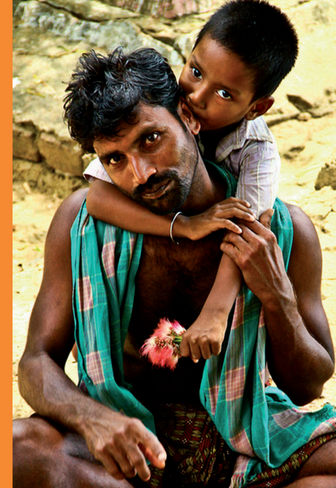

Annual Report 2010

IRRI
INTERNATIONAL RICE RESEARCH INSTITUTE

The International Rice Research Institute (IRRI) was established in 1960 by the Ford and Rockefeller Foundations with the help and approval of the Government of the Philippines. Today, IRRI is one of the 15 nonprofit international research centers supported by the Consultative Group on International Agricultural Research (www.cgiar.org).

IRRI receives support from the following CGIAR members: Asian Development Bank, Australia, Bangladesh, Canada, China, European Commission, Food and Agriculture Organization, France, Germany, India, International Fund for Agricultural Development, Iran, Japan, Korea, Malaysia, Norway, Philippines, Portugal, Rockefeller Foundation, Sweden, Switzerland, Thailand, United Kingdom, United States of America, and the World Bank.

In 2010, IRRI also received support from Africa Rice Center, Bayer CropScience AG, Bill & Melinda Gates Foundation, Bioversity International, CGIAR/System-wide Genetic Resources Program/Special Program for Impact Assessment, Challenge Programs (Generation, HarvestPlus, and Water&Food), Cornell University, Global Crop Diversity Trust, Grand Challenges in Global Health, International Atomic Energy Association, International Center for Agricultural Research in the Dry Areas, International Crop Research Institute for the Semi-Arid Tropics, International Fertilizer Industry Association, International Food Policy Research Institute, International Plant Nutrition Institute, International Potash Institute, Kellogg Foundation, Nunhems BV, Pioneer Hi-Bred International, Plan International Cambodia, Syngenta Asia Pacific Pte. Ltd., Vietnam, and World Vision, Inc., among others.

The responsibility for this publication rests solely with the International Rice Research Institute.

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Suggested citation:
IRRI (International Rice Research Institute). 2011. Annual report 2010. Los Baños (Philippines): International Rice Research Institute.

On the cover: A montage of images depicting some of IRRI's key research activities in 2010 and the faces of our major stakeholders—the rice farmers and consumers of the world.

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Distribution: Lourdes Columbres

IRRI Annual Report 2010 (DVD)

Online version: http://irri.org/ar2010

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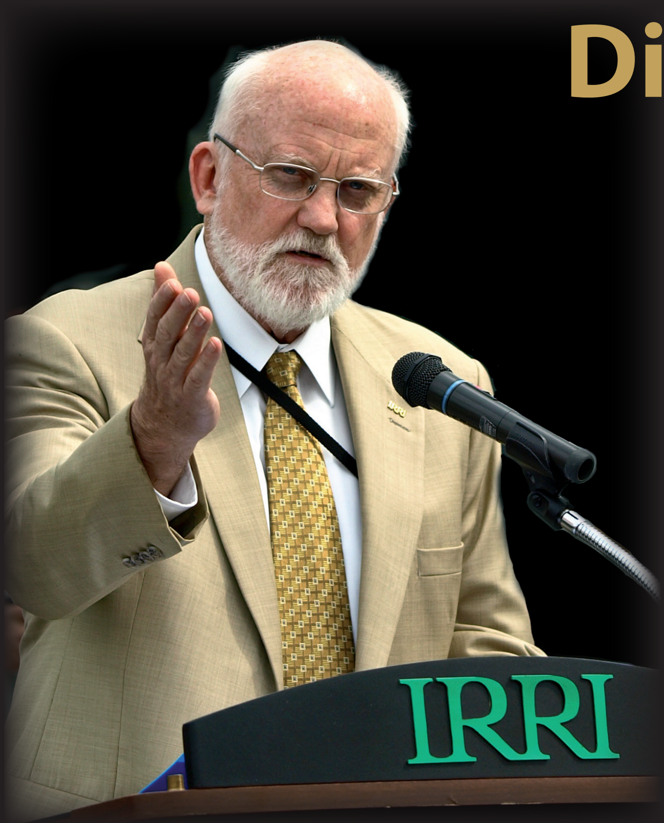

