, and environmental benefits.

3 PHYSICAL DESCRIPTION OF PILOT STUDY

Overall Project Deliverables

The project had three major components: (i) identifying the constraints on scaling up climate-smart water-saving mechanized technologies, and the policy, institutional, and logistics support needed to overcome those constraints; (ii) identifying and demonstrating CSA practices for rice-based systems that had been developed, refined, and tested and had been shown to improve crop productivity, resilience, and adaptive capacity; and (iii) developing databases (with survey, on-station, and participatory trial data), along with evidence of benefits from CSA practices using participatory approaches. Capacity-building of farmers and extension workers through training and awareness campaigns was also achieved.

Two related activities were implemented, to guide developing science-based evidence in terms of productivity, resource-use efficiency, cost–benefit, and environmental footprint. The activities were (i) well-designed demonstrations of best agronomic management practices in a climate-smart village concept to develop a robust gender-responsive platform for wider adoption and to increase awareness of the CSA technologies among farmers, extension personnel, and policy makers; and (ii) a comprehensive review and meta-analysis of available data sets (survey, on-station, and participatory trial data) for generating science-based scalable evidence for CSA practices in intensive rice-based systems.

Project Partners in the Three Countries

The project adopted a participatory approach involving men and women farmers in the three countries. Project site selection, as well as the involvement of farmers and staff, was carried out with the support of local and national partners, as follows:

Bangladesh

- Bangladesh Rice Research Institute (BRRI), Gazipur
- Ministry of Agriculture
- Bangladesh Agricultural Research Council
- Bangladesh Agricultural Research Institute (BARI)
- Department of Agricultural Extension (DAE)
- Bangladesh Water Development Board (BWDB)
- Muhuri Irrigation Project

- Private sector
- Farmers in the various regions

Cambodia
- Cambodian Agricultural Research and Development Institute (CARDI)
- General Directorate of Agriculture, Provincial Department of Agriculture, Forestry and Fisheries (PDAFF), Kampong Thom and Takeo
- Farmers in the various regions

Nepal
- Nepal Agricultural Research Council (NARC), Kathmandu
- Department of Agriculture
- Farmers in the various regions

In Bangladesh, the project was implemented with technical support from IRRI and from BRRI in Gazipur district, and with ADB financial assistance in the Muhuri Irrigation Project area. Support also came from the Ministry of Agriculture, the BWDB, the DAE, and BARI as collaborating agencies, and from the Bangladesh Agricultural Research Council and the Muhuri Irrigation Project. The private sector provided improvements in machinery.

In Cambodia, IRRI partnered with CARDI, and the General Directorate of Agriculture and PDAFF in Kampong Thom and Takeo for the implementation of the project activities, particularly the demonstration trials and farmers' participation. Nongovernment organizations, particularly the Cambodian alliance of agricultural cooperatives, progressive farmers, and local authorities also took part in conducting training activities.

In Nepal, collaboration with the Rani Jamara Kulariya Irrigation Project (RJKIP) and the municipality of Tikapur contributed significantly to the success of the project. RJKIP is a project run by the Government of Nepal, Department of Agriculture, with support from the World Bank. It has programs for agricultural modernization and mechanization support, especially in fruit production, seed production, and agribusiness, among others. The ADB–IRRI TA project linked up with Dhansinghpur, Narayanpur, and Jawalpur in Kailali district for effective collaboration and scaling up of appropriate technology in the following years. RJKIP provided additional fertilizer and pesticide support to farmers in Dhansinghpur, Narayanpur, and Jawalpur. RJKIP technical officers also helped monitor and provide technical support during field visits and training programs. Moreover, collaboration with the municipality of Tikapur was accomplished to help plan the details of the project and identify the farmers' most preferred technologies.

Country-Specific Information: Bangladesh

Areas Covered and Farmer-Beneficiaries

The TA project was implemented in the Muhuri Irrigation Project area in Feni district of Chittagong division as an experimental unit to test and validate appropriate CSA technologies and practices. Cooperative, progressive, and innovative farmers with suitable land and irrigation facilities were selected with the help of the DAE and BWDB for demonstration trials during the *T. aman* and *boro* seasons. Feni and Chittagong, having 23,076 ha of irrigated land area and 598 kilometers (km) under canals in the Muhuri Irrigation Project were also chosen as pilot sites. These are located in the middle of the southeastern region around the confluence of the Feni, Muhuri, and Kalidash–Pahalia rivers in the coastal belt of the Bay of Bengal. Climate-smart villages in each of the two districts were identified: Nurpur village in GM Hat union, GM Hat block, Fulgazi *upazila*, Feni district; and Olipur village, in Korerhat union, Korerhat block, Mirsharai *upazila* (subdistrict), Chittagong division. In each village, 10 ha of land was selected with a corresponding number of farmers. There were 62 farmers selected in Chittagong division and 43 in Feni, with a total area of 20 ha.

Technological Interventions

Pilot activities to show the efficacy of the technologies as well as the impact on climate change were (i) increasing productivity and cropping intensity by the introduction of climate-smart and potential cropping patterns; (ii) comparing the level of GHG emissions from climate-smart and traditional practices, and (iii) comparing the water savings from AWD irrigation and the traditional irrigation methods used by farmers. The project validated the following CSA practices under farmers' field conditions: (i) mechanized AWD technology (AWD irrigation method) in rice cultivation, (ii) rice varieties better suited to AWD, and (iii) diversified rice-based multiple cropping systems with high-value crops. Appendix 1 contains a brief technical description of the technology interventions.

Understanding farmers’ needs is critical for any type of intervention to be appropriate and acceptable to them. Through a dialogue, farmers expressed their need for the following: using seeds that are of good quality and optimum-aged seedlings; and knowledge in the proper preparation of the ideal seedbed, nursing of ideal seedbed, proper seedling uprooting, line transplanting, balanced fertilization, rainwater harvesting through mini pond development (*T. aman*), perching, supplementary irrigation, mulching after urea topdressing, and mechanized labor-saving agronomic management practices. These needs considered in the identification of the mix of technologies to be included in the interventions. The *T. aman*–fallow–*boro* pattern was the major cropping pattern at both project sites, where fields remained fallow and unproductive for 45–55 days before rice cultivation in the *boro* season. Farmers used long-duration rice varieties, such as the 140- to 145-day varieties BRRI Dhan 11, BRRI Dhan 49, and Noya Pajam, during the *T. aman* season because, their water requirement was greater, these were high-yielding varieties that adapted well to variable conditions and had good grain quality.

The project introduced the *T. aman*–mustard–*boro*, which was more productive, intensive, and cost-effective than the farmers' traditional cropping system. These crops were introduced to the sites characterized by available rainwater during *T. aman* rice and abundant surface water in *boro* rice cultivation. A comparatively short-duration rice variety, BRRI Dhan 75 (115 days), was used during the *T. aman* season. BARI Sorisa 14 (off-season mustard variety) was cultivated after the *T. aman* harvest, and BRRI Dhan 28, during the *boro* season. The whole package of climate-smart practices and varieties along with climate-smart/best agronomic management practices was adopted during the whole crop-growing period. The practices and varieties were as follows:

- use of good-quality seeds,
- preparation of community-based ideal seedbeds,
- proper uprooting of seedlings,
- transplanting of optimum-aged seedlings,
- balanced fertilization following the Rice Crop Manager (RCM) decision support tool,
- line transplanting,
- timely urea topdressing,
- mulching after urea topdressing,
- mechanical weeding,
- application of supplementary irrigation for rainfed conditions,
- crop residue retention, and
- use of perching for insect control.

Highlights of Project Activities

The on-farm participatory research trials were conducted on a total of 30 ha—15 ha in each village—involving 133 farmers' fields and 69 farmers in Chittagong division and 64 in Feni district. The project conducted experiments and field trials during the *T. aman* and *boro* seasons and held focus group discussions with farmers and key project partners to elicit feedback and other information, as well as dialogues with key partners. A focus group discussion on problem diagnosis and site characterization and a household survey firmed up the identification and analysis of constraints, identified additional policy needs, and led to institutional and logistics support for scaling up high-level climate-smart and water-saving mechanized technologies. Other participatory approaches were also employed to generate information about the farming communities, their existing systems, and the potential benefits of introducing the technologies.

During the first season, the mechanized AWD method of rice cultivation, consisting of transplanting, weed control, nutrient-water management, harvesting, threshing, packaging, and storage, was demonstrated and compared with the labor-intensive puddled transplanting system of rice cultivation. In the second season, the demonstration focused on mechanized dry direct seeding of mustard and potato using newly developed short-duration varieties suitable for the April–June gap period (*boro–kharif* rice season) of different crops (as decided in the workshop).

Measurements such as the amount of fertilizer used, crop growth duration, grain yield, and straw yield were also collected and total GHG emissions were calculated with the use of Cool Farm Beta-3 and expressed as global warming potential (considering all parameters) for different crops and practices. Emission factors calculated were fertilizer-induced nitrous oxide, fertilizer production, pesticide production, electricity use, and crop residue or organic amendments used, expressed in kilograms per hectare. Weather data, especially rainfall data, were recorded during the growing period of the cultivated rice crop. Other estimations made were measures of the benefits of labor–water–energy savings, reduction in GHG emissions, and yield components under mechanized AWD compared with the puddled transplanting of rice; the labor–energy savings from the mechanized method of cultivation of mustard and potato over currently followed practices of farmers; and the increase in yield, farmers' income, and farmers' and system productivity from the mechanized cultivation practices and varieties.

The project also generated policy support from the national government through prearranged visits. Likewise, a series of dialogues with officials from provincial and central offices helped to promote mechanization and insurance in agriculture. Workshops involving project partners and key stakeholders were conducted to develop a matrix of technologies suitable for different regions, in different seasons and for different crops, such as cropping patterns for different sites and areas, as well as suitable varieties for different crops.

Training and Other Support Systems

A total of 196 farmers (both women and men) and 26 sub-assistant agricultural officers were trained in six batches under the project. Training support was a necessary activity that capacitated the farmers on using the technologies as well as DAE field staff and project employees on the cumulative effects of agricultural practices on climate change, production technologies, environment-friendly processing and preservation of rice seed at the farmers' level, benefits of the AWD irrigation versus the standing-water method, GHG emission reduction during rice cultivation, the increased benefits from climate-smart cropping, and AWD implementation with emphasis on irrigation scheduling. The project also trained 100 farmers and extension workers on adopting the mechanized AWD system of rice cultivation, and 150 farmers and extension workers on adopting the mechanized system of mustard and potation cultivation. A total of 474 participants (extension workers and farmers) were trained at five organized training programs from 2016 to 2017.

Field visits and field days were also organized as a learning module that allowed active interaction among project partners and farmer-beneficiaries. Participatory approaches proved to be beneficial, since farmers actively participated and were moved to collective action. Farmer-participants were selected in consultation with the DAE and BWDB, paving the way for easier links to existing local programs and support.

From June–November 2018, the introduction of new climate-smart varieties necessitated the multiplication of seeds to ensure availability and good quality. Short-duration seeds of the BRRI Dhan 71 variety were distributed among the selected farmer-beneficiaries in two locations during the *T. aman* season. Fertilizer application conformed to RCM guidelines and was based on soil fertility, growth duration, cropping pattern, and land topography. Fertilizer was distributed to the selected farmers in the two locations, and 1.12 tons of good-quality seeds were provided. Seeds of BARI Sorisa 14 (8 kilograms per hectare [kg/ha]) and required fertilizer were supplied to the farmers after the *T. aman* harvest. Rice seeds (40 kg/ha) were distributed during the *boro* season. Seed multiplication during the second season involved the distribution of 0.5 tons of seed of the improved mustard varieties to 1,500 farmers. For the third season, 5.0 tons of seeds of the improved varieties under AWD were distributed to 2,500 farmers.

