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A Buff-banded Rail (*Gallirallus philippensis*) stares down the photographer who has interrupted the bird's food foraging in IRRI's rice fields.

Active at any time of the day, especially during twilight. They are often seen in the early morning on bunds between rice fields looking for worms, mollusks, crustaceans, insects, fish, amphibians, reptiles, and birds' eggs. Like most waterbirds, the Buff-banded rails' preferred habitat includes dense reeds and vegetation or crops near a clean water source in which it can hide, nest, and breed. They tend to use the mature rice as cover.

Photo by Segfredo Serrano/Philippine Department of Agriculture

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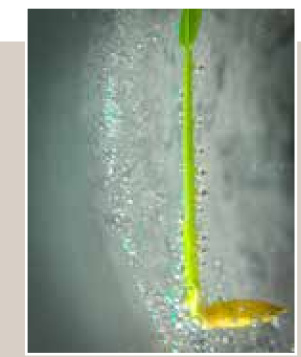

About the cover

A rice seedling in water symbolizing the crucial relationship between the world's most important crop and natural resource.

Photo by Isagani Serrano, IRRI

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International Rice Research Institute
DAPO Box 7777, Metro Manila, Philippines
Web: ricetoday.irri.org

Rice Today editorial
telephone: (+63-2) 580-5600 or (+63-2) 844-3351 to 53, ext 2725; fax: (+63-2) 580-5699 or (+63-2) 845-0606; email: info_ricetoday@irri.org

editor **Alaric Francis Santiaguel**
Africa editor **Savitri Mohapatra**
Latin America editor **Neil Palmer**
copy editors **Bill Hardy, Gene Hettel**
designer and production supervisor **Grant Leceta**
photo editor **Isagani Serrano**
printer **CGK formaprint**

The impossible balancing act in the face of water scarcity

Freshwater is the fuel that runs the engine of modern society. Without enough freshwater, life as we know it would grind to a halt. Freshwater is also the lifeblood of rice farming in Asia. It is a crucial part of the equation that produces the staple food that feeds both small towns and massive cities. Now, the relationship is under threat.

The amount of freshwater on Earth has remained fairly constant since before the time of the dinosaurs. But, the global population has experienced continuous growth since the end of the Great Famine and the Black Death in 1347-51. Freshwater—which is less than 1% of the total water on the planet—withdrawn from rivers, lakes, and dams, once used mainly for agriculture, is now being diverted to generate power for industry and cities, sparking a debate on who gets the water and how much of it.

Unfortunately, this tug-of-war will have no winners. Chronic or even sporadic water shortages could derail Asia's impressive economic growth of the past few decades. But, taking too much water away from rice farms could trigger widespread food shortages. Achieving a balance between water for society and water for rice production will be a key to how Asia's future unfolds.

Expansion of irrigated agriculture over the past 50 years and the recent urbanization and rapid economic growth of Southeast Asia have dramatically affected water use in the region. Cities demand increasing shares of available water for domestic consumption, industry, and even recreation, at the expense of irrigated agriculture. Asia's iconic rivers such as the Yangtze, the longest river in Asia, the Yellow River, and the Mekong are increasingly subject to major hydroelectric dam projects as countries scramble to meet their energy needs.

The diversion of river waters is potentially depriving downstream neighbors of water over the years. In some areas—with the flow of even major rivers dwindling to a trickle during drought years—surface water sources are bound to dry up eventually at current rates of use.

Although agriculture, and especially rice, remains the primary water user over much of Asia, competition is driving societies to confront a stark choice: shall existing water be used in the cities to power them or to feed them? This difficult choice of diverting water away from irrigation schemes into urban water systems is looming across Asia's most populated cities: Manila in the Philippines, Bandung in Indonesia, Bangkok and Chiang Mai in Thailand, and Hanoi in Vietnam.

Since the largest amount of irrigation water goes to rice cultivation in Asia, controlling how much water is used for growing rice is the way to ease the tensions between agricultural and urban/industrial water use. But, rice has tremendous political clout. Even though rice cannot express its sentiments through the ballot box, the huge rural populations that depend on rice cultivation for their livelihood (and those who "simply cannot live without it") can.

Rice cultivation occupies such an important part of a sense of social well-being within most Asian societies that any attempts to dramatically reduce it would be politically unwise, like removing the pin yourself from a grenade that's glued to your other hand. The political backlash could be swift and loud—and crippling.

For most rice-importing countries, the international rice market is simply not reliable enough to depend on for national food security. The jury is in: farmers need to grow more rice using less water.

When water becomes the raging enemy

Apart from the lack of it, water also directly affects food production and aggravates poverty in Asia's rural areas, where almost 60% of its population lives. Extreme monsoons, that bring forth raging floods, are just as challenging as water scarcity.

In August 2017, at least 401 million people were affected by massive floods that devastated South Asia after unusually heavy monsoon rains. About 2.4 million hectares of crops were lost. Only a month before, central China suffered the same fate. These floods put 137 million people in India, Bangladesh, and China at risk, according to a report by Ben Westcott and Steve George for CNN.

Floods are also becoming a major force of destruction in the Mekong Delta and many of Asia's coastal areas. Thailand was hit by floods in August, inundating 77 provinces, according to a Reuters' report. The floods affected 700,000 hectares of rice-growing farmland and decimated 160,000 hectares of rice crops. The following November, more than 30,000 people in Vietnam were evacuated to safer grounds when more than 40,000 hectares of crops, including rice fields, were damaged.

"In the next 30 years, it is projected that heavy rainfall events will be increasing ... in Asia, by about 20% for sure," said climate scientist Dewi Kirono at Australia's Commonwealth Scientific and Industrial Research Organisation who was quoted in the CNN report.

And now, the good news

It is no exaggeration to say that the economic miracle of Asia since the 1960s was enabled by tremendous advances in plant breeding and crop management, together with government policies and programs that supported the Green Revolution.

In the past 50 years, rice harvests in Asia more than doubled as farmers started planting new and improved rice varieties, using better crop management, along with the growing availability of irrigation.

Although past successes have been impressive, today's challenges facing scientists are greater than they were 50 years ago. Fortunately, available scientific tools and on-farm technologies are far more powerful than ever.

Rice researchers have identified genetic components from traditional rice varieties that make them tolerant of drought and flood. These genetic materials have been incorporated into new varieties that can produce significantly high grain yield even under environmentally stressful conditions. These varieties have been released in various countries and have improved the productivity of rice-growing areas regularly devastated by drought and floods. These varieties work best with management practices and technologies that promote sustainability as well as adaptability to climate change.

Some of the varieties, technologies, and research, which are already providing farmers some relief, are featured in this issue that focuses on water. ■

Why sustainable water management needs more than technologies

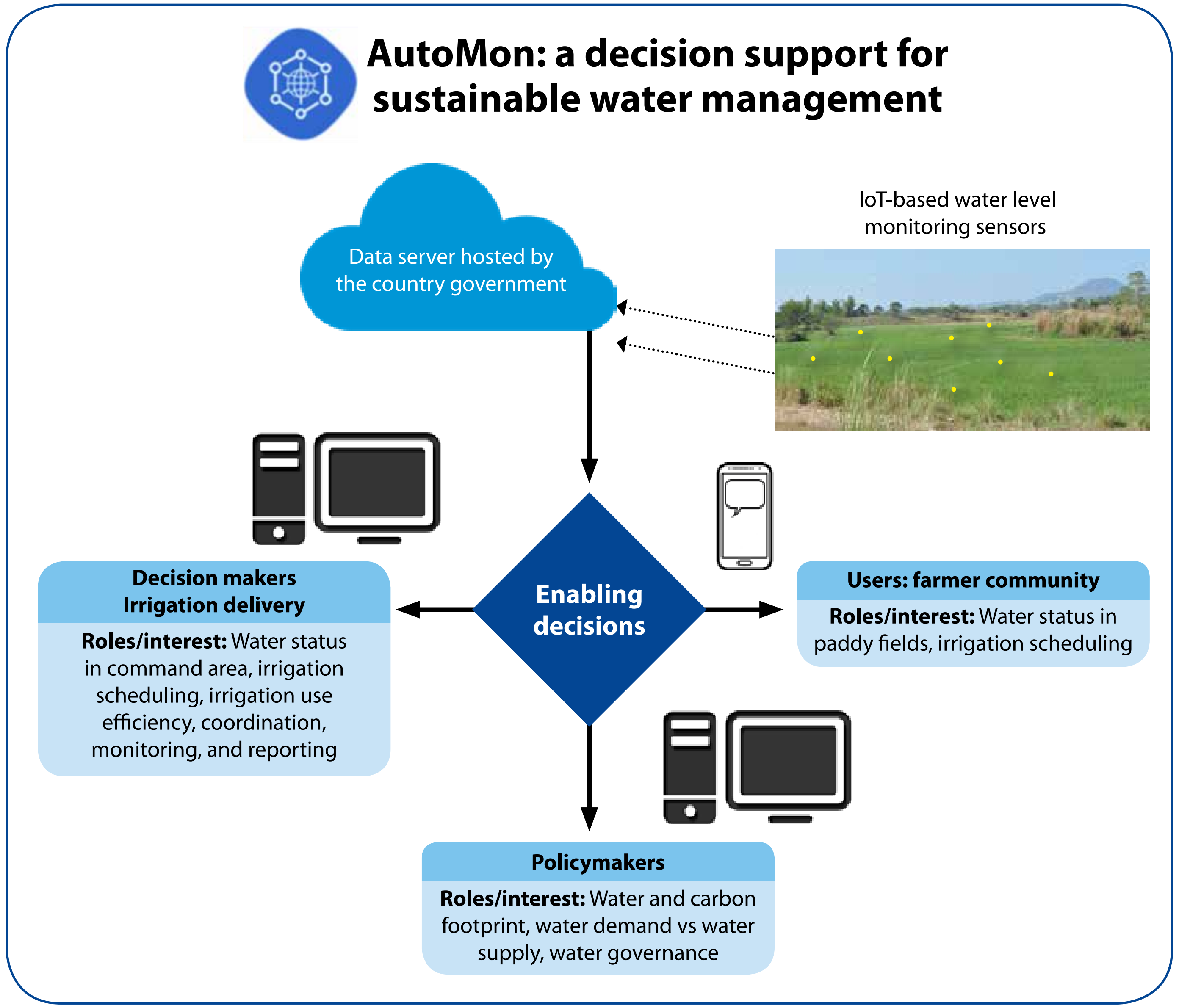
by Sudhir **Yadav**

A fast-growing population, expansion of irrigated agriculture, and rapid economic growth have dramatically affected freshwater use in Asia. Urban areas are now competing with irrigated agriculture by demanding an increasing share of the available water for domestic, industrial, and recreational uses. As a result, governments across the continent are diverting freshwater away from irrigation schemes in the countryside to water systems in their cities.

The sustainable use of freshwater in agriculture is a growing concern worldwide. More than 2.7 billion people must cope with less water than they need for at least one month every year. Globally, agriculture uses approximately 70% of available freshwater—and 35% of this is used for rice cultivation alone. With rice being a staple food for half of humanity, more than 3 billion people rely on this grain for their main source of livelihood. Therefore, enhancing rice production—and looking for ways to grow it with less water—will be essential to ensure food security in Asia, if not the world.

In addition to the socioeconomic pressures on the water-food security nexus in Asia, severe changes in climate are already directly affecting the region's irrigated rice production. Finding ways to use scarce water resources in agriculture more efficiently will help ensure food self-sufficiency and a sufficient water supply for use by both urban and rural areas. Worldwide, the challenge is enormous to produce almost 50% more food by 2030 and

Rice production is water-intensive and requires 2-3 times more water per hectare than other crops. It receives 34-43% of the world's irrigation water and 24-30% of the world's developed freshwater resources, according to the *Rice Almanac*.



to double food production by 2050. A "step change" is required in the ways we approach the water shortage challenge before we can chart a way forward with greater confidence to secure future harvests. The scope of the sustainable management of water resources in agriculture involves the responsibility of water managers and users to ensure that water resources are allocated efficiently and equitably, and used to achieve socially, environmentally, and economically beneficial outcomes.

Tremendous scope exists to increase both irrigation water productivity and rice production. Many options exist to greatly increase the quantity of rice grains produced per amount of irrigation water delivered to farmers' fields—by increasing yield and reducing irrigation input. There is great potential to close the yield gaps between current average yields and yields of the best farmers through the use of existing technologies (i.e., improved varieties and better management). A range of technologies is also available that reduce irrigation input to rice fields without reducing yield. Reducing irrigation input into individual fields can bring many benefits to farmers and consumers alike, such as enabling expansion of the area of irrigated rice during the dry season.

Many technologies can reduce water input in irrigation schemes. Examples include alternate wetting and drying (AWD), micro-irrigation, laser land leveling, avoidance of puddling, and short-duration, drought-tolerant rice varieties. However, their adoption has been very slow. It is easy to jump to the conclusion that this lethargy might be because of "free water" policies in Asia. But, in reality, many other factors come between technologies and the problems that they can solve. In the past, most efforts have considered water as a single-facet commodity, for example, irrigation use vs. farmers or irrigation vs. policies or irrigation savings vs. land scale. However, the concept of "sustainable water management" involves considering all processes and stakeholders involved in water management.

Gravity-fed/surface irrigation systems have the largest command area in Asia. Water delivery to rice farms involves a complex network of interactions among different stakeholders. The complexity of this system is not only in making decisions on "water quantity" diverted to different areas but also in "coordination" with different stakeholders. Local governments generally inform community-led irrigation associations when the water from the primary canal should be fed into lateral canals. The irrigation associations, in turn, decide when water from lateral canals will be released into an individual turnout (i.e., a contiguous area irrigated through one inlet). Each turnout contains multiple individual fields, all of which are irrigated through one inlet as the water flows from plot to plot.

The effectiveness of any water-saving technology is strongly linked to the timely action and decision-making capacity of the stakeholders. Water-use efficiency in many Asian countries is quite low because of many factors, including poor monitoring and coordination of infrastructure. The independent and manual approaches to monitoring and reporting result in knowledge gaps and lapses that hinder proper coordination among stakeholders. The manual approach to water management also results in large losses and significantly longer reaction times by decision makers, which create conflicts and tension among various sectors and communities. AWD is one such water management technique that can save irrigation water up to 30% without a yield penalty. Although AWD technology has been tested in many countries, its adoption has been relatively slow because of several challenges: (a) the water is managed by a farmers' association instead of by individual farmers, (b) the technology cannot be extrapolated to command areas, and (c) it is knowledge, labor, and time intensive.

The International Rice Research Institute (IRRI) with its national partners has developed a decision support tool called AutoMon (automated monitoring) for catalyzing the adoption of water-saving technologies through improved access to information, effective coordination among stakeholders, and transparency in water governance. The strategic use of space technologies and the Internet of Things (IoT) as a core component of the tool is facilitating improved monitoring and coordination among the stakeholders. The AutoMon tool will

- Allow effective and real-time monitoring of water status at multiple levels (from plot to river basin).
- Provide improved access to decision-enabling information for different stakeholders.
- Reduce transaction time and the cost of effective coordination among stakeholders.
- Enhance transparency in water governance.
- Create a real-time analytics platform for monitoring, evaluation, and learning.
- Establish an evidence repository to trigger policy change.

Real-time information and management advice on water status and demand are an important aspect of sustainable water use. However, a single-user tool might be helpful for technology introduction but not for actually finding solutions. It is therefore important to understand the potential stakeholders who need to be targeted for improving water-use efficiency. Linking the decision framework into an accessible multi-stakeholder interface can facilitate monitoring and evaluation at multi-scale.

Sustainable water management is critical to improving the spatial and temporal distribution of water and leading to increases in productivity and production (particularly in downstream regions) and ultimately contributing to food availability in Asia. A decision support tool such as AutoMon for monitoring and managing water at various levels can help countries to prioritize the areas that require this scarce resource, which will lead to large commercial and social gains in water-use efficiency aligned with United Nations Sustainable Development Goal 6. The tool can also assist stakeholders engaged in the water management chain in performing their responsibilities more effectively and in a timely manner while bringing in transparency, which is a key pillar of good water governance. ■

Dr. Yadav is a water scientist at IRRI.

UNDERSTANDING THE GRAIN YIELD LIMITATION AND INSTABILITY OF AEROBIC RICE

by Benoit **Clerget**

Do rice plants have a wild adaptive trait that is counterproductive to aerobic cropping systems?

In eastern Asia, the early farmers created a high-performing rice cropping system in which rice seedlings were grown in nurseries and then transplanted in paddy fields covered with shallow water during the entire cropping season.

In fact, the early farmers were mimicking the natural conditions of tropical swamps where this semi-aquatic species that produces highly valued grains originated. Because rice is a semi-aquatic plant, its seeds still need oxygen and cannot germinate in soil covered with a water layer, such as the conditions in a swamp after the first rainfall at the end of the dry season. Eventually, as monsoon rains quickly fill up the swamp, the rice plants continue to grow under water.

This transplanted-flooded cropping system was used for centuries and continues to be the cultivation method to obtain high grain yields. However, because of the increasing human population, it became necessary to grow rice twice or three times a year and expand rice-growing areas by using irrigation water from rivers or underground aquifers. Unfortunately, in many areas, water resources have become scarcer because of other uses or overexploitation. Thus, farmers must use much less water for their rice crop and are unable to maintain their fields under flooded conditions.