ISAGANI SERRANO

Well before former U.S. Vice President Al Gore coined the term *An Inconvenient Truth* for his 2006 documentary film of the same name to educate citizens about global warming, I talked about a *Convenient Convergence* of the nexus of food security and climate change.

What I mean by this is that, regardless of the impact of future climate change, most of the work that we do here at IRRI is intended to have—and in many places is already having—an impact on improving the lives of the very poor who live in areas that are affected by the same exact stresses in agriculture that are expected to become more widespread with climate change. Our research is also improving productivity and reducing the environmental footprint of agriculture.

The solutions for many farmers' most pressing problems—drought, floods, salinity due to seawater **intrusion**, etc., for growing rice and other crops—are converging with solutions to problems posed by future climate change. I stressed this point during a panel discussion on *Partnering with smallholders: Strategies for food security*, in which I participated during the 2010 Borlaug Dialogue of the World Food Prize events in Des Moines, Iowa, last October. I added that, by applying ourselves and then looking at the challenges from the perspectives of farmers' needs today, the needs of the environment tomorrow, and the challenges that farmers will be facing by 2050, we have an opportunity to develop multiple-win scenarios.

There is exciting research progress to report on for 2010, some of which illustrates my point about convenient convergences and multiple-win scenarios. For example, our scientists are conducting crop management research to squeeze even more yield out of our flood-tolerant rice varieties, such as Swarna-Sub1 (photo). In another project, we are looking to enhance our Sub1 varieties by incorporating salinity tolerance into them as well. And, in work that is directly related to dealing with the hotter days and nights of tomorrow, we are (1) developing varieties that can cope

ADAM BARCLAY

better under heat stress, (2) exploring technologies that will potentially cut down on the greenhouse gas emissions from rice production, and (3) re-engineering photosynthesis in our C_4 Rice Project, which, we hope, will enable the crop to produce 50% more grains while using less nitrogen and water at the same time.

The details of these and some other thrilling research thrusts are highlighted in both the following pages of this attractively printed version of the annual report and the award-winning DVD and Web formats that have become acclaimed digital standards over the last three years.

Although all of our major events and activities in 2010 are covered in detail in the "Milestones" section of the DVD and Web versions, I would like to call special attention to several here because, as I think about it, all involve convenient convergences to one degree or another.

First, rarely had we ever begun a year with the promise and potential that we saw for 2010. It had been decades since there was such broad and strong interest in (and concern about) agriculture and rice production as we are confronted by a sobering set of problems and challenges to achieve global food security and help reduce hunger and poverty in the face of the looming climate change that I have already alluded to. This converged nicely with IRRI turning 50 years old in 2010. This significant milestone gave us an unprecedented opportunity to pause and reflect on the lessons of the past, while looking forward to the incredible breakthroughs that science is set to bring the world in the future.

IRRI 50 1960-2010 Rice Science for a Better World

Our special birthday events, particularly in April with our alumni homecoming at headquarters and in November during the 3rd International Rice Congress in Hanoi, gave us grand stages upon which to showcase our important work to not only our clients and donors but also to a general public who may have—up to then—known little or nothing about us. During the Rice Congress, as the photo above right shows, I made every effort to talk to local media about what IRRI is doing.