Country-Specific Details: Cambodia

Areas Covered and Farmer-Beneficiaries

In Cambodia, the project aimed to implement CSA activities in the central dry zone. The sites served as model experimental units to test and validate CSA technologies and practices, specifically the mechanized DSR system, rice varieties better suited to DSR, and diversified rice-based cropping systems in Cambodia. The more popular crops grown at the project sites are cassava and watermelon in Baray district; cucumber in Kampong Svay district; eggplant, cucumber, white radish, tomato, pumpkin, and mung bean in Santuk district; and maize, mung bean, watermelon, pumpkin, peanut, sweet potato, and cucumber in Tram Kak district.

Three demonstration sites in Kampong Thom and two in Takeo were selected for two seasons. In Kampong Thom, the villages selected were Trapeang Svay, Boeung Samrith, and Doong in Balangk commune, Baray district; Banteay Yumareach village in Banteay Yumareach commune, Santuk district; and Trapeang Ruessei village in Trapeang Ruessei commune, Kampong Svay district. The Takeo sites were Tramkak district, O Saray commune, Steung village, and Trapeang Kranhoung commune, Trapeang Chak village, with a total area of 20.27 ha.

A total of 10 ha for testing mechanized DSR cultivation were identified for each province, and implementation of the project activities started in the fourth week of June and ran until the end of August of the 2017 wet season. CARDI had already introduced the seed drill in Kampong Thom with financial support from a government project in previous years, but not in the locations identified for this project. In the Tram Kak district of Takeo, several upgrades of seed drills had been developed and introduced under an Australian Centre for International Agricultural Research project in 2010. The seed drill was adopted by some groups of farmers and operated through a community leader, acting as service provider. Under the ADB TA project, mechanized DSR with a seed drill and in combination with new varieties was introduced in support of farm mechanization.

Technological Interventions

The technologies introduced at the two sites in the central dry zone were (i) rice-based cropping patterns, specifically rice–vegetables, rice–pulses, rice–cassava; and (ii) mechanized dry direct-seeded rice (DDSR) cultivation (10 ha at each site), followed by mechanized cultivation of pulses (8 ha at each site), cassava (1 ha at each site), and vegetables (1 ha at each site). DDSR is gaining in popularity because it is low-input technology and the seeds are sown directly into well-prepared dry soil.[7]

The succeeding crops were watermelon, melon, pumpkin, mung bean, cucumber, tomato, eggplant, cassava, maize, peanut, and white radish. The demonstration trials of succeeding crops started with many kinds of vegetables, pulses, and cassava, and took place from the end of December 2017 until January 2018 for Kampong Thom and from January to February 2018 for Takeo. The seed drill was used for mung bean after rice. The farmers at both sites trained in the proper operation of this machine in planting mung bean. Seeds, fertilizers, insecticides, pesticides, and other items were also distributed to the farmers under the project. Demonstration trials of succeeding crops in Kampong Thom and Takeo were conducted. Project staff members, the CARDI team, and Department of Agriculture (DOA) officials conducted regular monitoring trips to each project site to check on the progress of the demonstration field trials and the quality of the output.

CARDI provided support for the seed drill to the sites and a short training on how to operate the machine, calibrate the dropped seeds and depth level, as well as demonstrate the benefits of mechanized DSR. Seeding was completed in 1 week in all the fields in the Kampong Thom site. In Takeo province, seeding was delayed by an attack by mole cricket and by the onset of rainfall at the time of seeding. It was completed by the end of August 2017. Based on the preference of farmers and market demand in both target provinces, the varieties chosen for demonstration were Phka Rumduol and CAR14. The farmers received fertilizers, insecticides, and pesticides. A data sheet for measuring water and labor savings and GHG emission reduction was prepared and shared with partners in Cambodia.

[7] A. Kumar and M. Katagami. 2016. Developing and Disseminating Water-Saving Rice Technologies in Asia. *ADB Briefs* No. 60. Manila. June. www.adb.org/sites/default/files/publication/185485/water-saving-rice-tech.pdf.

Highlights of Project Activities

The main activities conducted were as follows: (i) inception meetings for the ADB-supported project at CARDI on 12 July 2017; (ii) visits by IRRI scientists to experimental sites and consultations with partners; (iii) selection of project site selection; (iv) experiments with DSR cultivation technology, mechanization, and associated management practices in the central dry zone; (v) experiments with mechanized cultivation of succeeding crops in rice-based cropping systems, and associated management practices in the central dry zone; (vi) distribution of seeds of rice varieties suited to DSR in dry regions of Cambodia; (vii) implementation of a seed multiplication program for promising lines; (viii) training for farmers and extension workers in mechanized DDSR cultivation; and (ix) a baseline survey on the identification of constraints, needed policy, institutional support, and logistics in adopting and scaling climate-smart water-saving mechanized technologies.

Training and Other Support Systems

Two training workshops in mechanized DDSR cultivation were successfully conducted on 21 November 2017 in Takeo and on 23 November 2017 in Kampong Thom. A total of 150 participants, including farmers from the two provinces, were trained in mechanized DDSR cultivation. Participants also received training in high-quality seed production and climate-smart cropping patterns. In Takeo, there were 72 training participants (12 women and 60 men) from the Takeo Provincial Department of Agriculture, Forestry, and Fisheries (PDAFF), DOA, nongovernment organizations, agricultural cooperatives, and progressive farmers and local authorities. The morning session consisted of a series of short presentations and discussions with the participants on mechanized (seed drill) DDSR cultivation and its benefits, updates on the newly developed DSR varieties, and short lessons in soil suitability, field preparation, and appropriate planting time and methods (including crop establishment, seed drill for seeding, seed quality, seeding depth, seed calibration, row spacing, and seed treatment). The afternoon session focused on nutrients, water use, weed, disease, and pest control under DSR cultivation. The constraints and opportunities in enhancing the adoption of climate-smart practices together with mechanized DSR in Cambodia were also discussed in detail.

In Kampong Thom, training was conducted for 68 participants (15 women and 53 men) from the PDAFF, DOA, nongovernment organizations, agricultural cooperatives, and progressive farmers and local authorities. The topics included the mechanized dry-seeded system of rice cultivation and its benefits, an update on newly developed varieties for DSR, an overview of mechanized (seed drill) DDSR in Cambodia, and short lessons on soil suitability and field preparation together with appropriate planting time and methods (crop establishment), seed drill for seeding, seed quality, seeding depth, seed calibration, row spacing and seed treatment, nutrients, and water, weeds, and diseases and pests under the DSR cultivation system. The constraints and opportunities in enhancing the adoption of climate-smart practices such as mechanized DSR in Cambodia were also discussed.

CAR14 (0.3 ha) and CAR15 (0.9 ha) seed multiplication plots were established at the Balangk Rice Research Station in Kampong Thom province during the first growing season in 2017. The harvest of certified seeds from the production fields amounted to 3,200 kg of clean seeds, consisting of 680 kg of CAR14 and 2,520 kg of CAR15. The seeds produced were packed in 5 kg kits. The project allocated 136 kits of CAR14 and 264 kits of CAR15 to farmers in Takeo; and the rest went to farmers in Kampong Thom. A series of seed distribution events was successfully organized in January 2018 in four communes: Our Saray, Trapeang Kranhung, Trapeang Thom Khang Cheung, and Cheang Tong in Tram Kak district, Takeo province. A total of 402 farmers (145 women and 257 men) from the four communes attended the events and received good-quality CAR14 and CAR15 seeds packed in separate 5 kg kits. The same distribution events were organized in Kampong Thom, for the same number of farmers.

The second-season seed multiplication for CARDI Chey mung-bean variety (released by CARDI) was done for an area of 1.3 ha in Trapeang Chak village, Trapeang Kranhung commune, Takeo province, in the early part of May 2018. The total amount of clean seeds collected from the mung-bean seed production fields amount to 288 kg. This was short of the planned 1,000 kg of seeds k the late start of the wet season, the long drought spell after planting, and heavy rainfall during the flowering and harvesting stages. There was also poor growth, broken flowers, short fruits, germinated grain inside the fruits, and missing plants after planting due to attacks of mold cricket and other insects.

Country-Specific Details: Nepal

Areas Covered and Farmer-Beneficiaries

This project identified CSA constraints and opportunities, policy recommendations, and activities aimed at promoting intensive rice-based farming in Nepal. It was implemented in the Bardiya and Kailali districts in western Nepal, where rice farms suffer from the severe challenges of prolonged drought, followed by delayed and intensive rainfall resulting in flooding. For the first season in December 2017 to May 2018, large farmers with more than 2 ha of farmland in Bardiya district were selected for mechanized lentil farming. Whenever possible, the farmers selected were those who had already acquired the seed drill machine.

For the demonstration of mechanized seeding, the sites were Srikoriya, Dhodari, and Mainapokhar in Bardiya district, and Khajura in Banke district. A demonstration farm for the traditional setup (control) was established in Khajura. For the second season, the project was implemented in the municipalities of Gulariya, Madhuban, and Badaiyatal in Bardiya district, and the municipalities of Tikapur, Joshipur, and Janaki in Kailali district. Three farmers in Bardiya district were selected for mechanized lentil cultivation, and one farmer in Banke district, for the traditional method. A total of

46 farmers participated in technology adoption. DSR activities were conducted on 39.7 ha of rice land (dry DSR on 31.2 ha and wet DSR on 8.5 ha).

Technological Interventions

The project sites served as experimental units for testing and validating CSA technologies and practices, such as mechanized DDSR, wet direct-seeded rice, and suitable rice varieties for DSR technology, as well as adaptable best management practices (BMPs) and diversified rice-based cropping systems in Nepal. For the first season, the seed drill machine for lentil crops (mechanized lentil sowing) was evaluated in mid-December. Lentil seeds, fertilizers, herbicides, insecticides, and pesticides were supplied to the participating farmers. NARC provided boom sprayers, sprinkler irrigation, and micro-irrigation support, as well as tractor-operated boom sprayers. The plots demonstrated the potential of DSR by adopting best rice varieties, best crop management practices, balanced dosage of fertilizer, effective weed management, water management, crop protection, and postharvest handling to maximize total returns per unit of farm area (Appendix 2).

On the comparison demonstration plots, drill was used for dry DSR (on 25 ha) and the drum seeder for wet DSR (on 15 ha). These demonstration plots in at least 10 locations for the machine-operated sowing of rice in adjacent fields planted the recommended rice varieties: Hardinath 3, Sukha Dhan 3, Ciherang-Sub1, and Shamba Mahsuli-Sub1. Other management practices used were pre-emergent and post-emergent herbicide application, and mechanical weed control.

For the second season, demonstration trials and seed production activities involved lead farmers in large plot demonstrations and seed production. There were four demonstration plots covering 40 ha of land in each of the two districts (Bardiya and Kailali). For this demonstration, farmers adopted the complete package of DSR technology with best rice varieties (with short duration, high yield potential, and suitability for direct-seeding rice cultivation), crop BMPs, balanced fertilizer dosage, effective weed management, water management, crop protection, and postharvest handling to maximize total returns per unit of farm. Foundation seeds were used to promote the production of seeds of the suitable varieties.

Highlights of Project Activities

For the first season, the project conducted a 1-day planning meeting on the rice-based climate-smart agriculture project in the NARC office in November 2017. Major activities included (i) identification of potential farmers and site selection for mechanized lentil demonstration activities in Bardiya and Banke districts; (ii) field-based training and orientation for farmers in CSA technologies and mechanized lentil farming; (iii) mechanized lentil cultivation in three locations in Bardiya district and one location in Banke district, covering a total of 12 ha; and (iv) farmers' field days and participatory field monitoring and evaluation in the mechanized lentil fields in Mainapokhar and Sir Kohiya. The popular variety Khajura 2 was planted on the demonstration plots. Meetings with farmers' groups or cooperatives were organized to share knowledge related to CSA under mechanized farming. During the planning meetings, project staff members and scientists discussed the importance of mechanized farming in helping overcome the negative impact of climatic fluctuations and labor-intensive farming, farming costs and benefits, and deterrents to farming, including plant care and management, weed control, and the need for herbicides and mechanical weeders.