Yield reduction in aerobic crops

The lack of a permanent water layer has many negative consequences, particularly for weed control and availability of nutrients. However, even when these two factors are well managed, potential grain yield is often, but not always, lower than in crops grown in constantly flooded fields.

In aerobic cropping systems, where rice is grown like wheat or maize, the crop is regularly irrigated with reduced volumes of water to maintain the soil moisture close to saturation. At these levels, paddy soils are very muddy and contain a lot of extractable water—around one-third of their volume.

Nevertheless, rice plants grown in such aerobic conditions are shorter, flower earlier, and bear smaller panicles than continuously flooded plants, even when grown at a low plant density as in the transplanted crop. To compensate, aerobic crops are sown at higher plant densities and, at flowering time, the shoot biomass of the whole crop is recurrently similar in both environments. Thus, the roots of the more numerous small plants in the aerobic crop can obtain the same quantity of water and nitrogen from the soil and the same quantity of solar radiation from the atmosphere to fix the same quantity of carbon dioxide as the bigger plants in the flooded crop.

Why are plants grown in aerobic fields smaller? One evolutionary hypothesis is that the modern rice plant retains the adaptive response of its wild ancestors to inadequate rainy seasons marked by the presence of air in the soil during the vegetative phase. During such seasons, only the plants that shortened their life cycle and reduced their water consumption were able to produce offspring and maintain the species. Perhaps it is possible to switch off this undesirable reaction once its metabolic pathways have been understood.

In search of physiological processes

In addition to the smaller size and earlier flowering, our team at International Rice Research Institute (IRRI) found that aerobic plants developed slower than flooded plants so their leaves appeared more slowly.

In rice, the cells divide in a small apical bud at the upper end of the stem and new leaf primordia (small groups of dividing cells) emerge from the lateral part of the apical bud at a stable rhythm. Cells of the new leaf organize in lines and divide with an exponential kinetics during 3.5 stem apical beats. At this moment, the leaf division zone reaches its maximal number of cells and the more distal cells start elongating while divisions continue for the other cells. This maximal number of cells in the division zone determines the final length of the leaf blade. After four beats, the leaf tip of the new growing leaves emerges from the enclosing sheath of the previous leaf. This four-beat duration from initiation to leaf appearance is stable in rice.

Thus, in aerobic plants, cells in the apical bud divide more slowly and the apical beat is longer than in flooded plants, giving it more time for leaf cells to divide. However, the leaf blades are shorter because there is less and slower cell division in the leaves.

The goal is to find a molecule from the roots that has the property to slow down cell division in the shoot, discover how this molecule is produced in the roots in response to aerobic conditions, and, if feasible, switch off this mechanism. ■

The author would like to acknowledge Dr. Crisanta Bueno of IRRI and his staff and participating students during his appointment at the institute.

Dr. Clerget is a crop physiologist at the French Agricultural Research Centre for International Development (CIRAD)-BIOS. He was a seconded scientist at IRRI (2010-2016) where he led a crop physiology team.

Improving water and nutrient management for double cropping in Cambodia

by Anika **Molesworth**

Growing dry-season crops after rice on hard-setting soils can pose serious challenges to Cambodian farmers seeking to diversify and intensify with greater efficiency, profitability, and sustainability.

Fried frog legs and duck tongues are still sizzling on the hot plate plonked down in front of me. My Cambodian dinner acquaintances smile broadly. I sometimes question whether the serving of these local delicacies is an act of hospitality or the blunt end of a wry sense of humor testing the reaction of foreigners trying hard not to offend.

Cambodians love their food and love eating it with company. No one should eat alone, they say. It's not surprising they appreciate sitting down with friends, family, and workmates to multiple plates piled with steaming greens, succulent meats, and a hefty serving of rice, as the horrific past of hunger, community dislocation, and nationwide devastation lingers in the not-too-distant past (see *Revisiting the "Killing Fields" 30 years later* on pages 22-29 in *Rice Today*, Vol. 15, No. 1).

Rice culture and cultivation

The staple food of Cambodians is rice. Only a few kilometers out from the capital city of Phnom Penh are verdant rice paddies offering a tranquil reprieve from the city's hustle and bustle.

Rice-based farming systems have been the mainstay of rural livelihoods in Southeast Asia for centuries. However, trends suggest an increasing diversification and intensification[1] within these systems, which are opening up new opportunities for farmers as well as highlighting existing production constraints.

Puddling or wet cultivation is the traditional method of land preparation for establishing rice—a practice that destroys soil aggregates, breaks the capillary pores through which water enters,

A market in Phnom Penh. Although the focus of Cambodian agricultural production is still on rice, farmers are also expanding their production to include crops like maize, cassava, and vegetables to generate more incomes. (Photo by Anika Molesworth)

disperses clay particles, and lowers soil strength in the puddled layer.[2–4] Repeated puddling leads to the formation of a dense layer of soil or hardpan below the topsoil layer that helps retain water in flooded rice fields. The hardpan has high bulk density, which reduces water loss through drainage and allows the field to maintain standing water required in growing the rice crop.[5]

Going beyond rice

In continuous rice culture, the formation and maintenance of the compacted lower soil layer that reduces water infiltration can be considered an investment in infrastructure. In the rice–nonrice system, however, the destruction of surface soil structure and the development of the hardpan can impose serious liabilities on the establishment and performance of crops grown after rice.

In Cambodia, hard-setting soils are widespread and strongly influence crop production during the dry season as these tend to limit the retention, movement, and plant use of water and nutrients.[6] This is due to two contrasting unfavorable physical conditions at different water contents, namely, the complete breakdown of large, air-dry soil aggregates into microaggregates with sudden immersion in water (slaking)[7,8] and an extremely hard structureless mass formed during drying[9], with a positive correlation between hard-setting and bulk density.[10]

Irrigation or rainfall after sowing can cause the soil surface to collapse while the subsequent drying may harden the surface, preventing the seedlings from emerging[11] or impeding the root growth of established plants.[9]

Growing dry-season crops after rice on hard-setting soils can pose serious challenges for farmers in Cambodia. Further understanding how land formation techniques (leveling, grading, and raised-bed construction) for improved water and nutrient management and efficiencies affect soil structure and the behavior of nutrient and water dynamics is required to develop refined and integrated management practices and realize the potential of high-value non-rice crops.

Dry-season farm productivity

The Australian Centre for International Agricultural Research (ACIAR) project *Improving water and nutrient management to enable double cropping in the rice-growing lowlands of Lao PDR and Cambodia* is seeking to increase dry-season farm productivity through irrigation design, better use of residual soil moisture, and clever nutrient strategies. A multi-year maize trial conducted on a hard-setting lowland *Prateah Lang* soil with the Cambodian Agricultural Research and Development Institute (CARDI) is investigating soil-water-plant dynamics with irrigation frequency, volume, and application method on soils amended with agricultural residues (rice straw, cattle manure, and biochar).

Land leveling, grading for slope, and raised-bed construction are used to improve water and nutrient management and efficiencies. Leveling can assist in water application as field gradients can reduce waterlogging in poorly drained soil types.[12] Crops grown on beds and furrow irrigated may experience slow wetting through capillary action, thereby reducing soil aggregate disruption.[6,13] However, despite land formation to improve irrigation water application, movement, and drainage, these practices risk exacerbating inherent hard-setting tendencies where there has been significant loss of soil organic matter as a result of topsoil removal (resulting in the loss of more labile fractions, which is an indicator of soil productivity and health)[14] or significant disruption of the topsoil has taken place in the land-forming process.

The retention and incorporation of organic amendments in hard-setting soils can be an important factor when land-forming on these soil types. The nutrient- and water-holding capacity of soils can be increased by adding organic amendments,[15,16] thereby enhancing soil fertility and increasing crop productivity.[17,18] Crop residue mulch, livestock manure, and biochar have been found to suppress weeds,[15,19] elevate soil fertility,[20,21] increase crop nitrogen uptake,[22] lower soil temperature[23] and tensile strength,[24] induce occlusion,[25] reduce soil water evaporation,[15] enhance lateral and vertical soil water movement, and improve crop root movement for access to nutrients and water.[26]

There is no misconception of the challenges that face the agricultural industry in this part of the world as farmers look to new horizons in production, water management, and nutrient strategies. It is therefore important that research on improving water and nutrient management for double cropping in Southeast Asia be undertaken as farmers seek to diversify and intensify with greater resource-use efficiency, profitability, and sustainability.

After a long, hot day in the field, there is no greater reward than sitting down with my Khmer colleagues, reflecting on the good work achieved and discussing the obstacles still to be overcome. The food on the table might be new and exotic; however, in the company of an ever-effervescent group laughing loudly at lost translations and giving detailed explanations of how the food is grown, it is hard not to enjoy the tastes and experiences of Cambodia. ■

Ms. Molesworth is a PhD candidate and works at the Centre for Regional and Rural Futures investigating soil-water-crop dynamics in Australia and Cambodia.

References can be viewed online at https://goo.gl/kyq2MK

Grown for thousands of years in Cambodia, rice is very much a part of its culture as the Robam Preah Reach Trop or the Khmer classical dance. Today, farmers are finding new opportunities with the diversification and intensification of the county's rice-based system. (Photo by Anika Molesworth)

RESEARCH TO IMPROVE WATER-USE EFFICIENCY IN RICE

by James **Quilty**, Arvind **Kumar**, Crisanta **Bueno**, and Sudhir **Yadav**

From its establishment, the International Rice Research Institute (IRRI) has made tremendous efforts to ensure that national institutes across many countries have access to the improved technologies developed at its Zeigler Experiment Station (ZES). IRRI was established before climate change and competition for water resources became widely accepted as significant risks to agricultural production. Therefore, the initial focus of water-use efficiency research at IRRI was on rainfed rice production systems.

Alternate wetting and drying

However, today, one of the most widely recognized water-saving technologies developed and disseminated by IRRI, in collaboration with many partner organizations, is alternate wetting and drying (AWD). This is a simple but effective irrigation scheduling technique that reduces both the water inputs in rice production and greenhouse gas emissions coming from rice fields.

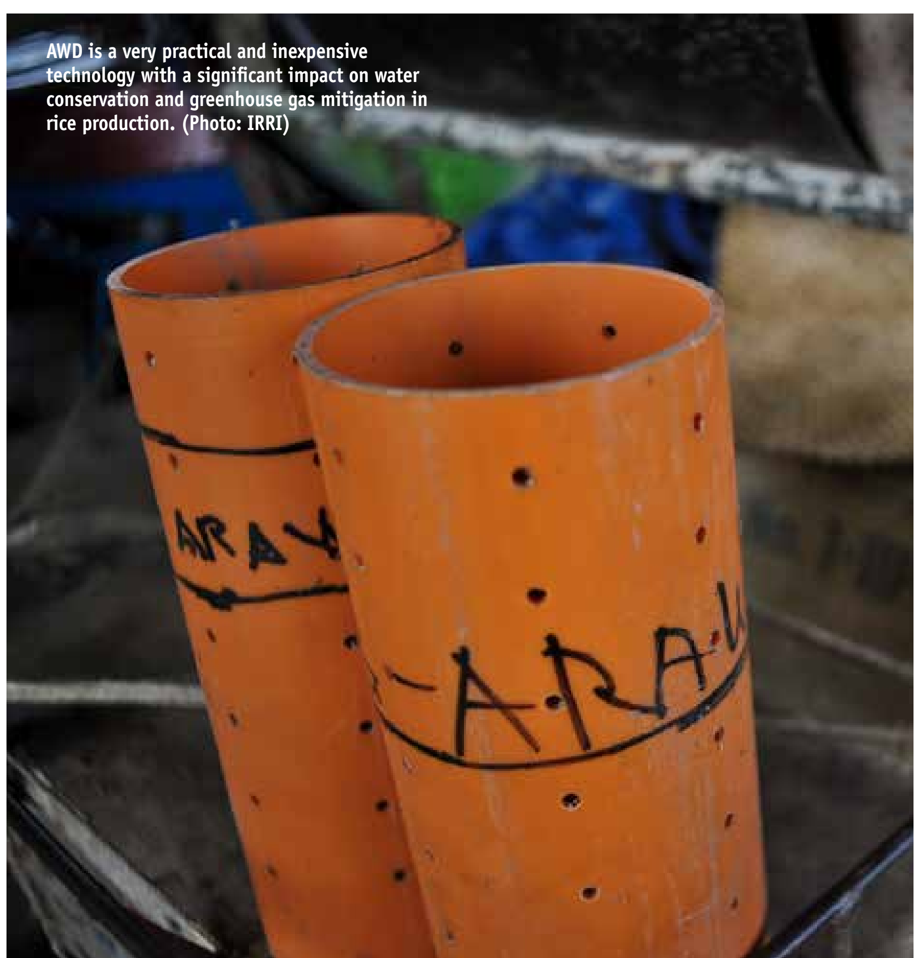
AWD as a water-saving technology combined with improved varieties has been disseminated on a large scale in Bangladesh through collaboration with the Bangladesh Rice Research Institute (BRRI) and with support from donors, including the Asian Development Bank.

This strategy can achieve water savings of 20–25% and can reduce methane emissions by as much as 50%. The water saved through the use of AWD and modern varieties has enabled farmers to plant a third nonrice crop in between two rice crops, thereby increasing the intensification of the rice-based system and the farmers' income.

Thousands of farmers in Bangladesh have been trained on the proper use of AWD and associated mechanized agricultural operations. Efforts have been made through policy dialogues with authorities of the different organizations to develop a mechanism to provide benefits of water saving to farmers, thereby encouraging AWD adoption by farmers.

The research behind AWD accelerated rapidly at the beginning of the 21st century, but IRRI continues to make significant efforts to improve the water-use efficiency of rice production beyond AWD. In irrigated lowland rice agro-ecosystems, timely and accurate data on the availability and distribution of water resources within irrigation networks and rice fields can help improve the use of irrigation water.

The water science team at IRRI is undertaking research at the ZES with the aim of developing innovative, affordable, and scalable digital technologies for irrigated rice production. This research aims to provide valuable information on water resources to all governance levels of water management within catchments and irrigation networks. To achieve these aims, IRRI has developed a decision tool called AutoMon (Automatic Monitoring). Along with robust data processing and a user-friendly interface, the tool consists of an affordable and robust device that can wirelessly transmit water depth data from within rice fields, and flow and volume data from within irrigation networks.


AWD is a very practical and inexpensive technology with a significant impact on water conservation and greenhouse gas mitigation in rice production. (Photo: IRRI)

The tool has been customized for water governance in the Philippines as AutoMon^{PH} and is an integral part of a larger project funded by the Philippine government called WateRice. The outcomes of this research will be improved irrigation management at field, farm, and catchment scales; improved distribution of water resources across irrigation systems; and more equitable distribution of water.

Direct seeding of rice

Although innovative solutions are being developed to improve the efficiency of water use in irrigated systems, IRRI is also creating opportunities to improve the resilience and productivity of rainfed rice production systems. Increasing water productivity in drought-prone rainfed systems is crucial to food security and to rice farming communities in many regions of South and Southeast Asia, and Africa. The work of IRRI to improve the productivity of rainfed and drought-prone agro-ecosystems is ensuring that the synergies between the genetic diversity in rice and agronomic practices are optimized.

The practice of direct seeding of rice (DSR) into dry soil reduces the need for water in land preparation and allows farmers to plant rice crops before the rains of the wet season arrive. This means that rainfall is used in supporting crop growth rather than in land preparation activities. Planting earlier can also help rice avoid drought that generally occurs late in the wet season in rainfed systems. With this in mind, efforts within the breeding program at IRRI targeting rainfed environments use DSR as the crop establishment method in field trials at the ZES. Embedding this practice in the breeding program helps ensure that both genetics and agronomy work together effectively to achieve the best outcome for farmers.


DSR reduces the need for water and allows farmers to plant rice before the onset of the wet season. (Photo: IRRI)

Mechanized DSR, which can reduce water and labor inputs in rice production, requires the introduction of innovative traits in rice varieties to increase their adaptation to DSR cultivation with minimum water requirements. Developing appropriate traits in modern varieties, including the improved ability of rice to germinate from deeper soil depths with conserved moisture, early vigor, extensive root systems for efficient nutrient uptake under fluctuating soil conditions, lodging resistance, and resistance to nematodes, will improve the capacity of rice to grow under limited water conditions.

IRRI and its partners continue to develop and optimize DSR and other effective water-saving technologies that can improve the livelihoods of rice farmers in regions threatened by water shortages. (Photo: IRRI)

Through research conducted at the ZES, quantitative trait loci (QTLs) linking or containing genes that control certain desirable traits have been identified. These include early uniform emergence, early vigor, higher nutrient uptake under soil fluctuations, and lodging and nematode resistance. The marker-assisted breeding experiments conducted at the ZES have successfully introduced many of these traits into elite breeding lines to increase rice adaptation to mechanized DSR.

The sowing depth for DSR can make a significant difference in the performance of a rice crop. In DSR systems, the targeted sowing depth is generally less than 3 cm. This depth aims to ensure that the crop emerges uniformly. Planting rice deeper than 3 cm often causes poor emergence rates and poor uniformity. However, particularly in rainfed systems, the wetting-and-drying cycle of the soil at 3-cm depth can be rapid and extreme. This can make the germinating seed vulnerable to desiccation as the surface layer of the soil dries out after rainfall. Additionally, achieving good rice germination at shallow soil depth requires moisture content at the soil surface that is also sufficient for weed seed germination. Consequently, both rice and weed seeds germinate together, creating an environment in which the emerging rice is immediately competing with weeds for space, moisture, nutrients, and light.