Our birthday party also gave us a "golden" opportunity to sponsor our 50th anniversary 5-year fund-raising campaign (www.irrifund.org) to find the

GENE HETTEL

resources and build the infrastructure IRRI will need to grow and accelerate its work in the decades to come. To enhance this effort, we launched the IRRI Foundation Hong Kong (IFHK) during a special event there in November. Support in Hong Kong for IRRI's work already comes from some anonymous donors, but, with the establishment of the IFHK, I expect the support will both increase and become more public. I'm very excited by the support we are already getting for the campaign—from personal donations of US$1,000 to larger gifts from big companies—and IRRI looks forward to working with the people of Hong Kong to help poor rice farmers in Asia.

During a panel discussion at the 29 November launch, I (at center in photo below) told the audience in attendance that, as a major business center in Asia and given the cultural value and importance of rice there, and China's role in the global rice industry, Hong Kong is ideally placed to help raise awareness about how rice research can help achieve food security and reduce poverty in Asia. I pointed out that we are meeting many motivated people in Hong Kong and the region who recognize this and want to support the campaign.

The launch of the IFHK follows the November 2009 launch of the IRRI Fund Singapore (IFS) in Singapore. These two new IRRI charities will be important

ASIA SOCIETY

LANIE C. REYES

mechanisms to enhance the Institute's fund-raising efforts and activities in Asia to provide additional support for the IRRI-led Global Rice Science Partnership (GRiSP), which involves another convenient convergence I want to mention next.

In early 2009, Achim Dobermann, our deputy director general for research (at center in photo above); the research staff; and I began to think about how rice research everywhere on the planet could be amalgamated through key partnerships to reduce rice prices, diminish the emission of greenhouse gases, and lift 150 million people out of poverty by 2035. The thinking, planning, and consulting with key partners for setting this up continued throughout 2010 and culminated with the official launch of GRiSP as the very first approved research program of the new CGIAR (Consultative Group on International Agricultural Research) in November during the International Rice Congress in Hanoi (photo).

Here, IRRI and its partners had an exciting new single strategic and work plan for enhancing global rice research, which conveniently converged with the CGIAR's urgent desire to find and fast-track a CRP (CGIAR Research Program) that meshed with its new business model. That model emphasizes clear lines of accountability and balances the partnership between those who conduct research, on the one hand, and those who fund it, on the other.

IRRI is leading GRiSP overall and activities in Asia, with the Africa Rice Center (AfricaRice) leading the work in Africa and the International Center for Tropical Agriculture (CIAT) the work in the Latin America and Caribbean region. Other internationally operating research organizations such as the Centre de Coopération Internationale en Recherche Agronomique pour le Développement (CIRAD), L'Institut de Recherche pour le Développement (IRD), and the Japan International Research Center for Agricultural Sciences (JIRCAS) are playing strategic roles in GRiSP as many more partnerships are being fostered.

I am excited to point out that GRiSP is leading scientists to embark on the most comprehensive attempt ever to deploy rice's genetic diversity. Cutting-edge research aimed at discovering new rice genes and deciphering their functions will feed into accelerated efforts to break the yield barrier in rice and to breed new generations of "climate-ready" rice with flooding tolerance and other traits that are essential for adapting production to future environmental challenges. I expect GRiSP to boost supplies enough to reduce anticipated increases in rice prices by an average of at least 6.5% by 2020, and at least 13% by 2035.

IRRI is very enthusiastic about the new programmatic thrust of the CGIAR and excited to be a part of it and to avail of some of the new funding for research that it should bring in. In a recent article in the journal *Nature*, Research sans frontières, I stated that the CGIAR used to be "physically isolated from the advanced research institutes" in developed countries. Today, the centers are forging partnerships with world-leading labs in Europe and the United States, working on challenging projects such as our own re-engineering of photosynthesis in rice to be more efficient (the C_4 project I mentioned earlier). This would have been unheard of a decade ago. I went on to say in the *Nature* piece that collaboration can boost citation impact, spread costs, and broaden research horizons—and that the work at IRRI is a shining example of this.