The following activities were conducted during the second season, from June to November 2018: (i) NARC and IRRI-Nepal scientists developed detailed plans for the field-level implementation of DSR and wet direct-seeded rice for CSA; the project planning workshop was held in March 2018; (ii) sites for wet and dry DSR demonstrations were identified and selected through field monitoring and a series of meetings with farmers from seven different locations of Bardiya and Kailali districts; (iii) four 1-day on-farm and hands-on technical training sessions in CSA technology, for 143 rice farmers and tractor operators from Bardiya and Kailali; and (iv) nine sessions of on-farm coaching in rice production BMPs, for 46 DSR farmers. The collaborating farmers were supported with technical services and with seeds, fertilizers, seed drill servicing, seeder machines, herbicides, weeders, and insecticides. Seed production was also carried out for fine rice (10 ha) and medium-fine rice varieties (16 ha) in different areas of Bardiya and Kailali.

Matthew Morell, IRRI director general, made a joint monitoring visit to the DSR fields in Kailali in June 2018. Morell was joined by IRRI representative in Nepal Krishna Dev Joshi, NARC scientists, extension professionals from the DOA, farmers, and entrepreneurs. Morell held discussions with the Tikapur municipality mayor and deputy mayor and other participants contributed to creating awareness and forging allies in technology dissemination. A three-member delegation from ADB also visited the project sites in Bardiya in October 2018. High-level officials from NARC and the Ministry of Agriculture and Livestock Development, IRRI scientists, farmers, and entrepreneurs participated in these events.

Training and Other Support Provided

Capacity-building activities were conducted under the project to develop local expertise, particularly for quick information dispatch and eventual uptake of validated technologies and practices. In addition to the five 1-day events, dealing with mechanized dry seeding of rice were organized. One event benefited 150 farmers, local government officials, private seed companies, rice millers, machinery service providers, machine operators, and agrovets owners to transfer new labor-, water-, and energy-saving technologies in rice farming. Enhancing technical ideas and developing skills through training are important components of any project in rice productivity. Rice farmers from Bardiya and Kailali districts participated in the training.

The sites visited were Satti in Tikapur municipality and Jawalpur in Janaki rural municipality in Kailali district, Khairapur and Tulsipur in Gulariya municipality, and Dhodari in Madhuban municipality, Bardiya district. A total of 143 paddy farmers (96 men and 47 women) gained technical ideas and skills in DSR technology and practices adopted in paddy farming. The training programs focused on a general understanding of DSR technology types and their importance in paddy farming, agronomic practices and crop varieties, fertilizer application rates and application, water management, plant protection, and insect and pest identification, control, and management. In the farmers' fields, the varieties grown were Bahuguni-1, Bahuguni-2, Hardinath 3, Shamba Mahsuli-Sub1, Sukha Dhan 3, Sukha Dhan 6, Chaite-5, Radha-4, and Ciherang-Sub1.

Two farmers' field day events and participatory field monitoring and evaluation of DSR fields in Kailali helped 72 farmers, 3 local service providers, and 7 agriculture officials and scientists gain knowledge of the technologies. Farmers' field day events serve as a good avenue to showcase the performance of the technologies and for farmers to directly interact with other farmers and extension people from other villages. For instance, in September 2018, farmers from Dhansinghpur, Narayanpur, and Joshipur gathered in the Jawalpur and Joshipur areas of Kailali district and joined in the participatory performance evaluation of DSR plots and transplanted plots, as well as in the evaluation of the agronomic characteristics, morphological characteristics, crop-cutting yield performance, disease and insect resistance, and farmers' perspectives. In Jawalpur, 34 farmers and 9 government officials or technical persons were present. The events in Joshipur drew the participation of 14 farmers and 4 government officials.

A total of 6 tons of seeds of improved varieties and 1 ton of lentils were provided under the project. Seed multiplication of stress-tolerant modern rice varieties was completed in Bardiya and Kailali districts. Seed producers' cooperatives and groups were identified and supported with foundation seeds and provided with technical training by the Regional Agriculture Research Station–Khajura and IRRI–Nepal. Sixteen farmers received seeds and were involved in seed multiplication in Dhodari, Sir Kohiya, Padnaha, Dhansinghpur, Jawalpur, and Joshipur. The 26 ha set aside for seed multiplication had an average yield of 4.10 tons (t) per ha. For mechanization demonstration trials and seed production purposes, 1,785 kg of seeds of nine newly released stress-tolerant rice varieties were distributed. Similarly, for fine-grain seed production in Padnaha village, farmers received an additional 450 kg of good-quality seeds of the Shamba Mahsuli-Sub1 variety.

Second-season activities mainly consisted of an awareness campaign for varietal preferences. Selected drought-tolerant rice varieties (Sukha Dhan 1, Sukha Dhan 3, Sukha Dhan 4, Sukha Dhan 6, and Hardinath 3) and submergence-tolerant rice varieties (Shamba Mahsuli-Sub1, Swarna-Sub1, and Ciherang-Sub1) were disseminated. Varieties tolerant of two stresses such as Bahuguni-1 and Bahuguni-2 were disseminated immediately after seed production. In accordance with protocol, partners from the private sector took the lead role in identifying and selecting the farmers who would also be crop seed producers, clustering seed production pockets (zones), providing technical support to farmers for the adoption of the complete package for crop BMPs, and further contracting with farmers. Also, 2 kg of these improved varieties were prepared and distributed widely among the farmers for trials and varietal promotion.

4
MAIN FINDINGS

Bangladesh

Effects on Yield

Based on experiments, the farmers' fields adopting existing fertilizer management produced lower rice yields than farms under the introduced CSA practices adopting fertilizer doses prescribed by the RCM guidelines. The farmers' selected rice varieties were of long duration, resulting in their inability to cultivate a *rabi* (winter) crop in between the *T. aman* and *boro* seasons. In Chattagram, BRRI Dhan 75 (shorter duration, 30 days earlier, or 114 days' duration) produced 20% higher grain yield (at 5.11 t/ha) than the farmers' varieties BRRI Dhan 11 and BRRI Dhan 49 (average yield of 4.26 t/ha, with an average of 145 days to maturity) during the *T. aman* season. All the tested varieties received the same package of cultivation practices. The encouraging yield performance of variety BRRI Dhan 75 following the recommended management practices was matched with lower input requirements. As a climate-smart variety, BRRI Dhan 75, with its shorter duration, avoided the damaging effects of terminal drought during the vegetative stage, without any supplementary costs.

Most farmers follow conventional crop and resource management practices, which result in low crop yield and input use inefficiencies in the project areas. Also, as water availability reduces, new water saving agricultural practices need to be introduced. Farmers generally use older seedlings and imbalanced fertilizer rates, resulting in lower yields. The farmers use BRRI Dhan 11 with a growth duration of 145 days and BRRI Dhan 49 with a growth duration of 135 days. The project introduced newly released short-duration *T. aman* variety BRRI Dhan 75 along with RCM-based management practices that include balanced fertilizers, seedlings that were 20–25 days old, optimum planting time, proper spacing, water management, and pest control. The popular and commonly cultivated high-yielding rice variety throughout the country, BRRI Dhan 28, was used as a cultivar and found suitable for irrigation.

The planting of a non-rice crop (the mustard variety BARI Sorisa 14) increased cropping intensity and led to a higher rice equivalent yield (REY). REY was 13.35 t/ha under climate-smart practices (*T. aman*–mustard–*boro*) compared with only 9.75 t/ha under the farmers' practice in Korerhat, Chittagong division. In Nurpur, Feni, where the *T. aman* crop was damaged by unusually heavy rainfall, REY was 8.10 t/ha under climate-smart practices compared with only 5.35 t/ha under the farmers' traditional practices. Farmers who were not selected for the project obtained lower rice yields than those who employed climate-smart practices in the *T. aman* and *boro* seasons. Total REY was higher if farmers adopted and grew a mustard crop between the *T. aman* and *boro* seasons.

Another important lesson learned by the farmers was the need to keep irrigation costs low as irrigation frequency decreased. For more effective and efficient use of technologies, the AWD water-saving method should be practiced by groups of farmers with adjacent plots. The same variety or different varieties with the same growth duration should be cultivated, seeded, and transplanted at shorter time intervals, in as much as the timing of irrigation under the AWD method follows the stages of rice growth.

Higher Income

Cost–benefit analysis was done for the *T. aman*–mustard–*boro* cropping pattern and under the climate-smart practices and farmers' existing practices at the two pilot sites (Table 3). Farmers adopting the project-introduced cropping pattern and management practices can expect an average increase in income of Tk30,642 to Tk36,321 per hectare (an average percentage increase of 52%–61%). REY was 13.35 t/ha under the newly introduced climate-smart pattern, versus only 9.75 t/ha under the farmers' conventional practice. Farmers gained Tk106,099 per hectare by adopting the newly introduced cropping pattern (*T. aman*–mustard–*boro*) compared to the benefit of only Tk69,778 per hectare in *T. aman*–fallow–*boro* pattern (Table 3). The benefit–cost ratio was higher for the farms under mechanized AWD (1.4) compared to the conventional continuous flooding, with only 1.02, representing an increase of 37%.

Table 3: Input–Output and Cost–Benefit Analysis of Project-Recommended Practices versus Farmers' Practices in Bangladesh

Project-Recommended *T. aman*–Mustard–*Boro* Cropping Pattern under Climate-Smart Practices, Two Project Sites

	T. aman (taka per hectare)			Mustard (taka per hectare)			*Boro* (taka per hectare)			Total Benefits (taka per hectare)
Location	Input	Output	Benefit	Input	Output	Benefit	Input	Output	Benefit	
Korerhat, Chittagong division	98,563	128,817	30,254	36,479	56,235	19,756	98,704	157,500	58,796	106,099
Nupur, Feni				39,249	59,500	20,251	94,503	154,750	60,247	80,498

Farmers' Practice *T. aman*–Fallow–*Boro* Cropping Pattern, Two Project Sites

	T. aman (taka per hectare)			Fallow period			*Boro* (taka per hectare)			Total Benefits (taka per hectare)
Location	Input	Output	Benefit	Input	Output	Benefit	Input	Output	Benefit	
Korerhat, Chittagong division	92,846	112,500	19,654				93,126	143,250	50,124	69,778
Nupur, Feni							89,894	139,750	49,856	49,856

Lower Production Costs

Using the low-cost insect management practice of perching during the 2017–2018 *boro* seasons in Korerhat produced savings amounting to Tk3,893 per hectare. On the other hand, labor costs between the use of mechanical threshing and manual threshing during the *boro* season indicated a decrease of Tk7,421 per hectare. This computation is based on the results for five farmers with landholdings ranging from 0.12 ha to 0.35 ha. Based on interviews with farmers, for a 0.17-ha area planted to rice, manual threshing requires four laborers who are paid at Tk500 each, while mechanical threshing costs Tk800. The production cost was also lower due to the shorter duration of BRRI Dhan 75 than the farmers' variety. Insect pest control provided savings of Tk3,893 per ha if the biological control method using perching was adopted. Non-target farmers used 60% more pesticide resulting in higher costs and environmental risks. Target farmer-adopters used mechanical threshing, which was labor saving, thus providing an additional benefit of Tk7,421/ha. Labor used in threshing (person-days per hectare) also decreased from 7% for continuous flooding to 2% for mechanized AWD, representing a 70% reduction in labor cost.

Water Savings

Based on the results in the pilot areas of 15 farmer-respondents, using AWD and continuous standing water (CSW) irrigation methods, and using the parameters per land area (decimal), the required number of irrigations, and the required water measured in millimeter (water flow meter), the amount of water saved was calculated. In Korerhat, during the *boro* season, the mean value of required irrigation number in CSW was 13.2 and in AWD was 10.4. As a result of the reduced number of irrigations, water saved was 21.17% lower than for the farmers' usual practice. Based on the total discharge for AWD and CSW measured by a water flow meter, water saved was 20% in mechanized AWD compared with CSW. Similarly, in Nurpur village, Feni district, water saved was 23.22% in terms of irrigation number, while water saved was 24.50% in mechanized AWD compared with CSW, based on the amount of water required (water flow). Water savings was 32% in terms of the number of irrigations under AWD compared with CSW, without any yield penalty.