Through the efforts of the rice breeding program at IRRI, sowing depths in DSR systems of 5 cm or more will be an improved option for farmers in the future. Rice varieties capable of emerging from sowing depths as deep as 10 cm are being developed at the ZES as part of the breeding program that targets rainfed environments. Sowing rice at depths of 5 cm or more into a region of the soil profile in which wetting-and-drying cycles are slower than in the top 3 cm helps protect the germinating rice seed from desiccation.

Sowing rice seed into soil moisture below a dry topsoil layer can also provide rice seed with a competitive head start over weeds trying to germinate in the dry soil above. To complement improved seedling vigor, and to ensure system optimization, field experiments on nutrient management and sowing depth, and research on weed control in DSR, are ongoing at the ZES.

In early February 2018, IRRI and its partners launched the Direct-Seeded Rice Consortium that will explore opportunities to maximize the efficiency of DSR, minimize water use, optimize productivity, and ensure the sustainability of rice production systems. At the ZES, the efforts of IRRI and its partners will continue to develop and optimize DSR and other effective water-saving technologies, and will create pathways to adoption and impact that can improve the livelihoods of rice farmers and their communities, particularly in rice-growing regions threatened by water shortages. ■

Dr. Quilty is the head of the ZES, Dr. Kumar leads the rainfed lowland South Asia plant breeding group, Dr. Bueno is an expert in ecophysiology, and Dr. Yadav is a water scientist at IRRI.

ERRATUM

On page 25 of *Rice Today* Vol. 16, No. 4, an article was incorrectly titled *A cleaner strategy for sustainable Bangladeshi basmati rice.* Although it contained facts about the use of chemical pesticides in Bangladesh, the article was about Pakistan's basmati rice production and the efforts to reduce the use of pesticides. We apologize for the oversight.

In Memoriam

JOHN MICHAEL SCHILLER

(1945-2017)

by Gene **Hettel**

John Schiller, 72, passed away in Brisbane, Australia on 8 December. For the International Rice Research Institute (IRRI), he was the team leader and research programmer of the Lao-IRRI Project from 1990-2001. He had spent 30 years of his life working in Southeast Asia, primarily in Thailand, Cambodia, and Laos.

Dr. Schiller was passionately committed to working with the people of Laos. As the leader of the Lao-IRRI Project, he was assisted by other IRRI scientists in the fields of agronomy, entomology, nutrient management, and genetic resources, but he also worked to develop the capabilities of Lao scientists and technicians for conducting research. He faced a prodigious task to build a national rice research capability in a country where nearly all of the research institutions had disbanded as a result of political changes in the region.

"Ultimately, the basis for successful international development programs is not external funding or expertise, but the political will of the countries to make the programs work," Dr. Schiller said in an interview. "The Lao-IRRI Project, supported by the Swiss Agency for Development and Cooperation (SDC), was an excellent example of institutional development and cooperation. The successful building of a strong research and extension system gave Laos a vital tool for feeding its people."

By 1997-98, much in Laos had changed; the Lao national rice research program was employing 130 people and had been extended to include all 16 provinces of the country and a network of seven research stations. During the

decade of the Lao-IRRI Project, Laos dramatically changed the way in which its farmers grew rice. An expansion in the country's irrigated area allowed it to become self-sufficient in rice production by 2000.

Also during his time in Laos, Dr. Schiller assisted with an SDC-funded biodiversity project. "Germplasm collection activities in the country were absolutely phenomenal," he said. "From 1995 to 2000, IRRI germplasm collectors and Lao colleagues gathered nearly 14,000 samples of cultivated indigenous rice varieties throughout the country. Unlike many rice germplasm collections, the results of these efforts were immediately used in the country's rice improvement program."

To wrap up his time in Laos, Dr. Schiller was the lead editor of a 2006 IRRI-ACIAR book, *Rice in Laos*, which documents the long association of Laos and its people with rice in historical, cultural, and agricultural contexts. *Rice: the fabric of life in Laos* is a 2002 IRRI-SDC publication that documents the achievements of the Lao-IRRI partnership during Dr. Schiller's tenure.

After departing IRRI in 2001, Dr. Schiller returned to Australia to assist the Australian Center for International Agricultural Research (ACIAR) with its program of research grants, which were made available to persons in research institutions, universities, and NGOs to train agricultural scientists in the developing world. He was also involved in six Crawford Fund training programs in Laos and Cambodia.

His lifelong commitment to building research capacity in Cambodia and Laos led him to conceptualizing and driving programs of research capacity building through the Cambodian Agricultural Research Fund and the Lao Agricultural Research Fund, which together have provided research funding and training opportunities for hundreds of young researchers over the past decade. He also worked with ACIAR to drive the publication of a Lao Agricultural Dictionary, a vital resource for new researchers. He was working on a similar dictionary for Cambodia at the time of his death.

In 2012, the Crawford Fund recognized Dr. Schiller's tremendous contribution to agricultural R&D by awarding him with the Crawford Fund Medal. Later, The Crawford Fund released a brief interview with him, in which he discussed his work and passion for Asia (see *https://youtu.be/jmY18df3B4g*).

Most recently, Dr. Schiller was as an honorary senior fellow in the Faculty of Science, School of Agriculture and Food Sciences at the University of Queensland, St. Lucia, Australia. ■

Mr. Hettel is a senior consulting editor and content specialist at IRRI.

From Warige to WeRise: better water management is coming to rainfed rice areas

by Keiichi **Hayashi**

Sukarni, a woman farmer from Pati District, Central Java, plays an active role in rainfed rice farming. "We look for signs from nature to determine when it's time to sow," she said. "Rain is our primary source of water for rice production. Some people have wells but these could dry up during the dry season."

Sukarni says transplanting and weeding are the most backbreaking chores for women farmers like her. Their chores become even more difficult with the lack of rain. "It is harder to pull out the seedlings and weeds when there is no water," she said.

WeRise could definitely improve her plight and those of other Indonesian farmers in rainfed rice-producing areas. (Photo by Keiichi Hayashi, JIRCAS/IRRI).

Central Lombok is one of the districts in West Nusa Tenggara, Indonesia, where rainfed rice is the dominant system of rice production. Farmers in Segala Anyar Village grow rice relying solely on rainfall as their source of water.

"On a particular sunny day during the dry season, we stand under the sun and look at our shade to foresee when the rain comes and we can start rice planting," one experienced farmer said.

This is the local wisdom called "Warige" practiced by the Sasak people. It is an ancient calendar that combines traditional Sasak astrology with Islamic and lunar calendars. Despite a rainy season that spans more than five months, farmers in this village grow rice only once a year because of severe drought at the beginning of past seasons as the weather has become more unpredictable than the earlier times when Warige was practiced.

Rice is not only food but is also a symbol of wealth in Sasak society. Working hard in the rice fields is the way to gain prosperity for families; hence, farmers are eager to grow rice. However, rice production in Segala Anyar is subsistence and farmers have to grow other crops such as mungbean after rice to surpass the subsistence.

Working hard for less

Serdang Village in Deli Serdang District is another rainfed area located in North Sumatera, a province on the northern tip of Sumatera Island. Unlike the farmers in Segala Anyar, the farmers in this village have shallow tube wells in their fields for supplementary irrigation during crop seasons. Despite the extra cost for fuel to operate water pumps, farmers can avoid drought stress during critical crop stages and aim for higher yield.

A researcher from AIAT North Sumatera interviews a rainfed rice farmer in Serdang Village (Photo by Iris Bugayong, IRRI).

However, a study found that they use more than enough water to obtain high rice production not only in the dry season but also during the rainy season. Many farmers take out loans through personal connections to pay for their production cost and what they earn from their harvest is only enough to cover what they paid. Eventually, they don't have many savings left for their household needs.

The poverty rate is comparatively higher in Central Lombok and Deli Serdang than in other areas. Rainfed rice farmers in both districts live on less than USD 1.90 a day. Although rice farming is laborious and rice farmers work very hard for their family, their lives remain subsistence because of a vicious cycle.

Modern-day Warige and more

WeRise, a weather-rice-nutrient integrated decision support system for rainfed rice areas, is an online ICT tool developed by the International Rice Research Institute (IRRI)-Japan Collaborative Research Project (IJCRP) with funding from the Ministry of Agriculture, Forestry and Fisheries of Japan. This system uses a seasonal-weather forecast that provides farmers with crucial weather information such as the start and end of the rainy season and rainfall distribution during the crop growing season. It also advises farmers when to sow and transplant, what variety is appropriate to use, and how to apply fertilizer efficiently.

It is similar to a free and friendly consultant that helps rainfed rice farmers to be strategic for better rice production and allows them to anticipate severe weather conditions and avoid risks during the cropping season. Through *WeRise*, rainfed rice farmers can see changes for the better by transforming the vicious cycle to a virtuous cycle. With better decisions that rice farmers can make at the beginning of the cropping season, the more improvements they can expect even in rainfed conditions.

In its current phase, the IJCRP is targeting the main rainfed rice areas in Sumatera, Java, and other areas of Indonesia. On-farm field validations are being conducted to demonstrate the strength of *WeRise*. The IJCRP is also collaborating with various stakeholders to accelerate the dissemination and adoption of the technology.

Changing outcomes and attitudes

WeRise can help farmers in Segala Anyar grow a second rice crop by providing the optimum sowing timing and using rainfall water more productively. *WeRise* can also help farmers in Serdang reduce the amount of water from supplementary irrigation during the rainy season by avoiding weather extremes, especially during panicle initiation and flowering stages.

WeRise was introduced to some rainfed rice farmers in Segala Anyar and Serdang as part of the baseline surveys and focus group discussions conducted by the IJCRP. "Can we try the predictions next cropping season?" was the most common request made during the orientations.

As with most new technologies, *WeRise* was met with some apprehension. A majority of the participating farmers in Segala Anyar said they would need more socialization and training on the use of this tool while most participating farmers in Serdang said they would need to see proof of its accuracy and tangible benefits. However, it was encouraging to see the farmers who were eager to try *WeRise*.

Rainfed fields are commonly described as an unfavorable environment because farmers rely on unpredictable weather for their water supply. With *WeRise*, people will say, "In rainfed areas, farmers have free water from the rain, their rice crop grows healthier, and their lives are better." ■

Dr. Hayashi is a soil scientist seconded from the Japan International Research Center for Agricultural Sciences and the coordinator of the IJCRP on Climate Change Adaptation through Development of a Decision-Support tool to guide Rainfed Rice production.

Officers of a farmers' association participate in a Focus Group Discussion in Serdang Village after attending an orientation on *WeRise* (Photo by Iris Bugayong, IRRI).

MENDING ASIA'S BROKEN RICE BOWLS

by Douglas J. **Merrey** and Nathan C. **Russell**

A decade of research demonstrates that "citizen science" has a major role to play in curbing ecosystem threats to the Ganges and Mekong River deltas.

Feeding fish in an irrigation-drainage canal in Bangladesh. (Photo: WLE)

Rich in natural resources, including fertile land, abundant water, and a wealth of biodiversity, coastal deltas across the tropics serve many nations as "breadbaskets" or "rice bowls." Such is the case for Asia's Ganges and Mekong River deltas, two of the world's largest. Providing livelihoods for rural people, they also produce nutritious food (rice, fruit, fish, and shrimp) for hundreds of millions of consumers.

Deltas under pressure

Yet, both deltas face a wide array of threats—from storm surges to water pollution. Like other tropical deltas, the Ganges and Mekong are particularly vulnerable to these hazards because of high population density, entrenched poverty, and heavy dependence on natural resources for livelihoods. Arguably, these deltas have neared a tipping point, beyond which damage to key ecological services will become irreparable, fraying the fabric of rural life and adding momentum to already high levels of outmigration.

The growing pressures have resulted to a large extent from human activities. So, in theory, it should be possible to curb or reverse the threats through concerted action. This is the thinking that prompted CGIAR researchers to embark over a decade ago on a search for solutions in partnership with national research institutes and nongovernment organizations in the Ganges and Mekong deltas. Their collaboration gave rise to efforts that today form part of the CGIAR Research Program on Water, Land and Ecosystems (WLE), which is led by the International Water Management Institute (IWMI).

A key conclusion of WLE research is that "citizen science" can be highly effective for testing and implementing management solutions that markedly improve ecosystem services in these deltas. This approach has proved especially useful for creating new market opportunities that appeal to young women and men. It works best when forming part of a wider effort to strengthen local resource management institutions.

Engineering is not enough

Since the 1960s, governments have tried to reduce the uncertainty surrounding agriculture in the Ganges and Mekong by investing heavily in infrastructure. This included polders in Bangladesh (a Dutch innovation involving the enclosure of low-lying areas with earthen embankments) to protect against flooding as well as better roads and domestic water supplies.

In Vietnam, drainage projects and rehabilitation of irrigation systems, combined with policy innovations and increased fertilizer use, enabled many farmers to grow three rice crops per year—a practice that is now becoming ecologically unsustainable, however. The construction of 139 polders in Bangladesh's coastal zone, in contrast, yielded less striking results. With flooding still a constant threat, agricultural production is far lower there than elsewhere in the country, partly because farmers grow tall traditional rice varieties in systems that also include the production of vegetables, shrimp, and fish in different combinations of fresh and brackish water.

In both countries, sustaining more intensive production will become increasingly difficult as climate change ramps up the pressure on the deltas' complex and fragile ecosystems. Droughts and floods, for example, have already become more common and severe. In many cases, water infrastructure no longer gives adequate protection against problems such as rising sea levels and salinization of agricultural lands.

The main reason is that dam construction upstream has altered water flows and sedimentation, an effect amplified by the Bangladesh polders themselves, which are often poorly maintained and managed. One key indicator of the resulting environmental damage in both deltas is a sharp decline in fish catches, which robs the poorest households of their main protein source.

In response, the infrastructure in place urgently requires renewal. But, there is mounting evidence that engineering solutions alone will not stabilize delta ecosystems. Changes in agricultural production systems offer a more viable development pathway. But, how to bring about such changes? Although the solutions vary between Bangladesh and Vietnam, both contain a strong dose of citizen science.

Rural people power

WLE research in Vietnam has centered on the use of a participatory research method, called *Thai Baan*. Its chief distinguishing feature is that the people whose livelihoods depend on natural resources take responsibility for building knowledge about their role in managing these resources. Local officials should preferably take part as well to ensure their buy-in for resulting innovations. Led by the Center for Water Resources Conservation and Development (WARECOD), researchers combined the method with another innovation called Photovoice, in which rural people, especially women, are trained to use photography and storytelling. This helps them spread research findings more widely.

The combination of techniques has given positive results, as farmers have learned how to adapt their production systems to problems such as saltwater intrusion. For this purpose, they grow rice when fresh water flows into local channels and then switch to shrimp farming when seawater arrives. Preliminary results suggest that the approach has potential for wider application in the Mekong Delta, offering farmers greater freedom of choice in adapting their systems.

In Bangladesh, where research was led by the International Rice Research Institute, the key to success proved to be encouraging community management of irrigation and drainage canals, which permits crop diversification in the coastal zone polders. This included a shift to early-maturing, high-yielding rice varieties, which required improvements in drainage during the rainy season. Community water management units played a key role in bringing about the necessary changes.

After harvesting rice, farmers can grow high-value crops such as sunflower during the dry season. Diversification gave rise to new business opportunities for women and young people, such as homestead production of sunflower oil and the establishment of rice mat nurseries. Even landless people captured a share of the benefits through collective management of fish farming on rice land. These are encouraging steps in the right direction. Even so, much further work is needed to overcome deep-seated barriers to gender equality and social inclusiveness in designing improvements and putting them to work.

A decade of research in the Ganges and Mekong deltas has produced promising results, though still on a pilot scale. The challenge now is to spread the use of citizen science through increased collaboration between investors and governments. Upgrading and better maintenance of engineered structures will continue to be important. But, their success depends on the active involvement of rural communities through local water management organizations that are up to the task. ■

Dr. Merrey is a consultant with WLE and Mr. Russell is IWMI's senior manager – Communications and Knowledge Management.

Fishing in a Mekong Delta rice field in Vietnam. (Photo: WARECOD)

water

Differences in precipitation

Globally, the annual precipitation on land is about **814 mm (110,000 km^3)**

56% is evapotranspired by forests and other natural landscapes

3% by rainfed agriculture

39% are the worldwide theoretically available annual renewable freshwater resources for human uses and the environment

=16,000 L/person/day (2014)

Middle East region is among the driest regions in the world with the Arabian Peninsula subregion receiving only **85 mm/year**

Countries with lowest & highest precipitation

Country	Precipitation	Amount of enewable freshwater resources:
Egypt	51 mm/year	1,900 L/person/day (2013) due to Nile River
Libya	56 mm/year	300 L/person/day
Saudi Arabia	59 mm/year	230 L/person/day
Costa Rica	2,926 mm/year	
São Tomé and Principe	3,200 mm/year	
Solomon Islands	3,028 mm/year	
Papua New Guinea	3,142 mm/year	

SW monsoon — **Jun - Sep**

For most parts of **India** the rainfall occurs between June and September, accounting for **70-95% of the annual rainfall.**

NE monsoon — **Oct - Nov**

In the southern coastal areas near the east coast much of the rainfall occurs during October and November.

Renewable freshwater resources

Depending on diet and lifestyle, about **2,000 to 5,000 liters of water** are said to be used to produce a person's daily food and meet the daily drinking water and sanitation requirements

So, theoretically there is more than enough water available worldwide

However, freshwater is very unevenly distributed and a large part of it is not easily accessible.

Asia is the continent with the lowest volume of renewable freshwater resources per person: **7,550 L/day**

China: **5,500 L/day**

India: **4,200 L/day**

In the Northern Africa and the Arabian Peninsula regions renewable freshwater resources are only 750 and 230 L/person/day respectively.

INFOGRAPHICS BY MARIA ANGELA PEÑAFIEL

Source: AQUASTAT-FAO

by Amelia **Henry**

How rice plants "manage" water under drought

Because of low rainfall and lack of irrigation infrastructure, water management is often not an option for rainfed lowland rice farmers. But, thanks to the latest rice breeding research, recently developed varieties that produce higher yield under drought have their own built-in water management strategy. These plants can capture and use water more effectively when it is limited. By planting these drought-tolerant varieties, rainfed rice farmers can take advantage of the limited amounts of water in their fields that otherwise would not be accessible if drought-susceptible varieties were grown.

Interestingly, each drought-tolerant variety appears to have its own unique water management strategy composed of multiple traits. Many of those traits are expressed by the plant only when it is stressed and not when it is growing under favorable (well-watered) conditions. By selecting for yield under drought, the breeders who developed these varieties were, in fact, also selecting for the optimum combinations of these various traits.

Sometimes, one drought-tolerant variety can show the opposite response for a trait compared with another drought-tolerant variety depending on what other traits are expressed in that variety. Why would a plant's strategy for having higher yield under drought be so complicated? This is probably because drought stress itself is complicated. Drought can occur at any growth stage, it can be intermittent with some rain in between, or it can develop progressively. And, it can range from mild to severe.

Rainfed rice farmers cannot predict what kind of stress conditions might occur in a season—and neither can rice plants. Therefore, the plants that can respond to the stress in a variety of ways are probably those that are most resilient to unpredictable levels of stress.

Several drought-tolerant rice varieties have been released over the past decade and more promising genotypes are in the pipeline for testing and release as varieties. These varieties were selected for their grain yield under drought, but we have also been tracking their drought-response traits along the way.

Based on our work at the International Rice Research Institute (IRRI), the diagram (on pages 23-24) summarizes some of the unique strategies of different drought-tolerant varieties. These varieties can help manage the limited available water in rainfed systems—even when farmers cannot. ■

Dr. Henry leads the Drought Physiology Group at IRRI.

Harvest index

Sahbhagi dhan[a] is a drought-tolerant variety that is able to continue transporting resources to the developing grain to maintain a high grain to biomass ratio under drought (harvest index).[3]

Timing of flowering

Flowering relatively early in the season can help a plant set seed before the soil dries too much. This strategy is observed in many drought-tolerant genotypes.[1,2,3,5] Other varieties are able to maintain a flowering time similar to that in well-watered conditions although drought typically delays flowering in rice.[4,8]

Reduced transpiration

Some genotypes can save water by transpiring less. This has been observed especially in upland varieties.[1,2]

Increased transpiration

Other varieties such as IR64-drought[b] can continue to transpire even when the soil becomes dry.[4] This is often related to increased root growth and is observed under lowland conditions.

Fewer shallow roots

Rice typically has a tremendous number of roots near the soil surface in flooded paddies, but some genotypes reduce root growth in shallow soil where water is less available during drought stress.[5]

Water transport

Some traditional drought- tolerant varieties tend to restrict water transport at certain times of the day,[6,7] whereas other genotypes show higher water transport under drought.[4]

More deep roots: lateral roots

Many drought-tolerant varieties exhibit increased growth and branching of fine (lateral) roots in deeper soil where water is more available.[1,2,3]

More deep roots: nodal roots

Elongation of the main axial (nodal) roots into deeper soil is another strategy to access more water observed in some drought-tolerant genotypes.[8]

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[a] Sahbhagi dhan was released in India, and the same genotype was released as BRRI dhan56 in Bangladesh and as Sukha dhan3 in Nepal.

[b] IR64-drought was released as a variety in India, and its sister line was released as Sukha dhan4 in Nepal.

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A nozzle of a pivot irrigation system delivers a controlled amount of water to rice plants. Pivot irrigation systems make better use of water resources because the amount of water applied can be adjusted to the requirement of the crop. (Photo by Isagani Serrano, IRRI)

The food-water-energy nexus: Using gravity drainage to intensify production systems in the coastal zone of Bangladesh

by Manoranjan **Mondal** and Sudhir **Yadav**

Sustained economic growth, the quality of life, and the social stability of a rapidly growing Bangladesh depend largely on food security. Chronic or even sporadic food shortages could derail Bangladesh's impressive economic growth of the last few decades. Although Bangladesh as a whole is currently self-sufficient in rice production, the country faces immense challenges to sustaining its self-sufficiency status.

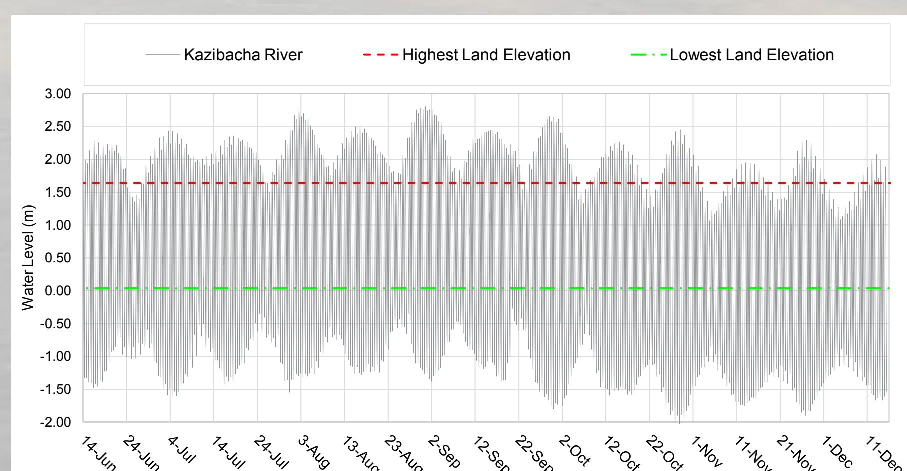
To maintain food self-sufficiency for its growing population, little scope exists to further increase cropping system intensity, except in the underused coastal zone lands. The coastal zone of Bangladesh comprises low-lying lands within a dense network of large rivers and their tributaries. The rivers are tidal and this effect extends about 150 km inland, with diurnal water level fluctuations of 2 to 3 meters (m). These river water resources are vital for crop production, ecosystem sustenance, and livelihoods of the coastal zone.

A low-productivity zone

Out of the 2.9 million hectares (ha) of coastal and offshore lands, about 1.2 million ha of agricultural lands were enclosed in 139 polders in the 1960s and 1970s to reduce the loss of life, prevent inundation and saline-water intrusion, and enable the production of aman (monsoon season) rice. Inside the polders are also dense, natural drainage networks (*khals* or canals), and some of the larger internal canals are connected to the surrounding rivers by sluice gates installed in the polder embankments.

Tens of millions of dollars have been invested in developing and maintaining the polders. The availability of appropriate improved agricultural technologies has greatly benefited other parts of Bangladesh. However, the productivity of the coastal zone remains low and it is still home to the world's poorest, most food-insecure, and most vulnerable rural people. Unlike the rest of the country, the farmers in the polders have not widely adopted modern high-yielding rice varieties (HYVs) because their shorter stature makes them unsuitable for the high water depths (20–70 cm) that often prevail from July to December. And, because of delayed drainage at the end of the monsoon, the soil remains too wet and the farmers have to plant the dry-season (rabi) crops late. As a result, these crops greatly risk damage or complete loss by pre-monsoon rains and cyclones in May, with severe losses in the past five years.

Many researchers have reported the feasibility of increasing productivity in the polders by intensifying and diversifying cropping systems. However, despite considerable investment and efforts from government, nongovernment, and international organizations, adoption of improved production systems in the polders of the coastal zone of Bangladesh has been low. The main reason was that the key determinant, hydrology of the coastal zone, was not considered for its upscaling process or pathways.



Variation in tide level in the Kazibacha River against mean sea level during the wet season.

Integrated water management unit

Achieving large-scale adoption of a year-round production system requires proper investment in water management infrastructure. This should be guided by a new paradigm with fundamental changes in thinking about the polders and their roles. Each polder must be considered as an integrated water management unit, rural infrastructure (roads) should be capitalized on as a boundary of community water management units, and improving drainage should be regarded as the key intervention and the entry point for cropping intensification and diversification.

The integrated crop and water management study conducted by the International Rice Research Institute (IRRI) and the Institute of Water Modelling showed that drainage of excess water from agricultural lands by gravity is viable. Tremendous opportunities exist to capitalize on polder ecosystem services (especially tidal river dynamics and dense internal natural drainage networks) and existing infrastructure (sluice gates, roads) and community organizations (water management groups, water management associations) to reduce waterlogging and greatly increase cropping system productivity.

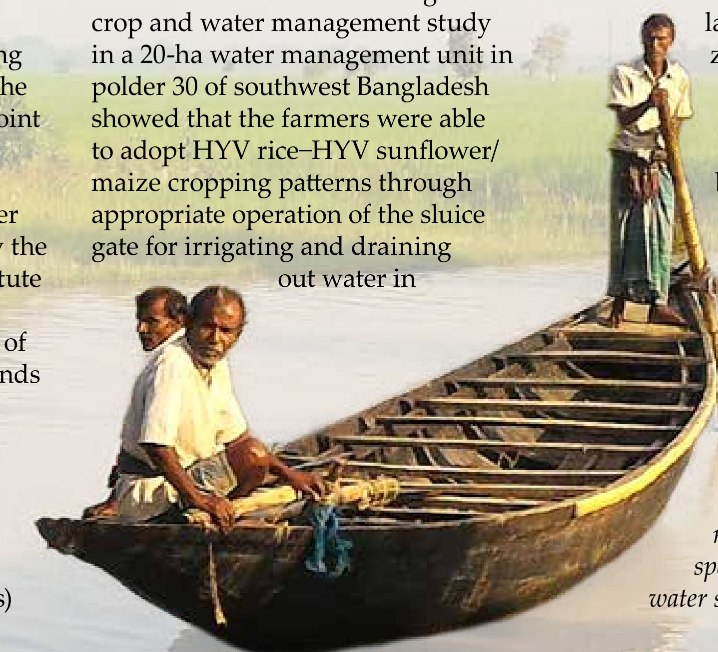
This can be easily achieved by systematic operation of sluice gates synchronized with the tidal phenomenon in the river systems, together with the creation of hydrologically defined community water management units (by constructing small farm levees/drains to separate lands of different elevation) and synchronized cropping involving the community.

The elevation of the agricultural lands in polder 30 varied from +0.04 m to +1.64 m and that of the water levels of the peripheral rivers of the polder during low tides varied from −2.1 m to −0.1 m, that is, below mean sea level (see Figure). On the other hand, the highest river water elevation (+3.0 m during high tide) remains much higher than the highest land elevation (+1.64 m) of the polder, indicating potential gravity irrigation opportunities (in case of prolonged drought) on polder lands during high tides.

An excellent opportunity for food security

Polder ecosystems provide an excellent opportunity to greatly reduce waterlogging and to irrigate rice by gravity at minimal cost in the monsoon season. An integrated crop and water management study in a 20-ha water management unit in polder 30 of southwest Bangladesh showed that the farmers were able to adopt HYV rice–HYV sunflower/maize cropping patterns through appropriate operation of the sluice gate for irrigating and draining out water in synchronization with the growth stages of aman rice. The farmers harvested HYV rice (5.1 t/ha) at least a month earlier with about a 2 t/ha higher yield than traditional rice (3.4 t/ha). The higher rice yield contributed to their food security and employment generation for the landless (lean-season employment).

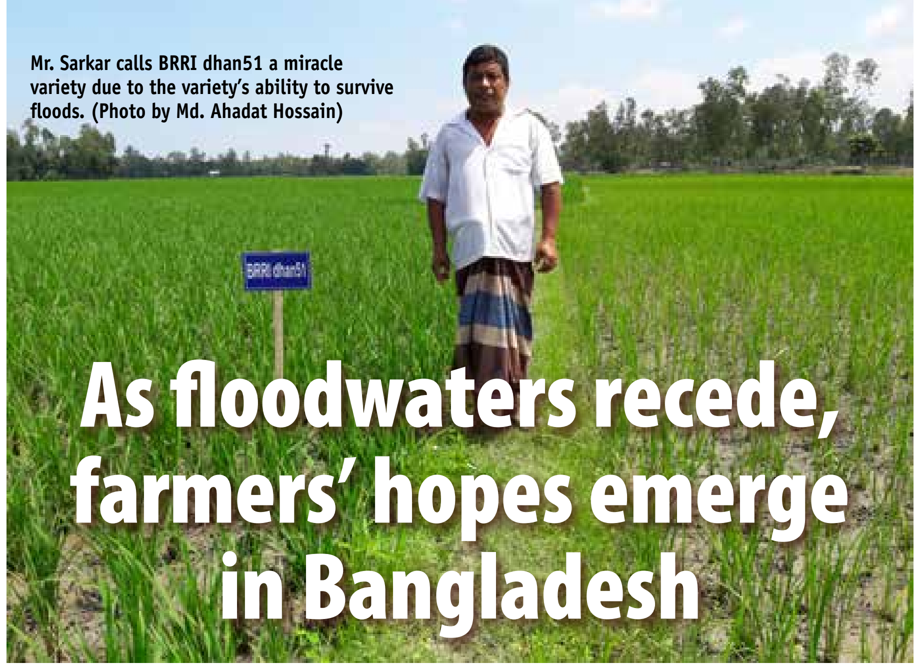
Since the cropping intensity and productivity in other parts of Bangladesh are already high, the underused agricultural lands of the coastal zone may well be the only region where significant gains in food production can be made through intelligent management of the land and water resources in the polders to meet future challenges to the food security of Bangladesh. ■



Dr. Mondal is a water resource management specialist and Dr. Yadav is a water scientist at IRRI.

Community coordination to manage sluice gates is an important factor for the intensification of polders. (Photo: IRRI)

As floodwaters recede, farmers' hopes emerge in Bangladesh



Mr. Sarkar calls BRRI dhan51 a miracle variety due to the variety's ability to survive floods. (Photo by Md. Ahadat Hossain)

by Shahreen **Haq**

For thousands of Bangladeshi farmers in flood-prone areas, growing rice is a risk they have to take each season.

In Bangladesh, water is both celebrated and feared.

Jitendra Nath Sarkar, a 60-year-old farmer in Kurigram District of Rangpur in the northern part of Bangladesh, is all too familiar with the nourishing nature of the rain and rivers—and the frighteningly destructive force of their raging floodwaters.

In August 2017, an unusually harsh monsoon brought the worst floods in 40 years, affecting 41 million people across South Asia. These floods have devastated Bangladesh's rice sector—representing the country's single most important crop. Because most of these farmlands were left submerged, a food shortage looms in the coming months.

A father of two, Mr. Sarkar is the sole breadwinner, making his family totally reliant on the income he earns from his boro or winter crops. Mostly, these consist of boro rice. If the rice crop fails, he will be unable to meet his family's basic needs. He cultivates around 3 hectares of land and his crops are often damaged by floods that occur almost every year during the aman season. It is a risk that he, along with thousands of farmers living in flood-prone areas, is willing to take each season. The farmers wait in anticipation, hoping the impact of flood will not cut too deeply into their meager income. When the floodwater does arrive, Mr. Sarkar waits for 10 to 15 days for the water to recede to assess the damage to his field. He is often forced to re-plant it, causing him to incur more expenses. The late planting also results in low production.

Mr. Sarkar and the hundreds of thousands of poor farmers like him have little choice but to endure the hardship and helplessly watch their crops and their already meager future wash away.

A history of raging calamities

Almost 20% of the country's arable land is prone to several floods each year. The scale of some of these floods is simply too large to comprehend. For example, in August 1998, at least 30 million people in Bangladesh were affected by flooding that covered two-thirds of the country.

In *Water, water everywhere but... The '98 Bangladeshi Floods*,[1] Julian Francis, a disaster preparedness delegate for the International Federation of Red Cross and Red Crescent Societies (IFRCS) in Dhaka, documented the human cost brought on by the 1998 flood:

A landless agricultural laborer would, normally, at this time of the year, be earning about 60–70 taka a day transplanting paddy seedling. The floodwaters had put that paddy land ten feet underwater, making this kind of work hard to find. If he owned any animals, he would have to spend his days collecting water hyacinth with which to feed them as the price of cattle fodder has doubled in the last few weeks.

The fruit trees that his wife would normally tend close to their homestead would have been destroyed by the floods. Rather than go in search of the elusive relief supplies of the government and NGOs, many of these people had decided to borrow money even if the "interest" was as much as 8% per month. Many families had already resorted to panic selling of livestock so that the price of meat came down on the Dhaka markets. Forlorn and sodden pointed stacks of rice straw (normally used as animal fodder) stood in the water. It was unlikely that any of this would be of much use except to plough into the soil for the next crop, and, in any case, most of the livestock had been sold or swept away by the floods.

The tragedy that repeats itself

In 2017, an unusually harsh monsoon brought the worst floods in decades—even worse than those in 1998. The floods affected at least 41 million people across South Asia and were the most serious in 40 years, according to the IFRCS.