Climate Change–Related Benefits

In Korerhat, during the *T. aman* season, total GHG emissions were lower by about 13% for BRRI Dhan 75 (1,649 carbon dioxide equivalent [CO_2eq] kilograms per hectare [kg/ha]) than for the farmers' variety (1,888 CO_2eq kg/ha) because of its shorter duration and fewer required cultural operations, such as a lesser number of irrigation applications and lesser duration of water ponded in the paddy field. Total GHG emissions for a cropping season were also lower for the climate-smart system than for the farmers' traditional practice (Table 4). During the *boro* season, total GHG emissions were 41% lower under AWD irrigation than under the CSW method, in both Nurpur and Korerhat villages (Table 5). Soil carbon loss decreased because of mustard cultivation and improved soil fertility. On the other hand, cropping intensity and crop diversity increased under the *T. aman*–mustard–*boro* cropping pattern. Crop-based GHG emissions were higher with the farmers' practice.

Table 4: Crop Yield and Greenhouse Gas Emissions from Climate-Smart *T. aman*–Mustard–*Boro* Cropping Pattern, Bangladesh, 2017–2018

Location/Treatment	*T. aman* (t/ha)	Mustard (t/ha)	*Boro* (t/ha)	REY (t/ha)	Total GHG Emissions (CO_2eq kg/ha)
Korerhat, Chittagong division					
Climate-smart practices	5.11	1.02	6.24	13.35	6,061
Farmers' practice	4.26	Fallow	5.49	9.75	7,469
Nurpur, Feni					
Climate-smart practices	Damaged	1.07	5.96	8.10	4,408
Farmers' practice	Damaged	Fallow	5.35	5.35	5,436

CO_2 eq = carbon dioxide equivalent, GHG = greenhouse gas, ha = hectare, kg = kilogram, REY = rice equivalent yield, t = ton.
Source: International Rice Research Institute. 2018. Climate-smart practices and varieties for intensive rice-based systems in Bangladesh and Cambodia. IRRI Ref. No. A-2016-167.

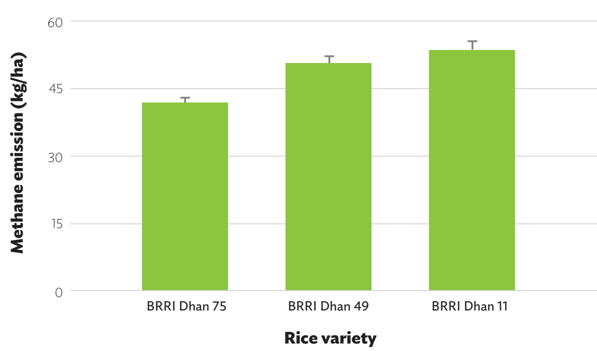
Table 5: Greenhouse Gas Emissions under Alternate Wetting and Drying and Continuous Standing Water Irrigation, *Boro* Season (Rainfed), Bangladesh

Location/Irrigation Method	Total GHG Emissions (CO_2eq kg/ha)	Decrease from Level under Traditional Irrigation (%)	Grain Yield (t/ha)
Nurpur, Feni			
AWD irrigation	3,203	41.06	5.95
Continuous irrigation	5,435		5.79
Korerhat, Chittagong division			
AWD irrigation	3,207	41.86	6.06
Continuous irrigation	5,516		6.24

AWD = alternate wetting and drying, CO_2eq = carbon dioxide equivalent, GHG = greenhouse gas, ha = hectare, kg = kilogram, t = ton.
Source: International Rice Research Institute. 2018. Climate-smart practices and varieties for intensive rice-based systems in Bangladesh and Cambodia. IRRI Ref. No. A-2016-167.

Among the varieties used, the lowest emissions of methane were noted with BRRI Dhan 75 (44 kg/ha), compared with 48 kg/ha if using BRRI Dhan 49 and 50 kg/ha if using BRRI Dhan 11 (Figure 1). In addition, BRRI Dhan 75 is considered a climate-smart variety contributing less to global warming, mainly because of its short duration and early maturity (Figure 2). Methane emissions were always higher in CSW irrigation than in AWD application (both locations) during the *boro* season (irrigated ecosystem).

Figure 1: Methane Emission as Influenced by Climate-Smart Varieties in Korerhat, Chittagong division, under the Alternate Wetting and Drying System



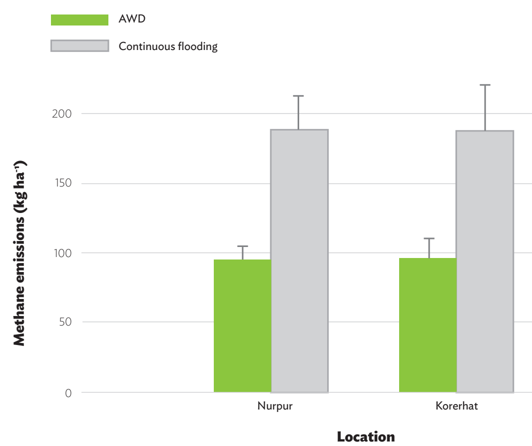
BRRI= Bangladesh Rice Research Institute, kg = kilogram, ha = hectare.
Source: International Rice Research Institute. 2017. Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific. IRRI Ref. No. A-2016-167. November.

Figure 2: Global Warming Potential as Influenced by Climate-Smart Varieties under the Alternate Wetting and Drying System, in Korerhat, Chittagong division

BRRI= Bangladesh Rice Research Institute, CO_2eq = carbon dioxide equivalent, ha = hectare, kg = kilogram.
Source: International Rice Research Institute. 2017. Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific. IRRI Ref. No. A-2016-167. November.

In both locations, methane emissions under AWD irrigation were always lower than the level produced under the traditional CSW method during the *boro* season (irrigated ecosystem) (Figure 3). Global warming potential, which is positively correlated with methane emissions, is therefore also higher for CSW irrigation.

Figure 3: Methane Emissions Under the Alternate Wetting and Drying and Continuous Standing Water Irrigation for BRRI Dhan 75 at Different Locations during the *Boro* Season



AWD = alternate wetting and drying, kg = kilogram, ha = hectare.
Source: International Rice Research Institute. 2017. Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific. IRRI Ref. No. A-2016-167. November.

CAMBODIA

Labor Savings

For the first season, the puddled and DSR cultivation methods were compared and the labor savings from the DSR method were estimated. Significant differences were observed between the two methods with regard to plant height, grain yield, and straw biomass in Kampong Thom, and for days to 50% flowering, maturity, plant height, grain yield, and straw biomass at Takeo sites. Labor savings of 43%–49% (in number of person-hours) was noted in Cambodia under the direct-seeded system of rice cultivation (Table 6). Significant variation in number of labor days (hours) used was also observed in mechanized DSR and the transplanted puddled system of rice cultivation, with an average percentage reduction of 57%–79% if shifting to mechanized DSR.

Table 6: Labor Savings under Transplanted versus Mechanized Direct-Seeded Rice Cultivation, Kampong Thom and Takeo, Cambodia

Location/Variable	Puddled Transplanted (Mean)	Mechanized DSR (Mean)	Standard Deviation	Standard Error	Probability (> I t I)
Kampong Thom					
Number of laborers	90	46.08	9.02	2.33	0.000[a]
Number of hours	680	146.03	49.94	12.89	0.000[a]
Cost (KR)	1,635,000	1,233,857	130,238	33,627	0.000[a]
Takeo					
Number of laborers	100	56.72	20.05	6.34	0.000[a]
Number of hours	325	140.13	51.42	16.26	0.000[a]
Cost (KR)	1,635,000	1,116,240	230,654	72,939	0.000[a]

DSR = direct-seeded rice, KR = Cambodian riel.

Note: Sample size is n = 10.

[a] Statistical significance is at 99%.

Source: International Rice Research Institute. 2018. Climate-smart practices and varieties for intensive rice-based systems in Bangladesh and Cambodia. IRRI Ref. No. A-2016-167.

In terms of labor savings for succeeding crops, there were significant differences in the number of laborers used and number of hours under traditional practices compared with the mechanized method of mung bean and watermelon cultivation for Kampong Thom and Takeo provinces. Labor savings of 23%–28% for mung bean planting and of 26%–31% for watermelon was calculated for the mechanized method of cultivation in Kampong Thom and Takeo (Tables 7 and 8).

Table 7: Labor Savings under Traditional versus Mechanized Practice of Growing Succeeding Crops at Kampong Thom Sites, Cambodia

Crop/Variables	Average Labor Savings		Standard Deviation	Standard Error	Probability (> I t I)
	Traditional Method	Mechanized Method			
Mung bean					
Number of laborers	41.00	29.67	2.45	1.45	0.016[a]
Number of hours	143.00	126.00	3.61	2.08	0.014[a]
Cost (KR)	2,232,000	1,660,278	29,016	16,752	0.000[a]
Watermelon					
Number of laborers	56.00	38.60	4.88	2.18	0.001[a]
Number of hours	158.00	114.80	17.96	8.03	0.006[a]
Cost (KR)	3,435,556	2,927,429	87,956	39,335	0.000[a]

KR = Cambodian riel.
Note: Sample sizes were n = 3 for mung bean, and n = 5 for watermelon.
[a] Statistical significance is at 95%.
Source: International Rice Research Institute. 2018. Climate-smart practices and varieties for intensive rice-based systems in Bangladesh and Cambodia. IRRI Ref. No. A-2016-167.

Table 8: Labor Savings under Traditional versus Mechanized Method of Growing Succeeding Crops, Takeo, Cambodia

Crop/Variables	Average Labor Savings		Standard Deviation	Standard Error	Probability (> I t I)
	Traditional Method	Mechanized Method			
Mung bean					
Number of laborers	43.00	33.17	3.76	1.54	0.001[a]
Number of hours	145.00	119.00	9.44	3.86	0.001[a]
Cost (KR)	2,292,500	1,845,342	82,870	33,832	0.000[a]
Watermelon					
Number of laborers	58.00	43.00	2.16	1.08	0.000[a]
Number of hours	140.00	121.50	14.55	7.27	0.084[a]
Cost (KR)	3,112,000	2,954,250	133,906	66,953	0.000[a]

KR = Cambodian riel.
Note: Sample sizes were n = 6 for mung bean, and n = 4 for watermelon.
[a] Statistical significance is at 95%.
Source: Cambodian Agricultural Research and Development Institute. 2018. Climate-smart practices and varieties for intensive rice-based systems in Bangladesh and Cambodia. IRRI Ref. No. A-2016-167.

Water and Energy Savings

Energy used in pumping water was significantly different for the Kampong Thom sites that used the direct-seeded versus the transplanted puddled system, with a reduction from 30.0 liters (l) to 16.1 l average diesel consumption in terms of liters per growth stage. For the Takeo sites, a reduction was also observed; however, it was not significant. Water savings ranging from 19% to 32% were observed in the Cambodian provinces that used DSR cultivation rather than the transplanted puddled system.

For succeeding crops, the energy consumed for the whole crop cycle was significantly different under the mechanized method versus the traditional method. A 16%–28% reduction was observed for watermelon at the two sites; for mung bean, 18% less energy was consumed at the Takeo sites (Table 9). The energy consumed for the whole crop cycle was significantly different in the mechanized method of watermelon for Kampong Thom, and for mung bean and watermelon for Takeo sites compared with the traditional method.