The floods had a devastating impact on Bangladesh's rice sector. Almost half of Bangladeshi farmers' livelihood is tied directly to agriculture. The government estimates that 61,877 hectares of cropland, mostly rice, have been "completely damaged," while 531 million hectares have been "partially damaged," according to a report by CNN's Steve George.[2] Because most of the country's farmlands were left submerged, food shortage looms in the coming months.

Beyond the staggering statistics are stories of the gritty reality of what it's like to be caught in the midst of the deluge. Adere Begum, 34, was at home in the village with her two daughters when the floodwaters came. Begum lost many of her ducks, chickens, and cows in the flood, according to the CNN report.

Michael Holtz of *The Christian Science Monitor*[3] also reported how the impact of the floods could linger long after the waters subsided. By the time the floodwaters began to recede, Sufia and her husband from the countryside of Tangail District, about 80 kilometers north of Dhaka, saw their rice crop ruined.

"We'll have to wait two or three months before we can plant rice again," says Sufia, who uses only one name. In the meantime, she and her husband have taken out a loan to buy food and repair their home. "There's nothing else we can do."

Water recedes, hope emerges

Fortunately, some farmers, such as Mr. Sarkar, have found a way to overcome this debilitating reality. Beginning in 2007, the Bill & Melinda Gates Foundation (BMGF) has been working with the International Rice Research Institute (IRRI) and the Africa Rice Center to ease the effect of floods on the lives of farmers.

IRRI, through the Stress-Tolerant Rice for Africa and South Asia (STRASA) project, works closely with the national government in developing and promoting the use of rice varieties that can withstand environmental pressures, such as flooding, faced by millions of poor farmers. Developed by IRRI in conjunction with its national partners such as the Bangladesh Rice Research Institute (BRRI), these varieties include BRRI dhan51, a variety that can survive under floodwater for up to two weeks while most rice plants die in a matter of days.

During the 2010 aman season, Mr. Sarkar received some BRRI dhan51 seedlings from BRRI in Rangpur. He transplanted these on 250 square meters of his land. He also received training on quality seed production and seed preservation from STRASA.

Soon after, floodwater inundated his entire field for at least two weeks. He thought that, like the previous years, his crops were damaged beyond hope. But, Mr. Sarkar saw his BRRI dhan51 emerging from the rotten remains of his other crops. Within a few days, the flood-tolerant rice plants were growing as if nothing had happened.

A venture pays off

Farmers often perceive new technology as a risk. With no previous experience with a novel crop management method or a rice variety, farmers tend to be cautious. But, Mr. Sarkar's venture paid off.

From his BRRI dhan51, he harvested a bumper crop of more than 7 tons of rice and sold it for nearly USD 3,700. Since then, his commitment to these new rice varieties has grown along with his family's financial stability. In 2012, he produced almost 5 tons of rice and made USD 2,200 in profits. In 2016, Mr. Sarkar received nearly USD 2,000 from the 3.5 tons of rice he harvested. A second crop of BRRI dhan51 produced nearly 4 tons of rice and brought in nearly USD 2,100.

"The results were really terrific," Mr. Sarkar said. "I experienced three- to fivefold increases in my rice yield due to the variety's ability to survive floods. I planted and harvested it the usual way. It tastes the same as the other rice I have grown."

He also noted that the variety needs less urea fertilizer. He calls BRRI dhan51 a miracle variety and believes that it changed his life.

"I have more food for my family and have extra rice to sell in the market to bring a little bit more money into the household," Mr. Sarkar said. Today, his family is doing much better and he has saved enough money for his sons' education.

A new paradigm in farming

Without knowing it, Mr. Sarkar is also helping others cope with their situation. Other farmers were astonished to see the outstanding performance of BRRI dhan51. His field was proof of its potential to keep farmers afloat during the annual flooding.

"Flood-tolerant rice varieties can help improve the livelihood of other farmers," he said. "I hope many more will adopt them."

Farming with nature

It is impossible to control the forces of nature, and the infamous floods of Bangladesh and India are no exception. But, finally, hope is emerging. These flood-tolerant varieties are becoming more popular among the farmers because of their higher yields, with 80% higher survival rate. In addition, these flood-tolerant varieties mature earlier so that they can also provide farmers with opportunities for multiple crops in one year.

About 84% of the 165 million people of Bangladesh are directly or indirectly engaged in a wide range of agricultural activities. Thousands of farmers in most of the districts in the country have been inspired and convinced to cultivate BRRI dhan51. Other flood-tolerant rice varieties, such as BRRI dhan52 and BINA dhan11, were also adopted and planted during the aman season.

The resilience and hope offered by the flood-tolerant varieties give vulnerable farmers a chance to not only survive but also thrive in the face of a changing climate. Scientific innovations, such as BRRI dhan51, BRRI dhan52, and BINA dhan11, will play a vital role in increasing rice production on the floodplains and contribute to the country's food security. ■

Ms. Haq is a communications and stakeholders management specialist at IRRI-Bangladesh.

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3 Holtz M. (2017 September). As waters recede, Bangladesh takes stock – and plans for more flood-prone future. Retrieved from https://www.csmonitor.com/World/Asia-South-Central/2017/0925/As-waters-recede-Bangladesh-takes-stock-and-plans-for-more-flood-prone-future.

Scuba rice goes against the flow of woes in flood-prone eastern India

by Mayank **Sharma**, Najam **Zaidi**, Manzoor **Dar**, and Umesh **Singh**

The challenge to double the income of Indian smallholder farmers around the globe by 2022 requires a comprehensive strategy that includes stabilizing and enhancing crop production under adverse environmental conditions. Flood, drought, and salinity are among the major constraints to crop production, especially in rainfed areas of eastern India.

About 5 million hectares of land planted to rice in eastern India are prone to flooding. Although major flash floods do not occur every year, farmers are constantly in danger of losing their crops when these do occur. Under submerged conditions, rice plants die within days and farmers lose an estimated 3 tons per hectare. For decades, smallholder farmers in flood-prone areas could do little as floodwater inundated their rice crops.

Scuba rice makes a splash

In 2009, the International Rice Research Institute (IRRI) and its partners developed rice varieties that carry the *SUB1* gene. This gene originated from a low-yielding traditional variety grown in limited areas in the Indian state of Odisha and it enables rice to survive submergence for as long as two weeks. Given this ability to tolerate flooding, the varieties are also called Scuba rice.

In 2010, IRRI, through its partner agencies, started disseminating Swarna-Sub1 seed to farmers in the region. Swarna-Sub1, a flood-tolerant version of the popular variety Swarna, is the first high-yielding Scuba rice in India. Field trials conducted in Odisha showed that yields of Swarna-Sub1 could be 45% higher than those of Swarna even when it was submerged for up to two weeks. Indian farmers have been cultivating Swarna-Sub1 at unprecedented rates. By 2013, more than 1.7 million hectares of flood-prone land in India were planted with the variety. This initiative enables farmers to obtain higher yields not only after adverse conditions but also when no floods occur.

Against the current

In Bihar, the flash floodwater typically recedes within 8 to 10 days. However, the damage to the rice crop remains devastating. In 2017, Bihar and Uttar Pradesh experienced a major flooding event—the worst in several years—as rivers overflowed their banks.

In the Madhubani Region in north Bihar, stretches of rich farmlands were rendered barren due to flooding caused by the Kosi River. Although many farmers of the region lament the devastating result of the flood, others, such as Maha Jha, 49, from Singhia Village, have a different ending to a familiar story.

"It started with heavy rains and the downpour continued for many hours," said Mr. Jha, recalling the days before the flooding. "The water level from the rivers started rising, completely submerging our crops for 15 days."

He cultivates traditional variety Malhar on his nearly 1-hectare farm and purchases his seeds from the market every year. In 2017, he bought Swarna-Sub1 seed based on a vendor's recommendation. It was a decision that paid off.

"I lost hope of harvesting anything from my plots," Mr. Jha said. "But, as the water receded, the Swarna-Sub1 plants started growing again while the local variety showed no signs of recovery. I applied urea fertilizer in the Swarna-Sub1 plot and I am truly happy to see its growth now."

In Majaura Village, 62-year-old D.D. Jha also has a positive experience with Scuba rice.

"I've been growing Swarna-Sub1 on my farmland of about 1 hectare for more than six years," Mr. Jha said. "I started planting this rice variety in 2011. Although we have not experienced any major floods in my village since, I continued with Swarna-Sub1 because of its high yield. With the recent flood, all other varieties in my field, mainly hybrid and local, were washed away. The Swarna-Sub1 withstood the floodwater for 12–13 days."

Floods ravage the village of Samhauta in Bettiah, Bihar, almost every other year. Many people are displaced and thousands of hectares of standing crops died.

"My village has been flooded several times in the past 10 years," said Anand Singh, 42. "This is why I continued planting Swarna-Sub1 when other farmers started planting hybrid rice and other varieties. In the 2017 flood, their crops were dead while you can see the standing crop in my field."

Many other villages in eastern Uttar Pradesh lie in the floodplains of rivers descending from the Nepal Himalayas. Rice fields in these regions are easily flooded as waters from Nepal submerge the low-lying plains of Ganga. Floodwaters inundated Malwar Village in Siddharth Nagar District in eastern Uttar Pradesh for more than 15 days.

"This flash flood of 2017 has been more destructive than any flood I can remember," said Hardev Mishra, 39, a farmer in Malwar. "Farmers in this region grow hybrids and other high-yielding varieties. All these died out. Luckily, I obtained seeds of Samba-Sub1 from the Krishi Vigyan Kendra for trial purposes. This variety stood out and survived. It's the only crop that survived the floods in the entire village."

Rice for the new normal

The effects of climate change are already being felt in eastern India with the rising extreme weather conditions. Although hundreds of rice varieties have the potential to give high yields under normal conditions, their performance suffers when exposed to environmental stresses that hurt farmers' livelihood. Varieties tolerant of conditions such as floods can be an important part of increasing the productivity, resilience, and income of smallholder farmers.

Stress-tolerant varieties are being disseminated in India, Bangladesh, Nepal, Kenya, Tanzania, Mozambique, Nigeria, Madagascar, and others through the Stress-Tolerant Rice for Africa and South Asia (STRASA) project. STRASA is a project of IRRI and the Africa Rice Center and is funded by the Bill & Melinda Gates Foundation.

The impact of stress-tolerant varieties is also spilling over to the Philippines, Cambodia, Lao PDR, Indonesia, and Myanmar. STRASA aims to raise yields in stress-affected areas by 50% over 10 years through improved cultivars and management, benefiting an estimated 18 million households in target countries. ■

Mr. Sharma is an M&E specialist at STRASA-South Asia. Dr. Zaidi is a plant pathologist and Dr.Dar is development specialist in agricultural research at IRRI India. Dr. Singh is the South Asia Regional Coordinator for STRASA.

Climate change-ready rice varieties are a milestone in doubling the income of Indian farmers.

As the floodwater receded, Mr. Jha's Swarna-Sub1 rice plants started growing again while the other varieties planted on the other side of his field showed no signs of recovery. (Photo: STRASA)

STRASA's innovative approach to faster adoption of modern rice varieties and technologies

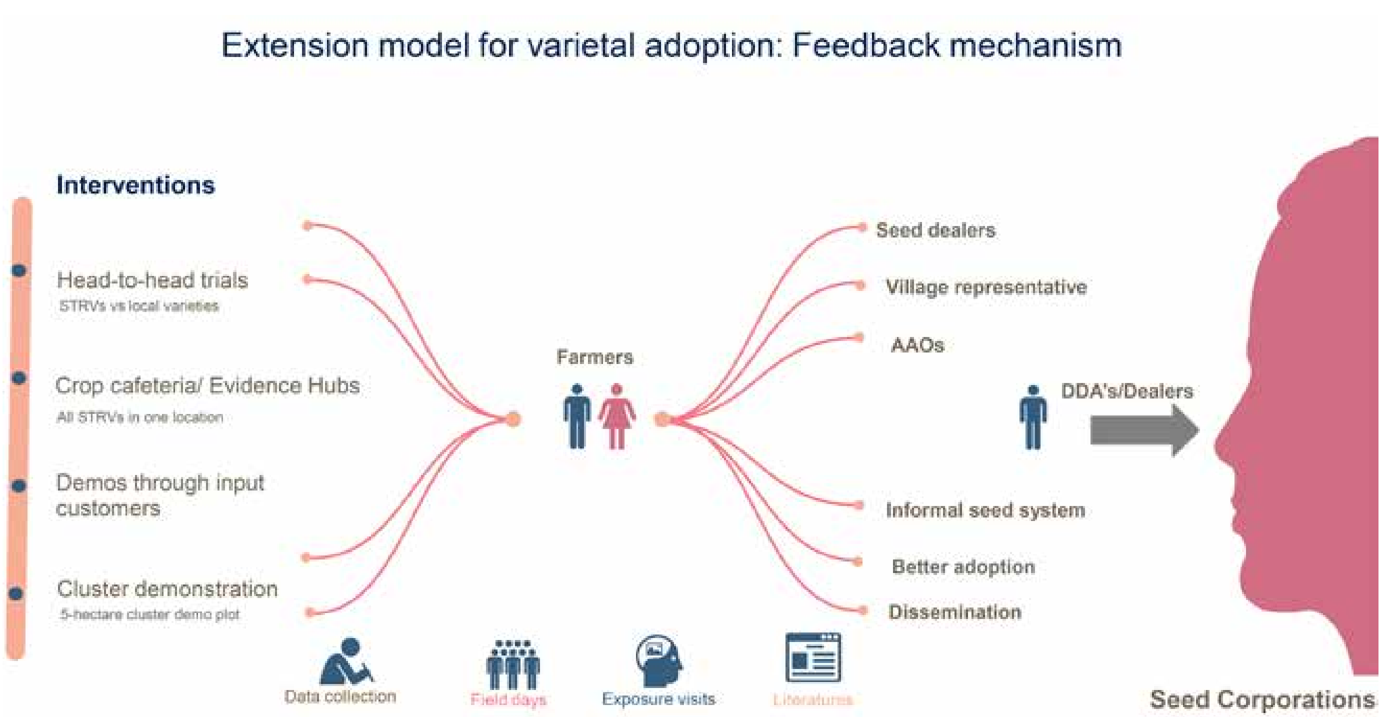
by Mayank **Sharma**, Manzoor **Dar**, and Uma **Singh**

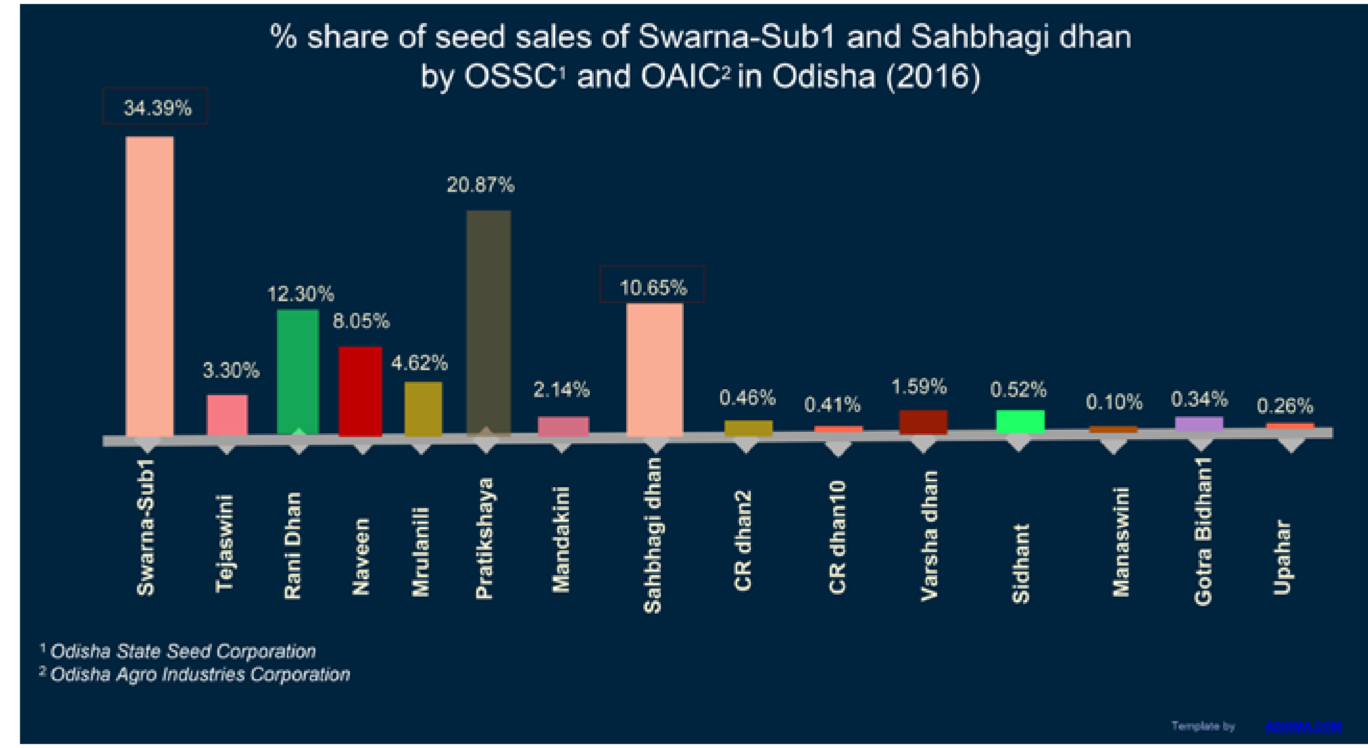
Developing new climate-resilient rice varieties and technologies is simply not enough to mitigate the impact of climate change on rice production and increase the productivity of rainfed areas. It is critical to design strategies that will bring these varieties and practices to farmers as quickly as possible and ensure that these varieties and practices perform efficiently. There are several ways to promote any new variety or technology. The most common approaches are field demonstrations, seed minikit distribution, and field days. However, the traditional model for extension is becoming outdated in today's more competitive, market-oriented agriculture.