Table 9: Energy Savings under Traditional and Mechanized Practices, Kampong Thom and Takeo Sites, Cambodia

Location/Crops	Average Diesel Fuel (l)		Standard Deviation	Standard Error	Probability (> l t l)
	Traditional Method	Mechanized Method			
Kampong Thom					
Mung bean	39.00	33.00	3.46	2.00	0.095[a]
Watermelon	49.00	41.17	4.92	2.01	0.011[b]
Takeo					
Mung bean	43.00	35.20	2.59	1.16	0.002[b]
Watermelon	54.00	38.00	8.91	4.45	0.037[b]

l = liter

Note: Sample sizes were n = 3 for mung bean, and n = 6 for watermelon.

[a] Not statistically significant.

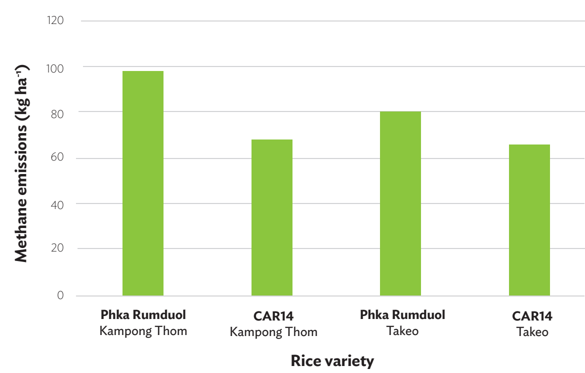
[b] Statistical significance is at 95%.

Source: Cambodian Agricultural Research and Development Institute. 2018. Climate-smart practices and varieties for intensive rice-based systems in Bangladesh and Cambodia. IRRI Ref. No. A-2016-167.

Climate Change–Related Benefits

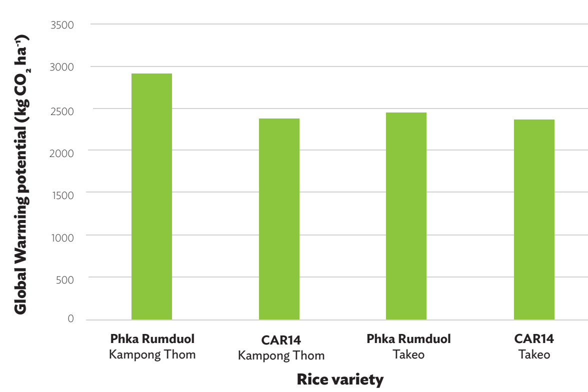
Among the varieties used, the lowest emissions of methane were noted with Cambodian Agricultural Research 14 (CAR14), 68 kg/ha in Kampong Thom and 66 kg/ha in Takeo, compared with 98 kg/ha in Kampong Thom and 80 kg/ha in Takeo if using Phka Rumduol (Figure 4). In addition, CAR14 was considered a climate-smart variety contributing less to global warming, mainly due to its short duration and early maturity (Figure 5). The differences in methane emissions between Kampong Thom and Takeo could be due to different dates of planting and different amounts of rainfall and water ponded in the field.

Figure 4: Methane Emissions from Traditional (Phka Rumduol) and Climate-Smart Varieties, Kampong Thom and Takeo, Cambodia



kg = kilogram, ha = hectare.
Source: International Rice Research Institute. 2017. Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific. IRRI Ref. No. A-2016-167.

Figure 5: Global Warming Potential of Traditional (Phka Rumduol) and Climate-Smart Rice Farming, Kampong Thom and Takeo, Cambodia



kg = kilogram, CO_2 = carbon dioxide, ha = hectare.
Source: International Rice Research Institute. 2017. Investment Assessment and Application of High-Level Technology for Food Security in Asia and the Pacific. IRRI Ref. No. A-2016-167.

Effects on Yield

An agronomic evaluation of rice traits under the two methods (transplanted puddled and mechanized DSR cultivation systems) was done at the two sites in the two provinces. Grain yield increased from 2.49 t/ha under puddled transplanting to 3.14 t/ha under DSR in Kampong Thom, for a 26% increase in yield. A similar trend was observed at Takeo sites, with an increase in yield from 2.36 t/ha under puddled transplanting to 3.54 t/ha under DSR, representing a 50% increase in yield.

During the second season, the project focused on labor and energy savings and yield evaluation under traditional and mechanized cultivation of succeeding crops after rice. The succeeding crops were watermelon, melon, pumpkin, mung bean, cucumber, tomato, eggplant, cassava, maize, peanut, and white radish. Demonstration trials started for crop establishment with many kinds of vegetables, pulses, and cassava, from the end of December 2017 until January 2018 for Kampong Thom, and then from January to February 2018 for the Takeo sites. Seed drill technology was used for mung bean after rice.

Among the possible succeeding crops demonstrated after rice, two crops—mung bean and watermelon—were selected for an analysis of farmers' income and cost-and-return ratio, increase in yield, and labor and energy savings under mechanized cultivation versus the traditional method (control condition). Significant increases in grain yield of mung bean at both Kampong Thom and Takeo sites, and in fruit yield of watermelon at Kampong Thom sites, were observed under mechanized cultivation, compared with the traditional method. For mung bean, grain yield increased from 0.65 t/ha to 0.77 t/ha in Kampong Thom, and from 0.62 t/ha to 0.70 t/ha in Takeo. Watermelon fruit yield increased from 18.4 t/ha to 19.8 t/ha in Kampong Thom, and from 18.6 t/ha to 20.8 t/ha in Takeo (Table 10).

Table 10: Evaluation of the Increase in Yield under Traditional versus Mechanized Practice, Kampong Thom and Takeo, Cambodia

	Increase in Yield (t/ha)				
Location/Crops	Traditional Method	Mechanized Method	Standard Deviation	Standard Error	Probability (> I t I)
Kampong Thom					
Mung bean (grain yield, n = 3)	0.65	0.77	0.02	0.01	0.000[a]
Watermelon (fruit yield, n = 5)	18.41	19.78	2.45	1.09	0.042[a]

continued on next page

Table 10 *continued*

Location/Crops	Increase in Yield (t/ha) Traditional Method	Increase in Yield (t/ha) Mechanized Method	Standard Deviation	Standard Error	Probability (> I t I)
Takeo					
Mung bean (grain yield, n = 6)	0.62	0.70	0.04	0.04	0.000[a]
Watermelon (fruit yield, n = 4)	18.60	20.84	3.12	1.56	0.166[b]

ha = hectare, t = ton.

[a] Statistical significance is at 95%.

[b] Not significant.

Source: Cambodian Agricultural Research and Development Institute. 2018. Climate-smart practices and varieties for intensive rice-based systems in Bangladesh and Cambodia. IRRI Ref. No. A-2016-167.

Higher Income

Cash cost per hectare under the traditional and mechanized methods of cultivation for succeeding crops showed similar trends, both in Kampong Thom and in Takeo. The cash cost for mung bean and watermelon was always higher under traditional cultivation than under the mechanized method. This cost can be attributed to the higher labor requirement for manual planting and harvesting, mostly done by hired labor. There were slight variations in mung bean grain yield and watermelon fruit yield at both sites. However, it was noted that, on average, the higher cash cost resulted in a lower benefit–cost ratio for the traditional method of mung bean at the Kampong Thom and Takeo sites.

The benefit–cost ratio was higher for the mechanized method than for the traditional method of cultivating the succeeding crops, mung bean and watermelon. For mung bean, the ratio was 1.25 for mechanized method and 0.40 for the traditional method in Kampong Thom. For watermelon, the benefit–cost ratio was 1.97 for mechanized cultivation and 1.36 the conventional method. In Takeo, the trend was similar, with a benefit–cost ratio of 0.97 for the mechanized method, compared with 0.41 for the traditional method of mung bean cultivation. On the other hand, the ratio for the mechanized cultivation of watermelon was also higher, at 1.82, compared with 1.39 for the traditional method.

NEPAL

Water and Labor Savings

DSR technology does not require setting up a nursery since seed is sown directly in the main field with a tractor-operated seed drill. This technology also saves water, as it does not require puddling irrigation, and needs only pre-monsoon irrigation for germination and maintenance of the crop stand. Normally, the irrigation requirement for rice is critical during the transplanting, or sowing, tillering, panicle initiation, and grain filling stages; but available rainfall may contribute one or two required applications. Therefore, after transplanting, at least three irrigation applications are required. Similarly, in DSR fields, soil cracking (or thermal shrinkage) decreased significantly because of higher soil porosity, reducing bulk density. Soil under the DSR system has more pore spaces and thus has a higher water-holding capacity, and air spaces requiring less water for irrigation, than the conventional method.

DSR technology, combined with the use of a machine-operated boom sprayer for plant protection and a combine harvester, reduced the total cost by 25% compared with the conventional method. The use of this technology led to an 83% reduction in the total labor requirement compared with the conventional method. The contribution of DSR technology to labor cost was only 10%–15%, while that of conventional farming was 45%–50%. In this case, clearly, DSR technology can help solve the problem of labor deficiency during the peak season for labor demand in rice production.

Effect on Greenhouse Gas Emissions

In DSR technology, tractor hours decreased slightly, by 8%–10%, versus the conventional method. DSR reduced GHG emissions by at least 8%, by reducing tractor hours and increasing the working life of tractors. This report recommends that more research be done on GHG emissions in DSR technology and the conventional method.

Effects on Yield and Income

For the first season, the use of the mechanized seed drill in lentil production (with reports from three farmers) showed impressive results. Lentil production by farmers Ram Chandra Yadav and Raghav Chandra provided success stories that supported a better understanding of the impact of adopting the technology package. The average national lentil production is 1.02 t/ha. According to a report from the whole-plot harvest, both farmers exceeded the national average: Ram Chandra was able to produce 25% higher at 1.26 t/ha, while Raghav Chandra's production was 19% higher than the national average, at 1.2 t/ha. Another farmer had a lower production of lentil than the national average due to poor soil moisture, poor germination, and fungal infestation in midwinter. Laxman Chaudhari, on the other hand, used the traditional method in his farm and his yield was only 5% higher than the national average. This shows that sowing at the proper time and using a seed drill for lentil production can improve yield performance.

The details of the benefit–cost analysis showed a higher ratio for the system under mechanized DSR (1.40, with yield of 4.2 t/ha) than for the traditional puddled system (1.08, with the same yield) (Table 11). Calculations indicate that yield potential of up to 6.0 t/ha with net profit of up to NRs62,000 and a benefit–cost ratio of 2.0 can be achieved under better management practices combined with mechanized DSR technology. Seed used decreased from 80 kg/ha under continuous flooding to only 45 kg/ha under mechanized DSR, thus reducing production costs and increasing income.

Table 11: Cost–Benefit Analysis of the Mechanized Direct-Seeded Rice Method and the Traditional Puddled System of Rice Cultivation, Nepal

	Traditional Puddled System			Mechanized Direct-Seeded Rice		
Activity	Quantity	Rate (NRe)	Amount (NRe)	Quantity	Rate (NRe)	Amount (NRe)
Seed	45.00	45	2,025	45.0	45	2,025
Nursery raising			3,800			
Field preparation			10,200			5,100
Transplanting or sowing in DSR			16,000			3,000
Fertilizer management			10,220			13,240
Water management			10,125			12,750
Puddling irrigation (ha)	20.00	125	2,500			
Irrigation pre-monsoon, two times (ha)				50.0	125	6,250
Irrigation during monsoon, three times (ha)	45.00	125	5,625	36.0	125	4,500
Labor for pipe laying and irrigation	5.00	400	2,000	5.0	400	2,000
Plant protection (weed, insect, pest management)			9,400			11,786
Harvesting and threshing			18,525			12,800
Depreciation of tools, equipment			1,500			2,000
Total cost of rice or paddy production (NRe)			81,795			62,701
Grain yield (kg)	4,200	20	84,000	4,200.0	20	84,000
Straw yield, trolley (NRe)	2.0	2,000	4,000	2.0	2,000	4,000
Total income			88,000			88,000
Net profit (NRe)			6,205		2,000	25,299
Cost–benefit ratio			1.08			1.40
Labor	101.00	400	40,400	17.00	400	6,800
Tractor hours	10.75		17,425	9.75		23,100
Irrigation hours	90.00		10,625	86.00		10,750

DSR = direct-seeded rice, ha = hectare, kg = kilogram, NRe = Nepalese rupee.

Source: International Rice Research Institute. 2018. Climate-smart practices and varieties for intensive rice-based systems in Bangladesh and Cambodia. IRRI Ref. No. A-2016-167.

5
BENEFICIARIES' PERCEPTIONS AND LESSONS LEARNED

BANGLADESH

New Climate-Smart Variety

The new climate-smart variety BRRI Dhan 71 distributed to farmers from June–November 2018 did remarkably well in farmers' fields. The farmers were impressed with the results. BRRI Dhan 71 produced from 0.75 t/ha to 1.50 t/ha higher yield (yield of 5.28 t/ha–5.55 t/ha) than the farmers' varieties BRRI Dhan 11, BRRI Dhan 22, and BRRI Dhan 49 (which had average yield of 3.78–4.09 t/ha). Farmers were normally produced long-growth-duration varieties. The short growth duration of BRRI Dhan 71 (maturing 30–35 days earlier) enabled the farmers to avoid severe damage due to terminal drought. Other characteristics that the farmers liked about the variety were its non-lodging ability, higher straw yield, good and acceptable grain quality, and its ability to command a higher market price. Because of the variety's short duration, farmers were also able to plan an off-season crop (mustard) cultivated under *boro* season that also contributed to a higher income for the farms.

Institutional Partners

In the scale-out and scale-up of promising technologies, eliciting the support of institutional partners cannot be overemphasized. In many project cases, the farmers' field days and field visits are opportune times to showcase what the new technologies can do to ease the plight of poor farmers. These are ways of obtaining their feedback based on their own experience and getting them to share their learning and awareness of the new technologies. This project, implemented by ADB and IRRI, had the support of the DAE and other key government entities in the target districts, and at the *upazila* level. Public broadcasting units and print media also proved to be important allies in reaching a wider audience for the new technologies.

Negative Impact of Technologies

Although new technologies are assessed for readiness as practical solutions before they are actually disseminated, one should be aware of any potential negative impact, depending on the characteristics of the area where they were tested, the situation in the area, and the management skills of the farmers and extension agents involved in their delivery. For instance, the use of BRRI Dhan 71 as an early-maturing variety may cause changes in ecological conditions such as untimely bird attacks and rice bug infestation because of the early planting of the crop. These possibilities should be taken into consideration in planning for the planting or cropping season. Changes in labor input should also be well understood, as farmers often perceive new management practices as time-consuming and possibly adding to the labor requirement. In this case, the economic benefits as well as any negative implications to encourage farmers to adopt these technologies.

CAMBODIA

Farmer Feedback on Climate-Smart Practices

Feedback from the farmer-cooperators was collected as part of the technology evaluation of climate-smart practices and varieties for intensive rice-based systems. CARDI works with cooperatives and seed associations in Takeo and Kampong Thom, and with nongovernment organizations in Battambong. These tie-ups can help with dissemination of suitable technologies. Farmers reported that using the modified seed drill reduced their seed requirement. The seed rate for broadcasting was 100 kg/ha to 120 kg/ha; using the seed drill required only 45 kg/ha–60 kg/ha. No seeds were wasted. Because the seeds were covered, they could not be eaten by birds. The fields had uniform crop stands and thus looked impressive. Plants also had more tillers. More importantly, the farmers' yield increased. The farmers' response and attitude toward the pilot-tested systems centered mainly on the need to obtain further training in the technical aspects of the technologies.

Seed-Drilling Technology

Benefits to users. A baseline survey of 150 farmers was conducted in the provinces of Takeo and Kampong Thom to understand the constraints on technology adoption better. The farmers described their current crop production practices and discussed their perceptions of, and interest in, the use of the seed drill for mechanized dry DDSR. Those who had used the seed drill indicated that the most common benefit was that seeding rates lower than those for broadcasting. In addition, rice is grown in properly spaced rows, making it easier and less labor-intensive to apply fertilizer, control weed, and harvest the crops. Because rice is sown directly in the main field, the plants do not have to recover from transplant shock and therefore mature earlier. Some farmers, particularly those in Kampong Thom, noted an increase in yield resulting from the use of the seed drill. Very few farmers reported drawbacks, such as the need to use the drill on dry soil, longer germination time compared with broadcast seeding, and non-germination of seeds in some parts of the field (which also occurs in broadcasting).

Constraints on use. On the other hand, constraints to the adoption of the seed drill identified by farmers were lack of awareness of the technology and its benefits, shortage of service providers, low availability of the seed drill when needed, and additional rental cost. Besides, some farmers prefer traditional farming. Farmers suggested advertising the advantages of using the seed drill in DDSR, conducting more demonstration trials to persuade more farmers to adopt the technology, increasing the number of service providers for the seed drill in response to the growing interest among farmers, and involving active nongovernment organizations in technology dissemination. Among the farmers interviewed, almost 70% expressed willingness to adopt the seed drill and were willing to pay the rental cost.

The farmers raised several issues and concerns regarding the use of the seed drill, and suggested some improvements. The seed drill cannot be used on wet or saturated soils. To address the issue of early-onset rains, the farmers suggested that a seed drill be developed for used in both wet and dry conditions. Land should be well prepared. The seed drill now available is heavy and requires two people to attach it to a two-wheel tractor. The farmers suggested using lightweight materials to modify prototypes of the seed drill. There is an overlap in seeds dropped at the edge of the plot when the two-wheel tractor turns; an adjustable seed drill should be able to match the required row spacing (e.g., from 15 centimeters to 20 centimeters). Adjustments can also be made in the prototype seed drill to allow it to drop seeds at preset intervals instead of continuously, thus decreasing the seed rate to the required level.

Farm Service Provision

Many farm activities are contracted out because of labor shortage. Combine harvesters are widely used; 90%–100% of the farmers in Baray district in Kampong Thom and Our Saray commune in Takeo use this technology. There are many service providers for combine harvesters within communes or nearby. In some cases, land preparation is also contracted out, with some farmers such as those in Kranhoung, Kampong Thom, providing this paid service. Broadcasting by hand is widely used, but only about 10% is done by women. In Tram Kak district, Takeo, 80% of the farmers have adopted the practice and only 20% transplant seedlings. In Banteay Yumareach commune, Santuk district, Kampong Thom, 100% practice hand broadcasting. The seed drill is not yet well known at the Kampong Thom sites. Farmers in Our Saray commune said that members of their cooperative do not pay to use the seed drill. They are pay only for fuel and provide lunch for the operator. The service provider can seed 1.5 ha in 6 hours and in one season can seed a maximum of 20 ha with good planning. There are two possible service provision models: (i) combined land preparation and seeding at $75 per hectare (ha) and (ii) seeding only at $20/ha. Only areas with at least 1 ha will be considered. The rates and terms are agreeable to the farmers, who consider them reasonable and are willing to pay.

Regarding the growing of a non-rice crop, 47% expressed willingness to adopt this system after wet-season rice production to generate more income, to supply home consumption needs, and to improve soil fertility. The lack of time, labor, and funds for cultivation and unavailability of irrigation facilities could discourage farmers from adopting this technology. Crops that farmers would like to grow after wet-season rice are watermelon, cucumber, mung bean, cassava, pumpkin, and eggplant. Some farmers are already growing these crops during the dry season.

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Feedback from the farmers was gathered through joint monitoring visits, farmers' field days at demonstration sites, project monitoring visits, and awareness-building events that drew local farmers, government officials, and private sector representatives from different cooperatives, among others. Each event had from 5 to 50 participants observing the performance of zero-tillage lentil in farmers' fields and other technology packages, and collecting and sharing information in a participatory way with other researchers, extension workers, and farmers. Climatic conditions, such as limited rain during winter and foggy weather, greatly affected crop performance, yet lentil variety Khajura 2 among others, showed encouraging results. Farmers were interest in the use of the zero-till drill in lentil production. They also suggested testing more lentil genotypes to select the most promising varieties for Mainapokhar, Bardiya district, as well as for Banke, Kapilvatu, and other districts where varietal heat tolerance is necessary. One visit to the site in Gulariya municipality, Khairapur town, in Bardiya district focused on the importance of machine use in lentil and rice production because of the shortage of labor.

Other DSR-related issues, particularly weed, disease, and insect pest control, were discussed, as farmers shared their knowledge and experience from other completed projects such as the Cereal Systems Initiative for South Asia. The following is a summary of the feedback and observations from farmers and other stakeholders, obtained during the monitoring visits and from summary reports.

Technical Support

(i) **Low level of technical capacity of farmers, service providers, and local technicians**. Farmers still adhere to the conventional or traditional way of thinking in farming. They should have regular access to technical support and a resource person, especially during the first month, to ensure that DSR farmers in the field are constantly engaged and that crops are properly cared for and managed until they are well established. Farms need intensive care, supervision, and technical support especially during the critical stages of plant growth. The low technical capacity of machine service providers and agricultural technicians for machine calibration and operation should be addressed.

(ii) **Available suitable varieties for DSR.** Short-duration improved varieties should be promoted as more suitable than long-duration varieties. Farmers observed that stress-tolerant early-maturing varieties have high plant vigor and are better than indigenous varieties. Dry DSR in the field (with Hardinath 3, Sukha Dhan 3) is managed well. Farmers expressed preferred for Ciherang-Sub1 because its higher yield and shorter time requirement than other varieties, except for the bold grains.

(iii) Related practices. For DSR technology to succeed, a proper package of practices, such as the use of pre-emergent and post-emergent herbicides, should be followed.

(iv) Lack of appropriate machines. There is a lack (a very limited number) of appropriate machines with service providers, and small farmers are in need of seed drills and drum seeders powered by a two-wheel (mini) tractor. Farmers declared their willingness to multiply seeds and use DDSR technology if the necessary machines are available.

Crops and Technology Performance

(i) Farmers in all field visits indicated that the crops were growing vigorously and had good panicles.
(ii) Observations about crop response under different technologies, such as the relatively higher weed infestation under dry DSR, should be evaluated further. Better crop planning, considering the findings, should be done to deal with the problems found.
(iii) Cropping land for DSR (both dry and wet) should be clay loam to loamy as it has good water retention capacity while sandy loam to sandy soil should be prohibited for DSR.
(iv) Leveling and expanding of the farm to a plot of at least 0.3 ha is necessary for mechanization and ease in farm activities. This reduces the water needed for irrigation and increases the net cropping area and total production.
(v) Farmers attested to the efficacy of DSR technology. Although relatively new, the technology is considered a good option because of ease sowing and the labor savings, higher income, and increased productivity it makes possible. Non-participant farmers have expressed interest in dry DSR, a fuel- and energy-saving technology.
(vi) This labor-saving technology can halve labor cost under the conventional method.
(vii) Yield is comparable to that from the puddled transplanting system.
(viii) Proper soil moisture and proper depth of sowing should be maintained for good germination of DSR and effective herbicide use.
(ix) The optimum date of planting of lentil crops is better than late planting. Crop performance in this area was much better than in Mainapokhar due to medium soil fertility and availability of sprinkler irrigation.
(x) Land should be leveled properly with a laser land leveler. This equipment was not available in the project areas.
(xi) DSR technology should be adopted in areas with irrigation and drainage facilities.
(xii) The technology is more useful to large and medium farmers with landholdings of more than 0.5 ha. Although small farmers generally have household or family labor available, their small farm size discourages them from adopting the technology even if it is labor-saving.
(xiii) The technologies are not suited for use on farms where land is unleveled and fragmented, fields are small and scattered, and irrigation and drainage facilities are limited.

Water-saving technology. The laser land leveler improves crop yields and saves water. (Photo by IRRI)

Other Support Systems

(i) Publications, broadcast media, and sharing of success stories with the general public and farmers to create awareness are important for broader adoption of appropriate technology. Farmers are happy and satisfied with the technology, but still need support for its scale-up.
(ii) Resource leverage and collaboration with local government will ensure program ownership, monitoring, technical updates, and sustainability.
(iii) Linking farmers to markets or industry and the private sector will enable system input to be channeled into final output.
(iv) Showing farmers the extent to which DSR reduces production costs and improves on the net returns from rice transplanting will help persuade more of them to adopt DSR technology.