Take Swarna-Sub1, for example, the flood-tolerant version of the popular mega-variety Swarna (MTU 7029). Swarna-Sub1 is almost identical to its counterpart Swarna in terms of grain yield and grain quality, but it can survive full submergence for more than two weeks. It was developed by scientists from the International Rice Research Institute (IRRI) and disseminated by IRRI in collaboration with the national agricultural research and extension systems, government organizations, nongovernment organizations, and public and private seed companies.

Swarna-Sub1 was released in 2009. Various approaches such as pre-release varietal seed multiplication and promotion of Swarna-Sub1 and linking varietal dissemination with mega developmental schemes of the government and other organizations helped achieve seed multiplication and diffusion at an unprecedented speed in South Asia. In the eastern Indian state of Odisha, Swarna-Sub1 outpaced all rice varieties developed within the past 10 years in terms of seed production and sales by state-owned seed corporations in the 2016 kharif season.

Despite substantial evidence of the good performance of Swarna-Sub1 from field trials, the variety is suitable in some areas but not in others. Thus, introducing new varieties to inappropriate areas could cause unintended results and negatively affect the reputation and adoption of improved varieties. To avoid this problem, the Stress-Tolerant Rice for Africa and South Asia (STRASA) project employed more innovative approaches for faster varietal adoption.





Head-to-head trials

Head-to-head trials in farmers' fields are an awareness creation method for convincing farmers of the superiority of a variety. In this method, two varieties—a stress-tolerant rice variety (STRV) and a local variety—are planted separately in adjacent fields (or in a field divided into two parts) and cultivated using farmers' management practices followed from seed sowing to harvesting.

Crop cafeteria/evidence hub

Because people's priorities and incentives differ, the success of an intervention depends on the complex interaction of multiple stakeholders and institutions. In this method, the STRVs and other popular varieties are grown on a large tract of land where multiple stakeholders such as seed dealers, producers, district agriculture officials, scientists, and progressive farmers are invited to learn about the varieties and evaluate their performance.

Demos through input customers

Farmers often rely on input dealers or local seed shops when deciding on products that are available in the market. Because input dealers are one of the most prominent sources of information for farmers, they should be fully informed about new varieties and characteristics. One STRASA approach targets local dealers and input sellers and their network by providing them with the seeds of new varieties for testing.

The head-to-head trials directly compare the performance of newly developed variety and the farmer's variety grown under the farmer's management. (Photo: IRRI India)

Cluster demonstrations

Instead of going to varietal demonstrations on several hectares in one place, STRASA conducts varietal demonstrations in 5-hectare patches located at several focal points to ensure that these are more accessible to more stakeholders.

In the past few years, these approaches have been widely implemented across eastern India and it is encouraging to see a growing commitment from farmers, seed producers, and other stakeholders toward STRVs. ■

Mr. Sharma is an M&E specialist at STRASA-South Asia. Dr.Dar is development specialist in agricultural research at IRRI India. Dr. Singh is the South Asia Regional Coordinator for STRASA.

Severe bacterial blight infection in a susceptible rice variety from West Java, Indonesia (Photo by R. Oliva, IRRI)

A tool that tracks and stops bacterial blight outbreaks in rice

by Alaric Francis **Santiaguel**

A new, faster, and more accurate way of identifying infectious organisms—down to their genetic fingerprint—could finally put farmers a step ahead of bacterial blight.

A revolutionary tool called the *PathoTracer* has been developed at the International Rice Research Institute (IRRI) and it can identify the exact strain of the bacterium that cause bacterial blight present in a field in a matter of days instead of several months of laboratory work.

"It's like a paternity test that uses DNA profiling," said Ricardo Oliva, a plant pathologist at IRRI. "It will not only tell you that you have bacterial blight in your plant. It will tell you the particular strain of the pathogen so that we can recommend varieties resistant to it."

For more than four years, Dr. Oliva and his team worked on deciphering the genetic code of *Xanthomonas oryzae* pv. *oryzae,* the pathogen that causes bacterial blight, to develop the test. Bacterial blight is one of the most serious diseases of rice. The earlier the disease occurs, the higher the yield loss—which could be as much as 70% in vulnerable varieties.

"Bacterial blight is a persistent disease in rice fields," said Dr. Oliva. "The epidemic builds up every season when susceptible varieties are planted. The problem is that the bacterial strains vary from one place to another and farmers don't know which are the resistant varieties for that region. We were always behind because the pathogens always moved and evolved faster."

Identifying the strains of bacterial blight present in the field requires a lot of labor and time. You need people to collect as many samples as they can over large areas to accurately monitor the pathogen population. In addition, isolating the pathogens in the lab is laborious and it typically takes several months or even a year to determine the prevalent strains in a region.

The *PathoTracer* can identify the local bacteria in the field using small leaf discs as samples. The samples will be sent to a certified laboratory to perform the genetic test and the results will be analyzed by IRRI.

"It takes only a few days to analyze the samples," Dr. Oliva explained. "With the *PathoTracer,* we can bring a year's work down to probably two weeks. Because the tool can rapidly and efficiently monitor the pathogen present in each season, the information can be available before the cropping season ends."

It's like knowing the future, and predicting what would happen the next season can empower the farmers, according to Dr. Oliva.

"Recognizing the specific local bacteria present in the current season can help us plan for the next," he added. "We can come up with a list of recommended rice varieties that are resistant to the prevalent pathogen strains in the locality. By planting the recommended varieties, farmers can reduce the risk of an epidemic in the next season and increase their profits."

The *PathoTracer* was pilot tested in Mindanao in the southern part of the Philippines in April 2017. The rains came early in the region, just after the peak of the dry season, and that triggered an outbreak of bacterial blight.

"We went there and took samples from different fields," Dr. Oliva said. "By the end of April, we had the results and we were able to come up with a list of resistant varieties that could stop the pathogen. We submitted our recommendation to give farmers a choice in reducing the risk. If the farmers planted the same rice varieties in the succeeding rainy seasons, I am 100% sure the results would be very bad."

The speed at which *PathoTracer* can identify the strains of bacterial blight present in the field can be used for recommending resistant rice varieties to farmers for planting in the next cropping season. (Photo: IRRI)

The *PathoTracer* can run thousands of samples and can, therefore, easily cover large areas, making it an essential tool for extension workers of agriculture departments and private-sector rice producers, or it can be incorporated into monitoring platforms such as the Philippine Rice Information System (PRiSM) or Pest and Disease Risk Identification and Management (PRIME) to support national or regional crop health decision-making.

"National breeding programs could also make more informed decisions," Dr. Oliva said. "If you know the pathogen population in the entire Philippines, for example, the country's breeding program could target those strains."

IRRI is interested in expanding the genetic testing tool to include rice blast and, further down the road, all bacteria, viruses, and fungi that infect rice.

The *PathoTracer* has been tested in other Asian countries and IRRI expects to roll it out early in 2018. When it becomes available, the expected potential impact of the *PathoTracer* on a devastating disease that affects rice fields worldwide would be huge.

"Imagine if this tool prevented bacterial blight outbreaks every season across Asia," said Dr. Oliva. "It's super cool!" ■

Dr. Oliva (*third from the front in the right row*) and the team that developed *PathoTracer*. (Photo by Isagani Serrano)

Mr. Santiaguel is the editor of Rice Today.

For more information about bacterial blight, see Section II, Chapter 2 of IRRI's Rice Diseases Online Resource *at http://rice diseases.irri.org/home/contents.*

RICE SEED PRODUCTION:

What happens in the field?

by Judit **Johny**, Prakashan Chellatan **Veettil**, and Aldas **Janaiah**

Sustained increases in agricultural production and productivity require the continuous development of new rice varieties to meet the production challenges in various agro-climatic regions and encourage adoption by farmers. The majority of the rice areas in India are still planted with second-generation Green Revolution varieties such as Pooja, Swarna, Samba Mahsuri, MTU1010, and others.

There is a pressing need to look for sustainable ways to accelerate the production, dissemination, and adoption of new rice varieties to meet future demand and prevent cultivar depreciation from the continuous use of farm-saved seeds. Overcoming the inefficiencies in the seed value chain could be critical to achieving this.

India's rice seed system

The Indian rice seed system is unique and complex. The organized seed supply system is broadly composed of public and private players in seed production, certification, and distribution of improved and hybrid rice varieties at the state, regional, and national levels. The roles of these institutions are intertwined, leading to several discrepancies at each level of the value chain. As a result, there are problems that plague the seed supply system, such as the poor functioning of institutions, delay in introducing new varieties to the seed provisioning system, slow varietal turnover, mixing of different varieties, deterioration of seed quality, and unavailability of seeds.

To tackle these problems, there is an urgent need to look at the different levels of the seed supply chain and gain a better understanding of the realities at the ground level. As a first step, the International Rice Research Institute (IRRI) initiated a study in the state of Telangana, the seed bowl of India, to quantify and solve some of the problems affecting the production and distribution levels of the value chain.

Understanding the seed supply system

Seed producers are the most important part of the seed supply chain. High quality, adequate supply, and timely availability are largely dependent on the production process. It is therefore highly relevant to understand the institutional arrangements within the seed production system, for example, the formal and informal seed production contracts between seed growers and producing companies and institutions.

Each form of the contract comes with its own benefits and pitfalls. In developing countries, the nature of contracts is mainly verbal and informal based on trust and networks, often lacking legality. Interestingly, these informal agreements are commonly followed and, in some cases, are more efficient than legal contracts. The preference for legal versus verbal contracts could be dependent on the transaction, enforcement, or legal costs involved. On the other hand, informal contracts can lead to the exploitation of the vulnerable party involved. The distortions in an existing contract design and the enforcement mechanisms can have varied impacts on different aspects of the seed production and supply chain.

We conducted focus group discussions in a few villages in Telangana where large-scale seed production is carried out in Karimnagar, Warangal, Nizamabad, and Kurnool districts. Telangana, unlike other parts of the country, has a large presence of local, national, and multinational private seed production companies, particularly producing hybrid rice. These include Bayer BioScience, Syngenta, Pioneer, Dhaanya Seeds, Ganga Kaveri Seeds, Nath Seeds, and Nirmal Seeds. For inbred varieties, a few cooperatives, along with the private companies, are also engaged in seed production.

The seed production story

The discussions revealed that, in general, the private seed production sector is composed of companies and institutions, seed organizers, and seed growers. The companies and institutions provide the parental lines or foundation seeds as well as technical guidance to seed growers (seed farmers) through seed organizers.

Seed organizers

Seed organizers are individuals who facilitate the entire seed production process on behalf of the companies. They identify seed growers, provide them with adequate technical guidance, and facilitate seed production. These seed organizers are expected to deliver the specified quantity of quality seeds to the companies each season.

Each season, companies identify seed organizers who are willing to facilitate seed production for them. Typically, there is a written agreement between the company and its seed organizers, but this agreement does not have any legal implications. More importantly, the agreements are usually written in English and the organizers may or may not fully understand the conditions specified within the agreement. Seed organizers may not necessarily have copies of the document.

Some of the terms commonly agreed upon by the organizers and companies that were identified during the focus group discussions are as follows

- Quantity of seed to be produced in the season
- Minimum and maximum expected yield of the parental lines supplied by the company
- Service charges or commission per kilogram (kg) of seed produced
- 100% procurement from farm gate
- Advance payment before the start of the season

Organizers are expected to ensure that the growers do not sell the seeds elsewhere. The service charge or commission per kg of seed ranges from USD 0.04 per kg to USD 0.09 per kg, depending on the company, variety, and yield. The companies usually provide advance payment to the organizers to cover the initial costs, ranging from USD 116 to USD 155 per hectare (ha). This is deducted from the final payment.

Once the target quantity is specified by the company, the seed organizers identify farmers who meet the basic requirements and facilitate the contracts. In some cases, the organizers also undertake production of seeds. Depending on the target quantity for the season, each organizer could supervise 150 to 300 farmers who have undertaken seed production on 80 to 200 ha of land across different villages. The seed organizer is expected to have no association with other companies involved in seed production of the same crop, facilitates all aspects of production, and delivers good-quality seeds to the company. Thus, trust is a crucial factor in selecting a seed organizer.

Seed organizers are primarily responsible for providing timely technical guidance to farmers and ensuring the quality of the seeds produced. For hybrid seed production, each seed organizer appoints one field assistant for every 24 ha under his or her area. These field assistants regularly visit the field at least twice a week and provide necessary guidance. The organizers also facilitate inputs such as fertilizer, materials required for supplementary pollination, and machinery for harvesting. In some cases, the organizers pay an initial advance or facilitate loans to farmers who have financial difficulties at the beginning of the season. In the event of late payment from the companies, the organizers are liable to pay at least 50% of the total payment to the farmers.

Procurement and transportation from the farm gate are organized and coordinated by the seed organizers. The organizers are held responsible if the company rejects the seed because of poor quality.

In inbred seed production, the role of organizers is relatively limited. Because the cultivation techniques used for seed production are largely the same as for grain production, the farmers do not require technical guidance. The main difference between grain and seed production is the removal of off-types according to the farmers. This is done several times by the farmers as well as organizers to ensure quality.

The organizers facilitate credit for farmers in need of financial assistance at the beginning of the season.

Seed farmers

Farmers are identified based on certain key characteristics of their farms, including land size, soil type, location, and availability of irrigation. In general, organizers will engage small farmers with an irrigation facility because irrigation is critical for hybrid seed production. The location of the field is another important factor as isolated areas have lower chances of pollen contamination, which determines the quality of the seed produced.

The financial capability of the farmer is also a factor considered in choosing seed growers because hybrid seed production involves upfront costs and several risks. Previous experience in seed production is not a limiting factor and inexperienced farmers who are willing to undertake hybrid seed production may also be selected.

Once the farmers are identified, the seed organizer communicates the terms and conditions and facilitates agreements. In some cases, there may be written or verbal agreements for the production of both hybrid and inbred varieties between the company and the farmers. Informal verbal agreements through the organizers are generally used by national and local companies while written informal agreements are usually employed by multinational companies. Farmers, in general, do not have a clear picture of the specifications in the agreement because it is usually written in English. As in the case of organizers, farmers do not have copies of the document.

There is usually no direct interaction between the company and the farmer. Any written agreement between the company and the farmer is usually facilitated by the organizers. This is true for the seed production of both hybrid and inbred varieties. The farmers are completely dependent on the organizer; thus, trust is a crucial factor. The farmers choose to produce for a particular company based on the seed organizer.

In hybrid seed production, companies supply the parental lines or foundation seeds and offer a procurement price based on the expected yield from the variety. For hybrid varieties, the procurement price per 100 kg and the expected yield per hectare from the parental lines supplied by the company at the beginning of the season are usually provided by the seed organizers. If the yield turns out to be lower than indicated by the company, some companies pay a higher price than originally offered to compensate for the loss.

In rabi 2016, one company offered each farmer compensation of USD 78 per ha if 70% of the total cropped area in the village under the company was affected because of poor-quality parental lines.

The procurement price is usually paid within 45 to 90 days. Few companies pay the farmers directly. This is generally preferred by the seed organizers as well as the farmers. Transportation costs from the farm gate are also shouldered by the companies.

Further, companies appoint representatives at several levels to provide farmers with technical guidance and supervision. Interestingly, most of the farmers are well experienced and technically sound and are often better than the company field staff, who are mostly inexperienced.

For inbred varieties, companies provide farmers with the foundation seeds. Several farmers have expressed concern about the quality of the foundation seeds provided by the companies. They believe that the companies give them seeds produced in the previous season for multiplication in the next season. This can have a serious impact on the quality of the seeds produced. The farmers are usually offered USD 0.008 per kg—more than the minimum support price declared by the government. Companies generally do not offer any compensation for yield loss for high-yielding varieties. The risk involved in inbred seed production is much lower.

Seed organizers and seed producers participate in a focus group discussion. (Photo by P. Chellatan, IRRI India)

Refining the seed pipeline

The insights from the focus group discussions give us a good understanding of the seed production scenario. This also raises several concerns about the efficiency of the production process. Although the farmers can choose among the companies, do they have any bargaining power when it comes to the price?

There appears to be no visible discontent among the hybrid rice farmers. Is this because the contract and enforcement designs are efficient or because the current situation is better than the existing alternative? Could it also be because the farmers are not aware of the distortion within the current contract design and the potential benefits they could gain from an improved design? Could transparency in price determination further improve the existing design and increase the profits of the farmers?

The presence of organizers seems to improve the seed production process. Are they rewarded adequately for the risks involved, particularly in hybrid seed production? On the other hand, the degree of trust placed in the organizers by the companies and farmers is extremely high. However, is there enough transparency in the activities undertaken by the organizers?

Are they making too much profit at the expense of the farmers? For example, a seed organizer could make large profits by falsely reporting a yield loss for a variety to obtain the compensation provided by a company. Alternatively, both farmers and organizers could manipulate the production process, causing low yield in order to make profits from the compensation offered.