Next Steps

(i) The efforts of the IRRI and NARC Regional Agriculture Research Station in mechanization in agriculture should be continued and used to develop technologies and programs to cover a larger number of small farmers.
(ii) Farmers showed interest in using the zero-tillage drill in paddy cultivation in the coming rice season, and declared their willingness to spread the technology among other farmers in the community.
(iii) Rice-related data should be updated according to the prescribed format, analyzed, and shared in high-level meetings.
(iv) Planning should be done in collaboration with the private sector and service providers to maximize operations according to farm capacity.
(v) The focus should be on developing the skills and capacity of farmers, farmers' cooperatives, and related groups—even of non-adopters of the improved technology or practice—to prepare them for future adoption.
(vi) Sustained implementation, with wider coverage and financial support, will encourage farmers and local governments to adopt best practices.

6 RECOMMENDATIONS AND NEXT STEPS

High-level climate-smart farming technologies in rice-based ecosystems are needed to attain higher productivity amid unrelenting population growth and the damage inflicted by climate change. As the ADB–IRRI project showed, climate-smart rice varieties, water-saving irrigation, and mechanization can make rice production more profitable and sustainable. The TA project was implemented in collaboration with BRRI, CARDI, NARC, and other partners to gain a better understanding of farming communities at target sites affected by drought and other climate-related problems, and to test and validate appropriate rice-growing varieties, cropping patterns, and technologies. Through consultation and dialogue, the project was able to identify the constraints on the scale-up of high-level climate-smart technologies, and the policy, institutional, and logistics support needed to deal with those constraints.

The project produced evidence that the recommended basket of options, particularly AWD, mechanized DSR, and climate-tolerant modern rice varieties, can boost productivity, and ultimately food security and farm incomes, on a more sustainable basis. These CSA practices were assessed through participatory evaluation and recommended practices were validated against key sustainable development indicators. Millions of farmers in stress-prone and resource-poor rice areas of Bangladesh, Cambodia, and Nepal stand to gain from these technological developments. Resources must be appropriately channeled to collective efforts to change the lives of these farming communities for the better.

Development workers and governments in the three countries should now prime themselves for the scale-up of the climate-smart rice varieties and practices. Recommendations based on the project findings are presented on the following pages to guide them in charting and taking the next step forward.

Identifying Potential Areas for Expansion

Technology targeting. Technology dissemination is not a one-size-fits-all activity. The first step is to define the expansion domain on the basis of concrete information or data. The key is to establish a clear picture of the situation at the target expansion sites and to determine the suitability of the planned mix of technologies. Climate-smart technologies are responses to complex biophysical and socioeconomic conditions, and therefore require a holistic approach to understanding the situation at the potential sites. This can be done by conducting, in a participatory manner, the characterization of sites and defining critical issues that would justify the need to scale up the technologies. Note that participation of farmers and stakeholders should be done at all stages of the development and scaling-up process. CSA technologies address specific production concerns, which could differ from village to village, township to township, or geographic and political demarcation, underscoring the importance of technology targeting and matching.

Technological traits and technology matching. Current practices, mechanization status, and service provision for machines and agricultural insurance at target sites must be assessed. The demonstration plots must show the economic differences between the new package of technologies and the existing farmers' current practices. IRRI and its partners in Asia have adopted participatory approaches to the selection, testing, and validation of newly released stress-tolerant varieties, underscoring the importance of need-based community programs. Technologies that attract users are normally those that are easy to use, can boost productivity, fit in with the current production system, cost less and more profitable, are more resource-efficient, and are in high demand. Programs should also adopt the gender-lens approach in delivering economically viable, ecologically sound, and socially acceptable solutions, as women have important roles to play in agricultural production.

Defining Requirements for Scaling Up Climate-Smart Agriculture Technologies

Investing in the development, validation, and dissemination of appropriate climate-smart agriculture technologies. Funding support must be channeled into the promotion of technologies that can contribute to food security and poverty reduction in resource-poor communities. Technologies are location-specific and their validation and dissemination require funding support to reach specific target users or beneficiaries. Enough funds must also be provided to sustain the research process, given the complexity and rapidly evolving state of development issues. This project has distilled important feedback from the farmer-users about the modifications that have to be made in the technologies recommended for adoption.

Conducting surveys and generating evidence of adoption and impact. The true measure of success of farm technology development and delivery is use of the innovations by farmers and their sustained application over a considerable period until they are superseded by more effective and efficient technology. Evidence of the benefits derived from the technologies is an important element of policy instruments and scale-up and scale-out processes.

Reviewing related and potential climate-smart water-saving technologies. For smart irrigation systems, related technologies and innovative systems, such as AWD, irrigation scheduling, volumetric pricing, solar pumping, smart prepaid card systems, efficient irrigation infrastructure, and community-based irrigation, should be assessed. Rural development or transformation can capitalize on the collective efforts of members of the farming community, mainly for information sharing and a more equitable spread of benefits among many others.

Establishing knowledge management support and information-sharing platforms. Different stakeholders must be made aware of the nature of the technologies, the benefits they provide, and the necessary conditions for scale-up, to ensure that the collective efforts of all concerned contribute to the speedy delivery of information. A well-designed knowledge management system for the scale-up efforts should determine the target audience, the content, and the means of delivery such as print and nonprint media. The following components of the knowledge-sharing platform were identified during the policy forum:

- **Training farmers.** Training will increase awareness of CSA technologies and capacity to make beneficial use of these technologies.
- **Establishing a knowledge-sharing platform.** With appropriate support from the government and other allies, the platform will require learning alliances or a communities of practice that can promote wider adoption.
- **Raising the profile of climate-smart agriculture.** This can be done by communicating successes to wider audiences, including evidence of economic, social, and environmental benefits to be derived from the technology package.
- **Providing smart extension services to improve farmers' access to information, technology, and knowledge.** This includes the use of information and communication technology in community water systems. An example is the decision tool AutoMonPH developed by IRRI to improve not only irrigation scheduling at the plot level but also water governance at different spatial scales. The decision tool collects real-time water-level data at the plot level, filters the information, and synthesizes it at different scales. The information derived can then be shared with different partners according to water governance roles and information needs.

Providing support and incentives to farmers for the adoption of climate-smart agriculture technologies. Credit facilities and farmers' easy access to credit and markets were identified as critical needs for the successful delivery of technologies. Farmers need financial resources to buy machinery and farm input such as seeds, fertilizers, and pesticides, and to gain access to support services. In many cases, farmers rely on traditional sources of rural credit, which impose high interest rates and tedious requirements for loan approval. Technology scale-up can also be speeded up through the provision of agricultural services in the form of technical support or training and availability of crop insurance.

Ensuring access to good-quality seeds and efficient seed multiplication. As in other countries in Asia, the lack of access to good-quality seeds, especially those of newly released varieties, was identified as a problem faced by farmers in Bangladesh, Cambodia, and Nepal. The introduction of suitable varieties requires the availability of good-quality seeds. Seed security is a precondition for food security. Studies show that poor-quality seeds can result in poor crop growth, low seedling vigor, nonuniform emergence and maturity, more weed competition, poor grain quality, and greater susceptibility to disease and attacks by insect pests.

Newly released stress-tolerant varieties that can be tested for suitability for AWD and other climate-smart practices are known to provide a yield advantage of 0.5 t/ha to 3.8 t/ha, depending on the severity and duration of the stress.[8] Several IRRI projects have supported the validation and seed multiplication of popular varieties. This momentum must be sustained as more farmers clamor for opportunities to increase productivity and income. Given these circumstances, establishing links with partners mandated to multiply seeds should be among the next steps. Appendix 3 lists possible partners for seed multiplication and distribution in Bangladesh. Farmers' associations tapped for the project can also start a seed business in their community. IRRI has documented models of community-based seed systems that have contributed to the quick dissemination of information about good-quality seeds and effective distribution channels. Training of farmers, extension workers, and development partners in the production, storage, packing, and distribution of seeds should be considered in succeeding rice intensification programs.

Developing infrastructure. Funding support for the construction or rehabilitation of irrigation facilities should be provided in areas that lack adequate irrigation water during the dry season as well as water for supplemental irrigation during water the wet season. The Muhuri Irrigation Project brought out management, operation, and maintenance concerns due to inadequate funding, poor irrigation water delivery (through an open earthen canal), and limited participation of farmer-beneficiaries, particularly in secondary- and tertiary-level water management, resulting in declining productivity. In many irrigation facilities, even if water is available, poor management leads to its inefficient use.

Linking farmers and farmers' groups to rice and grain value chains. Current business models for agriculture service provision must be examined, and viable models recommended. Areas needing policy and institutional support for strong farmer–market links should also be identified. Marketing services can help farmers and the rural community earn from their production surplus and achieve a higher income for the farm. Rural enterprises with a strong, evidence-based foundation programs such as technological packages are more likely to succeed in competitive markets, for both seed and grain distribution. Often, there is also a need to help farmers organize themselves into cooperatives or farmers' associations that can consolidate production for more efficient links to markets.

Reviewing government policies and priorities to align activities. This is done to establish the related policy recommendations that can help overcome some of the impediments to successful promotion and adoption of the recommended CSA. The following related issues were brought up during the policy dialogues in Bangladesh:

- **Water markets with flat rates for water use need to be reviewed.** The policy dialogue resulted in an important policy recommendation replacing the common practice of imposing a flat rate for water use, to ensure wider AWD adoption: more water, more charge; less water, less charge. Water is a critical

[8] L. Hassan. 2017. Seed Chain and Seed Availability of Climate-Smart Rice Varieties in Bangladesh. Unpublished.

resource in rice production. One policy issue that should be reviewed to create and increase awareness of AWD and other water-saving technologies among farmers pertains to the behavior of water markets in Bangladesh. Public sector irrigation is steadily declining because of the proliferation of privately owned and managed shallow tube wells, which now account for 85% of the total irrigated area. The clients in these water markets are farmers, who use the water for irrigation and are charged on the basis of a negotiated flat rate per unit area. Farmers therefore have no incentive to use less water and may not adopt water-saving technologies, particularly if adoption would mean changing their practices and labor requirements. In this case, the economic benefit resulting from the use of AWD accrues to water sellers and not to water buyers (the farmers). Unless water-pump owners are encouraged to charge less for water saved using AWD, this current system will pose a major hurdle for the dissemination of water-saving technologies such as AWD. The use of a prepaid smart card or automated system was part of the plan for sustainable operation and maintenance under the Muhuri Irrigation Project. Compared with flat-rate water pricing, this is a need-based irrigation scheme that ensures water-use efficiency, as only the needed amount of water is discharged, thus saving energy, water, and irrigation costs.

- **Water scheduling and water-sharing arrangements should be considered.** AWD dissemination efforts should also include innovative institutional arrangements in water markets, particularly for water sharing among farmers and between sellers and buyers to spread the benefits of reducing water use. Adoption becomes more likely once its economic benefits are made clearer to both parties. Wider adoption of this technology warrants a careful assessment (in any location or site) of the appropriateness of mechanized AWD, which is influenced by several factors including season, rainfall patterns, field elevation, and soil type. Location also affects the water requirement and timing on farms. Well-targeted AWD dissemination requires a properly defined physical domain. A key element of AWD promotion is flexible and demand-responsive AWD scheduling, especially for medium- to large-scale surface water or groundwater schemes, where farmers can participate in decision making. Alam[9] pointed out that AWD needs backing not only from farmers but, more importantly, from irrigation system administrators and managers, as well as from DAE extension providers, for proper implementation. Timely water delivery is critical in the AWD application, but, farmers often have no control over the irrigation scheme.

In Cambodia, the policy initiative is expected to focus on the financial support needed to scale up mechanized DSR, which will have to include access to affordable credit for farmers so they can pay for the additional costs of land preparation and machine rental, and ensure proper ownership of a seed drill in communes; improvements in the seed drill or the promotion of machinery (e.g., drum seeders)

[9] M. M. Alam. 2017. *Constraints in Adoption of Climate-Smart Water-Saving Technology—Alternate Wetting and Drying in Bangladesh.* Presentation at the Inception Meeting of the Climate-Smart Practices and Varieties for Intensive Rice-Based Systems in Bangladesh and Cambodia Project. Feni, Bangladesh. 20–21 August.

that can be used on wet soil; a study of opportunities for public–private partnership; viable business models and efficient machinery contracting; an enhanced profile for mechanized DSR through wider awareness of its benefits and successes; and improved extension services to farmers.

Scaling up mechanized direct seeded rice. The drum seeder helps in rice seeding in wet soil condition. (Photo by IRRI)

In Nepal, key stakeholders and farmers agree that there is a need to make farmers aware that DSR technology, coupled with good management practices, can increase yield per unit area while reducing production costs. Development programs aimed at diffusing technologies will not succeed as intended unless government prioritizes and invests in agriculture that will create an environment conducive to global climate change resilience and food security. A policy framework for specific programs should be launched for the purchase, hiring, and operation of farm machinery to enhance productivity. Nepal should improve production systems and productivity in the agriculture sector by adopting stress-tolerant climate-smart technologies and varieties and engaging poor people, the youth, and women farmers. Customizing DSR technology for rapid adoption is crucial. This technology should be cheap, handy, easily accessible, and farmer-friendly to make production more profitable. This tested solution and adaptable response mechanism can help the country overcome climate-related problems in agriculture. Research should be geared toward introducing and multiplying high-yielding, stress-tolerant varieties and conserving local germplasm. The Ministry of Agriculture and land management institutions should collaborate with agricultural universities for this purpose. The government should partner with the private sector and service providers to engage them in farm mechanization. The partners should also focus on improving business scale-up or the operation of cooperatives and agricultural groups through business planning, resource collaboration with different agencies, and strategic planning that takes feedback from stakeholders into consideration.

Forging Institutional Partnerships and Linking Up with National Programs

Sensitizing policy makers and obtaining policy support. This can be done through policy dialogues and visits to research sites. Potential allies in the government should be tapped as important partners in validating and disseminating packages of climate-smart technologies to bring the latest innovations to more farmers. Partnering with other government institutions is perhaps the shortest path to more productive delivery. This can lead to convergence in efforts and programs that allows sharing of resources and information and reduces the transaction costs of carrying out similar or related mandates, to reach a larger number of beneficiaries.

Mainstreaming climate-smart agriculture into national development programs. National and local programs should be aligned. Strong links among extension agents (government and nongovernment) and other development allies can allow multiplier effects to take place, thus beefing up technology delivery services at the least possible cost and within the shortest time possible.

Finding the right allies for technology delivery. DAE extension agents certainly have a crucial role, since the technologies are knowledge-intensive. But other local champions or partners can be tapped to provide the a big push for technology delivery. For instance, the success of many development efforts in different countries has been ascribed in large measure to the role of local champions from civil society, such as retired teachers, progressive farmer-leaders, extension agents from nongovernment organizations, and other private individuals who are committed to supporting rural transformation. As farmers are generally risk-averse, they would adopt technology only if assured of its economic benefits, as demonstrated by the experience of peers or trusted individuals in the farming community. Scaling up technologies requires creating an environment of co-ownership of solutions among stakeholders that can eventually lead to more equitable distribution of benefits from the development efforts.

Promoting public–private partnerships for a wider reach. Countries should propose methods for scaling up technologies and services through public–private partnerships. Dialogues and consultations in this area should begin to leverage these partnerships for farm mechanization and CSA dissemination. Defining the areas of partnership needs careful assessment of the strengths of each party that can support the promotion of CSA, such as provision of services, availability of machinery, expertise, resources, and systems for technology development and delivery, anchored on the principle of "give and take" in between the parties to ensure the attainment of common goals and objectives.

APPENDIX 1
Climate-Smart Varieties and Management Practices Introduced at the Project Sites in Bangladesh

The project conducted on-farm validation of the following water-saving technologies (Figure A1):

- **Alternate wetting and drying (AWD)**, a water-, labor-, and energy-saving technology suitable for both rainfed and water-short irrigated areas. AWD has the potential to ensure overall sustainability of rice cultivation systems when applied as a full package comprising laser-assisted land leveling; conservation tillage; crop establishment, harvesting, and processing using smart machines; integrated weed management; precision input delivery, especially of water and nutrients; rotations based on rice, pulses, beans, and vegetables; and suitable varieties. AWD can contribute to a 20%–30% reduction in water use, a 10%–20% reduction in greenhouse gas emissions, and a 10%–30% increase in economic returns.

The AWD system of irrigation is one of the simplest, most farmer-friendly, and most common water-saving techniques in practice to deal with the problem of water shortages in irrigated rice cultivation. It uses a single device (a water pipe) designed to observe the water level in rice fields for deciding when to irrigate (Figure A1). It consists of three key elements: (i) shallow flooding for the first 2 weeks after transplanting, to help the rice seedlings recover from transplanting shock and to suppress weeds; (ii) shallow ponding from heading to the end of flowering, to meet the high crop water requirement; and (iii) AWD during all other periods, with irrigation water applied at a depth of 2centimeters whenever the perched water table falls to about 15 centimeters below the soil surface.

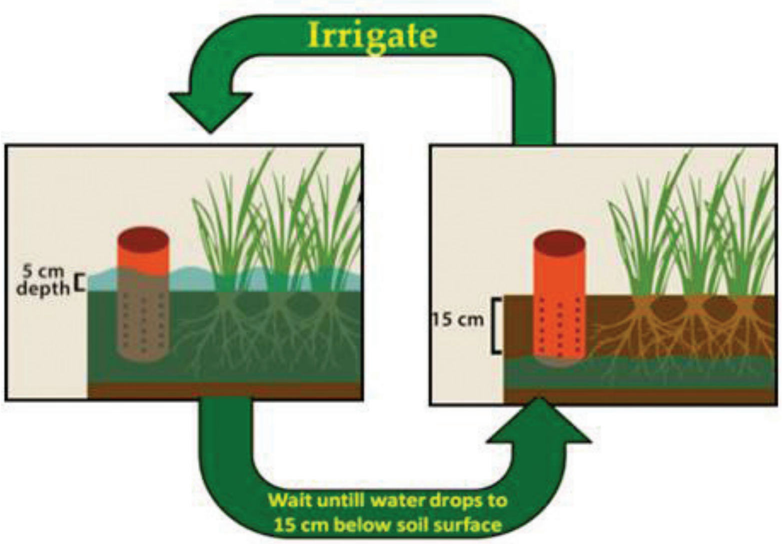
- **Rice intensification and diversification** in the project areas, using a new combination of *T. aman* rice–mustard–*boro* rice.

- **Rice varieties suitable for AWD conditions in Bangladesh (BRRI Dhan 28, BRRI Dhan 67, BRRI Dhan 69, BRRI Dhan 71, and BRRI Dhan 75)**. The project promoted BRRI Dhan 75 (115 days) for the *T. aman* crop and BRRI Dhan 28 for the *boro* season.

- **The cultivation of shorter-duration non-rice crops (such as lentil, mustard, mung bean, vegetables, and fruit crops) to fill the gap between rice-cropping periods and mature on residual paddy moisture.** The non-rice crop recommended under the project was BARI Sorisa 14 mustard. This variety lessens the degradation risk of continuous cereal cropping and provides more opportunities to increase food security as well as farmers' income.

- Climate-smart practices and varieties, along with best agronomic management practices were adopted during the whole crop-growing period. The techniques and climate-smart practices adopted were as follows: (i) use of good-quality seeds, (ii) preparation of community-based ideal seedbeds, (iii) proper uprooting of seedlings, (iv) transplanting of optimum-aged seedlings, (v) balanced fertilization according to Rice Crop Manager for agronomic and nutrient management, (vi) line transplanting, (vii) timely urea topdressing, (viii) mulching after urea topdressing, (ix) mechanical weeding, (x) application of supplementary irrigation for rainfed conditions, (xi) crop residue retention, and (xii) use of perching for insect control.

Figure A1: Testing Alternate Wetting and Drying Technology in Bangladesh



APPENDIX 2
Climate-Smart Varieties and Management Practices Introduced at the Project Sites in Nepal

The sites served as experimental units for testing and validating the following climate-smart agriculture technologies and practices: mechanized dry direct-seeded rice (DDSR), wet direct-seeded rice, rice varieties better suited to direct-seeded rice (DSR) technology, and best management practices and diversified rice-based cropping in Nepal. For the first season, the project evaluated the benefits of using a seed drill machine for lentil crops (mechanized lentil sowing). The Nepal Agricultural Research Council provided a boom sprayer and sprinkler irrigation, micro-irrigation support, and a tractor-mounted boom sprayer. The potential of DSR was demonstrated on the plots through the adoption of the entire package of DSR technology—best rice varieties, best crop management practices, balanced fertilizer dosage, effective weed management, water management, crop protection, and postharvest handling—to maximize the total returns per unit of farmland. This climate-smart intensification of rice production, adopting best management practices, was intended to replace labor-intensive production with the use of machinery or a combination of machinery and manual operations.

The DSR drill (for DDSR) was used on 25 hectares (ha) of demonstration plots, and the drum seeder (for wet DSR) on 15 ha, for comparison. The rice varieties Hardinath 3, Sukha Dhan 3, Ciherang-Sub1, and Shamba Mahsuli-Sub were mechanically sown on adjacent comparison plots. Other management practices used were pre-emergence and post-emergence herbicide application and machine weeding.

For the second season, demonstration trials and seed production were conducted. Lead farmers were involved in a large plot demonstration and seed production. For this demonstration, farmers adopted the complete package of DSR technology with best rice varieties, best crop management practices, a balanced dosage of fertilizers, effective weed management, water management, crop protection, and postharvest handling to maximize total returns per unit of farmland. Foundation seeds were used for promote seed production for the suitable rice varieties.

APPENDIX 3
Institutions That Can Be Involved in Seed Chains and Seed Availability in Bangladesh

The Stress-Tolerant Rice for Africa and South Asia project (funded by Bill & Melinda Gates Foundation) and other programs implemented on “seed multiplication and dissemination programs in Bangladesh indicated the possibility of partnerships with the following for program implementation: (footnote 1)

- **Research institutions.** The Bangladesh Rice Research Institute and the Bangladesh Institute of Nuclear Agriculture have produced breeder seeds.
- **Universities.** Universities such as the Bangladesh Agricultural University and the Patuakhali Science and Technology University can be tapped to produce foundation and certified seeds.
- **Bangladesh Agricultural Development Corporation.** The government agency can produce foundation seeds, certified seeds, and truthfully labeled seeds (TLSs) of both high-yielding and stress-tolerant varieties.
- **Department of Agricultural Extension.** This department produces and maintains its own seed production and storage in a farmer-level program and produces huge amounts of certified seeds and TLS; this includes the Farmer–to–Farmer Seed Exchange Program.
- **National seed companies.** They can produce foundation seeds, certified seeds, and TLSs.
- **Seed producer associations (local seed companies)**. They can produce foundation seeds and TLSs.
- **Nongovernment organizations.** They can be partners in technology demonstrations.
- **Farmers’ organizations and private seed companies.**

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Climate-Smart Practices for Intensive Rice-Based Systems in Bangladesh, Cambodia, and Nepal

This publication is an output of the partnership between Asian Development Bank and International Rice Research Institute to experiment climate-smart agricultural practices in Bangladesh, Cambodia, and Nepal. It captures the findings of these experiments and provides recommendations to promote climate-smart and resource-saving agriculture in these countries. The publication will help the policymakers to undertake evidence-based actions to address the challenges faced by the farmers in developing countries.

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