Further, seed quality is an important concern. Hybridization enables companies to recoup their investments and provide incentives to maintain quality and meet market demand. However, the private companies involved in inbred seed production have little or no incentive to invest in maintaining quality and large-scale production. There is an urgent need to look into the concerns raised by the farmers regarding the quality of the foundation seeds provided by the companies. Low seed quality can reduce productivity, increase the cost of cultivation, and decrease adoption, among others. Improving the seed value chain is important given that India continues to face a considerable amount of quality seed deficit, which negatively affects rice yield and productivity.

In general, there is a lack of quality incentives provided to farmers. Although farmers can always decline such arrangements, the percentage of rejection appears very low. The effects of introducing quality incentives in the existing contract design are worth examining. Through this study, we hope to delve deeper into the different aspects of contract design and enforcement mechanisms and find answers to these questions. ■

Ms. Johny and Dr. Veetil are assistant scientist and scientist, respectively, at IRRI India's Agri-Food Policy Unit. Dr. Janaiah is an economist and consultant at IRRI India.

From invisible farm women to agri-preneurs

by Sugandha **Munshi**, Ranjitha **Puskur**, Akhilesh **Kumar**, and Pranab **Nayak**

Women farmers in Munger take more active roles in food production. (Photo: ITC)

Women provide half of the labor in rice cultivation in India, according to the International Rice Research Institute (IRRI) Farm Household Survey (2008-10). They do most of the tedious and backbreaking work in rice cultivation such as nursery raising, transplanting, weeding, harvesting, and threshing. In spite of their significant contributions, the women are only recognized as wives of farmers—not as farmers.

However, this image of rural women has begun to change in Munger in the eastern state of Bihar through the ITC Limited Social Investment Programme-Mission Sunehra Kal (Golden Future).

An action-research partnership

ITC is a private company noted for its sustainability practices and innovations to make markets more inclusive for the poor. In 2014, it started a program in the district of Munger to provide women farmers with enhanced skills and knowledge. ITC collaborated with the Self-Employed Women's Association, comprising poor self-employed women who earn a living through their own labor or small businesses, as its project-implementing partner. ITC also works in partnership with the Cereal Systems Initiative for South Asia (CSISA) for technical guidance. The program, *Enhancing skills and knowledge of women farmers*, aims to boost agricultural production by empowering rural communities to conserve, augment, and manage their environmental capital through sustainable agricultural practices.

Through this action-research partnership, the target rural women are witnessing changes in their role in the agricultural sector. Through self-help groups, the women farmers started using seeds of improved rice varieties and transplanting equipment that significantly contributed to their productivity. These are helping shift society's perception of women: from "invisible" farm laborers, they are now entrepreneurs.

Mechanized women farmers

ITC established two women-led custom hiring centers (CHCs) to provide mechanization services to farming households in Munger District. Most of the members of these CHCs are landless farmers who grow crops on leased land or in a share-cropping arrangement.

These women-led CHCs serve as information hubs for sustainable agricultural practices such as direct-seeded rice, weed management practices, and mechanization. It is expected that this will lead to reduced labor requirement, decreased drudgery, lower cost of production, and timely agricultural operations.

In 2016, the CHCs provided services, from nursery raising to mechanical transplanting, harvesting, and threshing, to 153 farmers in 11 villages, covering around 77 hectares of farmland. The women—having acquired new skills and knowledge—are benefiting from increasing income.

They are also playing a critical role in agricultural innovation. Through the CHCs, women farmers are able to extend better farm management technologies and information to communities that are otherwise disconnected from these resources.

Wonder women

"We are the ones who are bringing new technology to our community," said Meera Kisan Behan from Haveli Kharagpur block who attended a training in operating the transplanter. "What makes us happy is the fact that we are able to create positive changes in both the social and economic realms. Here, a woman driving a machine and providing transplanting and other services is very uncommon. Many raised their eyebrows in the beginning but that couldn't stop me and my group from moving ahead."

Tara Devi of the ITC Sunehra Kal Sita Sewa CHC said that she is "proud and extremely happy" to become an entrepreneur.

"Through the CHC, we provide services, through farm equipment and other inputs, to our fellow farmers," she said, smiling.

In 2016, the total income of the CHCs generated from the service fees for their equipment for machine-transplanted non-puddled rice and zero-tillage methods, nursery enterprises, improved seeds varieties, and others reached USD 14,809, according to ITC.

Many more women farmers are leading the changes in their communities. The women-led CHCs and other innovations that promote the entrepreneurial skills of women in farming have the high potential for impact acceleration through reaching out to millions of yet unreached poor and marginalized farmers in India. ■

Ms. Munshi is a gender specialist for IRRI and CSISA in Bihar. Dr. Puskur leads IRRI's Gender Research Program. Mr. Kumar is the regional manager of ITC and Mr. Nayak is the ITC senior program officer.

Mechanized harvesting and threshing machinery at SFLF site. (Photo: IRRI)

Validating the small-farmers, large-field concept to double income

by Samarendu **Mohanty**, Sampriti **Baruah**, Bidhan **Mohapatra**, and Prakashan Challatan **Veettil**

Rice farming in Asia is changing because of rural outmigration and growing nonfarm opportunities. The consequential increase in labor scarcity has led to a rapid rise in wage rates in all rice-growing countries in Asia. Since rice farming is traditionally labor-intensive, and with labor costs accounting for nearly half of the total cost of production, farmers have been quick to explore the possibility of replacing labor-intensive activities such as land preparation, crop establishment, harvesting, and threshing with appropriate mechanization to lower the cost of production. Small-scale farm mechanization and custom-hiring arrangements with machines are quickly evolving as viable solutions for smallholder rice farmers in the region. To further counter the infeasibility of mechanization for small farmers, several models of virtual land consolidation have started to emerge in different parts of Asia. The "Small Farmers, Large Field" (SFLF) model in Vietnam, which allows small farmers to benefit from economies of scale by pooling their small farms into large fields of 50–500 hectares to lower the per unit cost of using farm machinery, such as combine harvesters, is becoming popular. In four years, the area under the SFLF model skyrocketed in Vietnam from 8 hectares in 2011 to 196,000 hectares in 2015, with an increase in farmers' profit of USD 110–180 per hectare.

Similarly, in Thailand, an industrial rice farming scheme introduced by the Suphanburi Rice Millers' Association, in collaboration with Suphanburi Rice Research Center, has convinced the farmers to grow one rice variety with synchronized planting and harvesting time on around 400 hectares. The idea is to lower the harvesting cost by 20–30% by providing service providers with a bigger contract for custom harvesting.

SFLF pilot experiment in Odisha

For the 2016–17 dry-season crop, we piloted a customized version of the SFLF model in Taraboisasan Hamlet near Bhubaneswar, the capital of the eastern state of Odisha in India. A total of 54 farmers with about 36 hectares participated in our pilot exercise. The participating farmers selected an eight-member committee to take on the role of facilitator between the farmers and implementing agencies. The participating farmers harmonized and synchronized selected activities and operations to achieve a scale effect and bargaining power. (A more detailed description of this experiment can be found in *Piloting the Vietnamese "Small Farmers, Large Field" scheme in eastern India* on pages 35-36 of *Rice Today* Vol. 16, No. 1.)

The participating farmers decided to grow a single variety (BINA 11) using seed purchased from a certified seed producer facilitated by seed producers. In the previous dry season (2015–16), these farmers primarily grew five different varieties (BINA 11, Samalai, Samrat, Lalat, and Rangabati) using seeds from different sources (their own, other farmers, government agencies, and research institutes). In the next step, the farmers set up a mat nursery in nine patches, with the largest patch serving 12 adjacent hectares.

"It used to be extremely difficult for a tractor to move around within a small piece of land and it consumed additional fuel," said Bimbadhar

Biswal, the secretary of the Laxminrusingha SFLF Committee. "It took time to visit different field locations at different times and the group nursery saved time, energy, labor, water, and money for the farmers."

We worked with the SFLF committee throughout the season in lining up input suppliers and service providers and negotiated cheaper prices for the farmers. The group identified the fertilizer requirement of each farmer and placed a single order with the Indian Farmers' Fertilizer Cooperative Limited (IFFCO) by pooling funds. IFFCO supplied the fertilizer at the farmers' doorstep at 15% lower than the retail price. IFFCO also conducted free soil testing for participating farmers but we let the farmers decide whether to follow the IFFCO recommendation on fertilizer application. Our observation is that none of the participating farmers followed the recommendation but instead made their own decision.

At the beginning of the season, we invited a few local millers to visit our site and explained our pilot project to them. The response was quite positive and they showed a keen interest in purchasing the paddy at a premium price because of the single variety. We facilitated a meeting between a combine harvest service provider and the village SFLF committee. The service provider readily agreed to charge USD 31 per hectare vis-à-vis the USD 39 per hectare paid by the SFLF farmers in the previous season. The farmers also spent less for land preparation, crop establishment, and herbicide and pesticide purchase. Before the harvest, the SFLF committee picked a miller based on offering price and reputation. The price received by SFLF farmers for their paddy was USD 16 per ton higher than the prevailing market price at that time. Based on the data collected from each participating farmer at the end of the season, the average per hectare profit was estimated to be USD 390 vis-à-vis USD 191 in the 2015-16 dry season.

Apart from the monetary benefits, the farmers saved time and energy in each of the farming activities done together. The farmers at our pilot site now mostly talk about the time they saved by having a group seedbed nursery and synchronized transplanting. The participating farmers also mentioned the time and money they saved because the fertilizer was delivered to them. Organizing themselves into a group also helped the participating farmers to obtain interest-free credit from each other under group solidarity rather than from micro-finance loans at an average 26% interest rate.

A miller's truck picks up the harvested paddy purchased from an SFLF village at the farmers' doorsteps. (Photo: IRRI).

Going forward

In the 2017–18 wet season, the number of participating farmers increased from 54 to 77 with a total of 69 hectares. Many farmers from the nearby hamlet (part of the same revenue village) joined the group this season. The eight-member committee has expanded to represent the new farmers. Our role this season has been significantly reduced because the expanded committee is making most of the decisions in consultation with participating farmers. In addition, we are piloting this SFLF farming model in Khanijpur Village in Puri District. All 35 participating farmers in this village are women who are primarily sharecroppers.

The SFLF pilot model seems to be a very attractive option for small farmers who can significantly increase their income by harmonizing and synchronizing selected operations to achieve scale and gain bargaining power in input purchase and output sales. But, our experience suggests that the scalability of this model is not guaranteed. The SFLF model can spread but each new group will require handholding, facilitation, and technical support for one or two seasons to streamline the process and gain each other's trust. Initial facilitation and local capacity building are crucial for the successful implementation of the model. It is also very clear that, once the process is in place, it is likely to be sustained for a longer time.

Over time, each group will customize the model based on its needs and requirements. Some will be very formal and fully integrated from end to end whereas others may be more informal and selective in their integration. ■

Dr. Mohanty is the former head of the Social Sciences Division at the International Rice Research Institute (IRRI) and currently regional director for Asia at the International Potato Center. Ms. Baruah is a PhD scholar at IRRI. Mr. Mohapatra is an assistant scientist in IRRI-India's Applied Socioeco-nomics Unit, and Dr. Veettil is a scientist in IRRI-India's Agri-Food Policy Unit.

Precision nutrient management tools help Indian farmers make smart fertilizer decisions

by Pratibha **Kumari**

Easy-to-use technologies are reducing farmers' fertilizer wastage, production cost, and impact on the environment.

The GreenSeeker® helps farmers effectively and precisely manage their crop inputs quickly and at any time. (Photo: CSISA)

Plant nutrients play an important role in crop production and the realization of food security is linked with the significant use of fertilizer. The proper amount of fertilizer, the correct nutrients in the right proportion, and the application of fertilizer at the right time and through appropriate methods help farming communities attain higher yields and profitability. Balanced fertilization also helps maintain soil health, which leads to environmentally sustainable farming.

In South Asia, however, most farmers are often unaware of the specific role and contribution of each plant nutrient. Farmers' fertilizer decision-making processes are commonly limited and usually based on perceptions that rarely follow the concept of balanced nutrition.

The hunger for nitrogen

Grain production is proportionate to fertilizer usage. Among the three major fertilizers—nitrogen, phosphorus, and potassium—the global use of nitrogenous fertilizers (urea) is the biggest. The world nitrogen fertilizer demand increased from more than 111.4 million tons in 2013 to 113.1 million tons in 2014 and it is expected to be around 119.4 million tons in 2018 (*World fertilizer trends and outlook to 2018*, FAO).

India is one of the world's largest consumers of urea. The consumption of urea in the country has increased manyfold after the Green Revolution. This is mainly due to the lack of soil testing facilities for a large number of marginal farmers who are mostly unaware of modern tools and techniques. Often, the farmers' decision to apply fertilizer is resource-driven rather than science-driven as they have no tools to measure the available nutrients present in the soil. They often have no idea of the soil's inherent capacity to supply nutrients.

Maximum effort, minimum impact

These practices not only result in low crop productivity but also adversely affect the environment. Although India produces 10% of world fertilizer, it relies on expensive imported urea to fulfill the local nitrogen consumption (FAOSTAT 2013). The cost of importing nitrogenous fertilizers and the government subsidy for urea increased tremendously from year 2005–06 to 2014–15 but did not result in any significant increase in cereal production, according to government and FAO data.

The 4Rs of nutrient management

In spite of the high cost and unwanted environmental impact of fertilizer, we cannot overcome the challenges of increasing global population and decreasing arable land without its use. Hence, the importance of knowledge on the efficient use of fertilizer is essential for economic reasons as well as for limiting the effect of its excess usage on the environment.

Precision nutrient management combined with soil health improvement will play a crucial role in crop production. This demands a better nutrient management recommendation guideline for farmers that is scientifically robust and user-friendly to help them adhere to the 4Rs: right amount, right source, right application method, and right application timing.

Farmer-friendly tools

Some farmers now have access to tools such as *Crop Manager*, GreenSeeker®, and the leaf color chart for site-specific fertilizer application. The major benefits of using nutrient management tools include smart fertilizer usage that cuts down wastage and the cost of production and, hence, brings about an increase in income, higher crop productivity, and lower greenhouse gas emissions from rice production.

Crop Manager. The International Rice Research Institute (IRRI), through the Cereal Systems Initiative for South Asia project, and collaborating government agencies have developed *Crop Manager*, a web- and Android-based decision-making tool that provides location-specific fertilizer recommendations for farmers growing rice-wheat and maize in Bihar and eastern Uttar Pradesh.

This easy-to-use app, designed for small-scale farmers and extension workers, can rapidly provide nutrient recommendations for individual farmers' fields with or without soil testing data. The farmers provide information about their field and crop management practices such as planting method, rice variety, typical yields, choice of fertilizer, method of harvesting, etc. Based on these inputs, this tool recommends how much nitrogen, phosphorus, and potassium to apply and the critical growth stages of the plant when these should be added to obtain a higher yield and profit. *Crop Manager* aims to increase farmers' income by USD 100 per hectare per crop.

GreenSeeker®. This tool can be used to readily derive the nitrogen requirement of a standing crop through a smart mobile application. This handy instrument determines the right amount, the right place, and the right time to apply nitrogen, thereby optimizing fertilizer input and yield.

Leaf color chart. Primarily developed for rice, this chart helps farmers rapidly assess leaf nitrogen status at crop growth stages as a basis for the amount of nitrogen to be applied. This tool has four green strips with colors ranging from yellow green to dark green. It determines the greenness of the rice leaf, which indicates its nitrogen content.

Soil health cards. In 2015, the Government of India launched the soil health cards to improve the soil health of individual farmers' fields. Under the scheme, soil samples from farmers' fields are analyzed in various soil testing laboratories across the nation for water content and water-retention capacity, the presence of macro- and micronutrients, pH and salinity levels, and clay content. The results are handed over to the farmers in the form of a soil health card to serve as a guide for applying fertilizer for various crops. ■

Ms. Kumari is an extension agronomist at IRRI-India.

An extension worker interviews a farmer to help formulate a specific fertilizer recommendation for his crop using *Crop Manager*. (Photo: CSISA)

CIAT's most distinguished "offspring" in Latin America

by Adriana **Varón**

They have been leaving home since 1967 and, although they are scattered across Latin America, they all have something in common: the surname CIAT. These are 377 rice varieties that have been released over the last 50 years and they all carry the germplasm of International Center for Tropical Agriculture (CIAT) in their blood.

According to research conducted by CIAT's Data, Information, and Knowledge team, out of 857 rice varieties released in 24 countries in Latin America and the Caribbean since CIAT began, 44% are its offspring of its germplasm.

According to Fernando Correa, leader of CIAT's Rice Program, some traits have remained common over the last 50 years of family history: they are short plants that do not fall over when the wind blows, they are high-yielding varieties with good-quality grains, and they are resistant to tropical pathogens, among other distinctive traits.

But, where does the lineage come from?

A year after CIAT was founded, a new rice variety, IR8, released in the Philippines by the International Rice Research Institute (IRRI), had accomplished the unimaginable: it prevented death by starvation of thousands of people in Asia. A semidwarf, early-maturing, and high-yielding rice variety had made it possible to move from producing 2–3 tons per hectare of paddy rice to an average of 4–6 tons, with a potential yield surpassing 9 tons. It marked a revolution, the so-called Green Revolution. In November 2016, IRRI celebrated the 50th anniversary of the official release of the rice variety that changed the world.

Peter Jennings, the scientist who led the breeding team that developed IR8, moved on to Latin America (see *Luck is the residue of design* on pages 10-11 of *Rice Today* Vol. 7, No. 1). One hundred kilograms of the miracle seed sent from the Philippines were enough for the variety to be disseminated by the Colombian National Federation of Rice Producers (Fedearroz) across Colombia and later throughout the rest of the region.

It was then that the rapidly growing CIAT found in Fedearroz and the Colombian Agricultural Institute (ICA) the best allies to develop new rice varieties emanating from IR8. Varieties Metica 1; Tikal 2; Oryzica 1; Oryzica Llanos 4 and Oryzica Llanos 5; Cica 4, 6, 7, and 8; and others began to be sown across the irrigated rice producing area of Colombia, with a 50% increase in the average national yield.

"The release of IR8 enabled rice breeding programs in Latin America, in close collaboration with the Rice Program at CIAT—led in its infancy by Dr. Jennings—to evolve and release varieties with a great potential onto the market," said Correa. This is demonstrated by the 487 varieties released in Latin America with IR8 among their ancestors.

The prodigious parent

The 1960s and '70s were just the beginning of the fertile pathway for rice in Latin America. In the first decade of research, ten varieties were released. Then, during the mid-1980s and '90s, the rice breeding program at CIAT discovered genes, performed crosses, moved forward, selected, and sent material to countries in Latin America and the Caribbean, its field of action. The acceptance of the varieties was such that 219 were released in 20 years, all of which were based on relatives or crosses made at CIAT.

Brazil, the largest rice production zone in Latin America (more than 12 million tons), appears as the country that most widely opened its doors to the release of varieties originating from CIAT germplasm: 79 varieties contain at least one gene from CIAT in their DNA, which represents 42% of the seed released in that country. Brazil is followed by Colombia with 59 released varieties, Costa Rica with 30 varieties, Venezuela with 28, and Panama with 24. Meanwhile, in the Caribbean, the presence of varieties with a CIAT ancestor is led by Guyana with seven varieties, Cuba with six, and the Dominican Republic with five. The study also estimates that more than 70% of the released varieties in Central America are related to CIAT germplasm.

As pointed out in the book *Forever Pioneers – CIAT: 50 Years Contributing to a Sustainable Food Future*, the most recent estimate from eight Andean and Central American countries is that 63% of the rice area in those countries is sown to varieties based on CIAT crosses. Likewise, it highlights that, over the past 50 years, on-farm rice yields in Latin America have increased at 2.3% annually, above the global average of 1.5%.

A resistant network

In 1995, the Latin American Fund for Irrigated Rice (FLAR) joined the family. Brazil, Colombia, Venezuela, and CIAT, the latter as a strategic partner, brought this network to life with the purpose of improving the competitiveness and sustainability of rice production systems in the region.

CIAT continued its research on rice breeding with a focus on broadening its germplasm base and gene discovery, based on requirements such as tolerance of high temperatures, low solar radiation, drought, and new diseases. As an invaluable legacy, the new lines were passed on to FLAR or national programs to be used in crossings. Over the last 20 years, 76 of the rice varieties that have been released in Latin America originate from CIAT and FLAR. (A study is being conducted to determine which of the 377 CIAT-origin released varieties have been adopted by farmers in Latin America and the Caribbean, and their economic impact in each country.)

Beating records

Having Latin American fields sown to "made at CIAT" rice varieties able to outperform regional mean yields is a source of family pride. This is the case for Peru, where 43% of the released varieties have a genetic combination of CIAT origin. Although the average national production is 7.7 tons, exceeding the regional average of 5 tons per hectare, some farmers in coastal areas, such as Piura and Arequipa, obtain yields of up to 16 tons per hectare—some of the world's highest.

For Eduardo Graterol, FLAR executive director, adopting modern varieties with high performance potential and acceptable resistance to pests and diseases, along with tolerance of environmental stresses, has played a critical role in achieving such high production.

CIAT's commitment to the region has focused not only on obtaining new improved varieties but also on training programs. The fields and laboratories at CIAT have constituted learning scenarios for researchers, technicians, and other outreach workers from public and private organizations.

The Rice Program at CIAT will continue to support different countries in the region. This will involve efforts to strengthen their capacity and establish mechanisms to enhance competitiveness through genetic material (e.g., conducting research on wild species). Through FLAR, it will also involve a renewed focus on agronomy, since better crop management practices can help realize the genetic potential of improved varieties, as well as the new hybrids being developed by CIAT and FLAR through the Consortium on Hybrid Rice for Latin America (HIAAL).

Certainly, the contribution of the "offspring" in Latin America over the last 50 years, and more recently of FLAR, has been extraordinary. The new rice varieties should increase yield and stress tolerance, but also ensure a grain quality that complies with consumer preferences in both domestic markets and lucrative international markets. In addition, technologies to improve producers' income and sustainability must be provided, regardless of the size of their farms.

The research of the Rice Program at CIAT and FLAR and the hundreds of researchers who have contributed to the progress over the last 50 years, as well as the management of their technologies through public-private partnerships, will ensure that the rice produced on our continent continues to be a core component of the family basket, while providing a source of income to help reduce poverty and rural migration, with a smaller environmental footprint than in the past. ■

Ms. Varon is the communicator chief for LAC at CIAT.

On the tracks of CT

It took CIAT's Data, Information, and Knowledge team more than three months to collect the information to determine the number of varieties with a CT (CIAT) origin grown in Latin America and the Caribbean. The team, led by Arturo Franco and Carolina García, turned to databases such as the Breeding Management System (BMS), from the software of the Integrated Breeding Platform, of which CGIAR is a member, that provides access to tools and cutting-edge services to update plant breeding programs around the world.

Through data mining, engineers started deciphering the family tree of the rice varieties released in the region. Support from CIAT and FLAR researchers, as well as from other international agencies, such as FAO, was also required to solve the puzzle.

"We started noting that the involvement of CIAT genes was becoming increasingly important in varieties registered to have been released in Latin America and the Caribbean," said systems engineer Carolina García. "And, although there were varieties we could not trace for lack of information, the results show that both IR8 and CIAT varieties have played a leading role in the development of rice in the region."

The BMS platform also has information on released varieties of cassava, beans, and tropical forages. While it is estimated that many of these varieties are also CIAT descendants, no study has been conducted to ascertain how many varieties proudly carry the CIAT surname.

Making a difference (Part 1)

Walter Cronkite, the late great reporter for CBS News in the U.S., once said, "A career can be called a success if one can look back and say, 'I made a difference.'" By this measure, four new International Rice Research Institute (IRRI) alumni, who retired in 2017, have been extremely successful. It is poignant that Roland Buresh, J.K. Ladha, Noel Magor, and Nollie Vera Cruz all boxed their papers and passed the baton on to their successors last year. But, it is certainly uplifting to revisit their time at IRRI over a combined 119 years of service to the institute. Fortunately, they were able to include me in their busy schedules for respective well-earned Pioneer Interviews before they departed for new adventures in retirement. In Part 1, Roland and J.K. discuss their days at IRRI. Part 2 will feature Noel and Nollie in the April-June issue of Rice Today.

PHOTOS: GENE HETTEL, IRRI

Forty years in the mud

Roland Buresh, who spent 24 years at IRRI as a soil scientist, worked primarily on nutrient and crop management, first as a visiting scientist in a 7-year stint in 1984-91 and then again to stay as a senior scientist in 2000 and as a principal scientist from 2010. Add to this his stints as a soil scientist at the International Centre for Research in Agroforestry (now World Forestry Center) in Nairobi, Kenya, and the International Fertilizer Development Center in the U.S., and this son of a Minnesota dairy farmer has, as he puts it, had a 40-year journey through the mud.

With an MS degree in soil science from North Dakota State University and a PhD in marine sciences from Louisiana State University, Roland, at IRRI, focused on site-specific nutrient management (SSNM) as well as sustainable management of intensive irrigated rice, crop residue, and rice-maize cropping systems. He also guided IRRI's Long-Term Continuous Cropping Experiment (LTCCE), one of the world's longest-running agricultural trials. As a spin-off from the SSNM work, Roland pioneered the development of various innovative knowledge transfer tools, culminating with *Rice Crop Manager*, which specifically aids small-scale farmers in Asia.

"When I came to IRRI in 2000, I inherited the institute's SSNM research," he explained. "This concept had been pioneered by agronomist Achim Dobermann and other scientists. In the 1990s, IRRI had already been very successful in developing and publishing the scientific principles for better site-specific management of nitrogen, phosphorus, and potassium fertilizers."

The challenge at that stage was to take this excellent science to the farmers. So, one of Roland's major tasks in the ensuing 17 years was to help take this scientifically proven technology into the hands of farmers.

"Along the way, we tried a number of things," recalled Roland. "First, we met with farmers to get a better understanding of their problems. That led to refinement of the leaf color chart to help determine nitrogen application rates. Eventually, we produced other printed materials in which SSNM principles were presented to extension workers and farmers. By 2006-07, we had developed one-page quick guides on how to manage fertilizer depending on yield targets and the crop-growing environment. In fact, for the Philippines, we developed quick-guide fertilizer recommendations based on SSNM principles for every rice-growing province in the country."

And then one morning, during his daily 4-km walk from home to office, it suddenly struck Roland that, if a farmer were asked approximately 10 questions about his or her specific farming situation and goals, an

In 2014, Roland and then Director General Robert Zeigler join in the ceremonial harvest of the 150th crop of the LTCCE at IRRI headquarters. Later, he explains the importance of the experiment to Bill Gates. Roland managed the landmark experiment at IRRI for 17 years. (Photos: IRRI)

extension agent could use the answers to construct a field-specific fertilizer recommendation that would be unique to that farmer's field. "That was the breakthrough!" Roland said.

However, even with the answers, it would not be easy for an extension worker to identify the correct recommendation from just the printed materials that IRRI had developed.

"Then, I got the idea in 2008, why not use a computer to make the calculations," he chimed. "That's how *Nutrient Manager for Rice* got started. It was initially programmed in Microsoft Access for the Philippines and then other countries, such as Indonesia and Bangladesh."

This effort required very close collaboration with national programs to obtain a better understanding of local crop-growing environments and to tailor questions for translating into local languages. "The next step was to try different versions of mobile smartphone applications," Roland added. "Interactive voice response was quite successful, especially in the Philippines and Indonesia."

Finally, when integrating this technology into web-based programs, Roland and his team realized that nutrient management recommendations alone were not enough for farmers. "There was a real need for additional information on the rice crop itself, such as variety used, how many crops each year, irrigated or rainfed, type of nursery preparation and transplanting, etc.," he said. "So, in 2013, we developed *Rice Crop Manager*, which provides farmers with personalized crop and nutrient management guidelines.

We've been particularly fortunate in the Philippines to have support from the government through its Department of Agriculture and the National Rice Program. Their funding and assistance have facilitated more research on and key dissemination of this technology."

In the four years after the introduction of *Rice Crop Manager*, 1.2 million recommendations have been generated and provided as printed guides to Filipino farmers. Certainly, an innovative way to make a difference for farmers!

Another of Roland's major projects was the LTCCE, in which more than 150 rice crops (three times annually) have now been grown continuously without a break since 1962. He believes the LTCCE has brought varieties together with good water and fertilizer management to allow researchers to make recommendations to sustain rice production (see *A never-ending season* on pages 10-15 in Vol. 13, No. 3 of *Rice Today*).

"The yield trends that we have observed through time in the LTCCE are driven in good part by variations in weather," he pointed out. "There's not only a difference between wet and dry seasons but also from year to year. Now, with a long historical record of yields and crop performance across seasons and years to analyze, I believe we have a unique opportunity to really look at sustainability from the perspective of change in climate, which involves dealing with increasing nighttime temperatures and changes in solar radiation."

In recognition of his innovative work to make a difference for Asian farmers, Roland won the International Fertilizer Association's 2011 Norman Borlaug Award for excellence in crop nutrition research. He received the 2016 People's Republic of China Friendship Award for his contributions to nutrient and crop management technology now used on 40% of the rice-growing area in Guangdong Province and steadily expanding elsewhere in China.

Grappling with an enigma and nurturing future scientists

Jagdish Kumar "J.K." Ladha, another retiring soil scientist with a long service to IRRI, is recognized internationally as an authority on cereal systems research, conservation agriculture, soil fertility, and plant nutrition. Hailing from Gwalior, a major city in the Indian state of Madhya Pradesh, he was interested, at an early age, in the tiny microbes that exist everywhere in nature, especially in plants and the soil. Armed with a PhD in botany from Banaras Hindu University, he set out in 1976 on a career in agriculture to do research on soil microbiology, fertility and plant nutrition, and cereal systems, subjects on which he has subsequently authored or co-authored more than 200 internationally refereed journal articles and 13 books.

Intrigued by the work at IRRI that had led to the high-yielding semi-dwarf rice varieties, such as IR8, he came to the institute as a postdoctoral fellow in 1980 for a "short" posting that ended 37 years later!

"I stayed all these years because I truly enjoyed the work here and the potential for achievement," J.K. relayed. "Over this time, I've managed several soil microbiology and nutrition research projects and have had some administrative responsibilities, including coordinating the Rice-Wheat Consortium for the Indo-Gangetic Plains and heading the IRRI-India Program for 12 years."

Throughout his career, a topic that has continually attracted his attention and interest is nitrogen, an "intriguing enigma," as he calls it. About half of all nitrogen fertilizer applications go to the three major cereals—rice, maize, and wheat. "Nitrogen's good side is that the nutrient is required for crop production," said J.K. "However, the element's bad side—here referring to synthetic nitrogen—is that excess amounts not used by plants go either into the groundwater as nitrate or into the atmosphere as nitrogen oxide, which can cause serious human and animal health problems and air pollution."

The challenge is to optimize nitrogen use while minimizing its negative impacts. "We have been encouraging farmers to efficiently apply nitrogen fertilizer only when the crop requires it," said J.K. "One of the most exciting projects for me at IRRI was working back in the 1990s on the international initiative to look into the feasibility of developing cereals, such as rice, that could fix biological nitrogen like legumes do."

According to J.K., before the idea was put back on the drawing board due to a funding shortage, the researchers determined that it would most likely take some complex genetic engineering to accomplish this, but what an achievement it would be.

During his 12-year stint as IRRI's representative for India, J.K. met with farmers such as Akhtar Kahn in Uttar Pradesh (*above*) and even Barack Obama when the then U.S. president visited Mumbai in 2010 (*upper right*). At right, he secures his own souvenir panicles during the ceremonial harvest of the LTCCE's 150th crop. (Photos: IRRI)

Along with his IRRI "comrade in soils," Roland Buresh, J.K. has analyzed with great interest the data coming out of the LTCCE. "In the experiment, we have watched rice yields decline starting in 1968, all the way through to 2015," J.K. pointed out. "So, growing three rice crops in a year is too intensive to be sustainable in the long term unless the relationships between varieties and agronomy are addressed. We also have to look at the soil's microbiology and chemistry over time and how these adjust to changes in climate. The volumes of information coming out of the LTCCE are proving to be very useful in developing and validating new rice-growing models for the future."

J.K. spent most of his last 15 IRRI years in India as the institute's country representative. "India has been a very strong natural partner of IRRI from the beginning," he said. "It's got all the agro-ecosystems that represent Asia as a whole. When I arrived there in 2004, research was shifting to the new frontier of unfavorable environments in eastern India, where much of the country's food production is and will be coming from."

In early August 2017, the Government of India and IRRI further bolstered their partnership with the establishment of the IRRI South Asia Regional Center in Varanasi, Uttar Pradesh, from where IRRI and India will be conducting joint research on breeding, agronomy, and grain quality, not only for India, but for neighboring countries as well.

"I think it's remarkable to have this kind of an agreement with India," J.K. beamed. "This fantastic model for a regional research hub will open the door for duplication in other regions of the developing world."

Notwithstanding all the research J.K. has conducted, he believes that he has made the biggest difference in nurturing the next generation of rice scientists. "I have been fortunate to work with many, many young students from all over Asia and the world," J.K. smiled. "It's very rewarding when these people finish their degree or nondegree training and then go back home to make their mark, some leading their own rice research programs." Related to education, J.K. has also found time to be a prolific writer, having one of the highest numbers of publications cited in the entire CGIAR system, with more than 18,000 listings on the citation index.

J.K. has won numerous accolades throughout his career, including the International Service in Crop Science Award from the Crop Science Society of America (CSSA), the Lifetime Achievement Award from the Soil Conservation Society of India, the International Service in Agronomy Award from the American Society of Agronomy (ASA), the International Service in Soil Science Award from the Soil Science Society of America (SSSA), the International Plant Nutrition Science Award from the International Plant Nutrition Institute, and the Agriculture Prize from the Third World Academy of Sciences. He is also a Fellow of the Indian Academy of Agriculture Science, American Association for the Advancement of Science, ASA, SSSA, and CSSA.

Roles for IRRI beyond 2020

Roland and J.K. were asked what they saw as IRRI's biggest challenge as the institute nears its 60th anniversary in 2020.

Roland believes that the research-to-technology link is critical for impact and a key area for innovations from IRRI now and in the future. "The dissemination part of the pathway is more about partnerships with national systems and creative technical inputs from IRRI," he said.

"I strongly believe that IRRI must stay on track with frontier areas of research," said J.K. "The institute must also continue its role as an honest broker that links developed-country advanced institutions and the private sector with national programs. I see this as a much more important function now than when IRRI started in the 1960s." ■

Mr. Hettel is a senior consulting editor and content specialist at IRRI.

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