To achieve what we must in our various research endeavors that are now a part of GRiSP, IRRI continued

IRRI

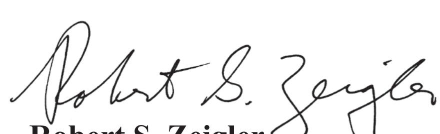
to grow in 2010. We hired 16 new people every month and a new member of the staff joined every three-quarters of a working day. In addition, we hired 358 people on short-term appointments. Toward the end of the year, we were still actively recruiting to fill 84 vacancies across the Institute (78 national staff, 4 international staff, and 2 postdoctoral fellows).

I am fully aware that IRRI will continue to be successful and carry on its award-winning tradition only if it can hire and retain high-quality staff members such as those in the photo above. That is why, in 2010, the Institute initiated a series of improvements in response to staff feedback. There are now formal, consistent, and transparent career paths for both international and national staff. And, there is ongoing support for internal advancement for staff who consistently achieve at a high level. For example, during the first three quarters of 2010, 68 national staff members (7% of the total national workforce) were promoted as a result of either position reclassification or a successful application for an internal vacancy. So, I invite young scientists and researchers around the world to consider joining us for a rewarding career as part of a team of more than 1,000 research and support staff working toward "rice science for a better world."

I would like to close with something that really has me worried. For several years now, I have been monitoring a world population clock on the front page of the IRRI Web site. This clock is forever ticking upward, while at the same time, just beneath it, there is a productive land clock forever ticking downward—an "inconvenient divergence" if I ever saw one!

Sometime during the fourth quarter of 2011, our clock will turn over to 7,000,000,000 souls, almost half of whom depend on rice for their staple food. Predictions are that the trend will continue, with the clock showing 9,000,000,000 by 2050—less than 40 years away! I read

in a recent Global Harvest Initiative press release that, if we are to feed all these people sharing our planet by then, we will need to produce as much food in the next 40 years as we have in the last 8,000! Focused and cutting-edge agricultural research, such as that done by IRRI and its partners, will be critical if we are to meet this formidable and daunting challenge.



Robert S. Zeigler
Director General

Snapshots from space

Rice production and space satellites may appear to have nothing in common, but, for IRRI and its partners, satellite observations are crucial for revealing the big picture. "Snapshots" from space provide information for better management of the world's agricultural resources. Remote-sensing satellite technology has opened up a new frontier in large-scale monitoring of crop production, detecting changes, and even predicting yield.

Rice plays an important role in supporting over 3 billion people around the world—with more than 6.7 billion bowls of rice consumed every day. This makes accurate information about the crop indispensable for making policies related to the spatial distribution of rice fields, water resource management, annual production projections, and market predictions. However, most agricultural surveys rely mainly on statistics based on limited ground samplings taken at the grass-roots level at which data are extrapolated on a national scale. Although a field-based census can provide statistical estimates, the slow and infrequent collection of data acts as a barrier for timely decision-making. Additionally, this method fails to provide reliable data on the spatial distribution of crops.

Farming from the sky

The advent of free and frequent imagery such as that provided by the Moderate Resolution Imaging Spectroradiometer (MODIS) carried aboard NASA's Terra and Aqua satellites is giving researchers a new point of view. Terra orbits Earth from north to south across the equator in the morning, while Aqua moves south to north over the equator in the afternoon. Thus, Terra MODIS, launched on 18 December 1999, and Aqua MODIS, launched on 4 May 2002, are scanning the surface of the entire planet every 1 to 2 days. This allows IRRI and its partners to continuously map and monitor the rice-growing areas across all of Asia.

IRRI uses MODIS surface reflectance images, which measure the part of solar radiation that is reflected by the land surface. "Different surfaces reflect this radiation in different ways, and for vegetation and especially field crops the surface reflection changes dramatically throughout the season," said Dr. Andrew Nelson, head of IRRI's Geographic Information Systems (GIS) group. "It is these changes in surface reflectance before, during, and after the rice season that enable us to detect and monitor rice-growing areas."

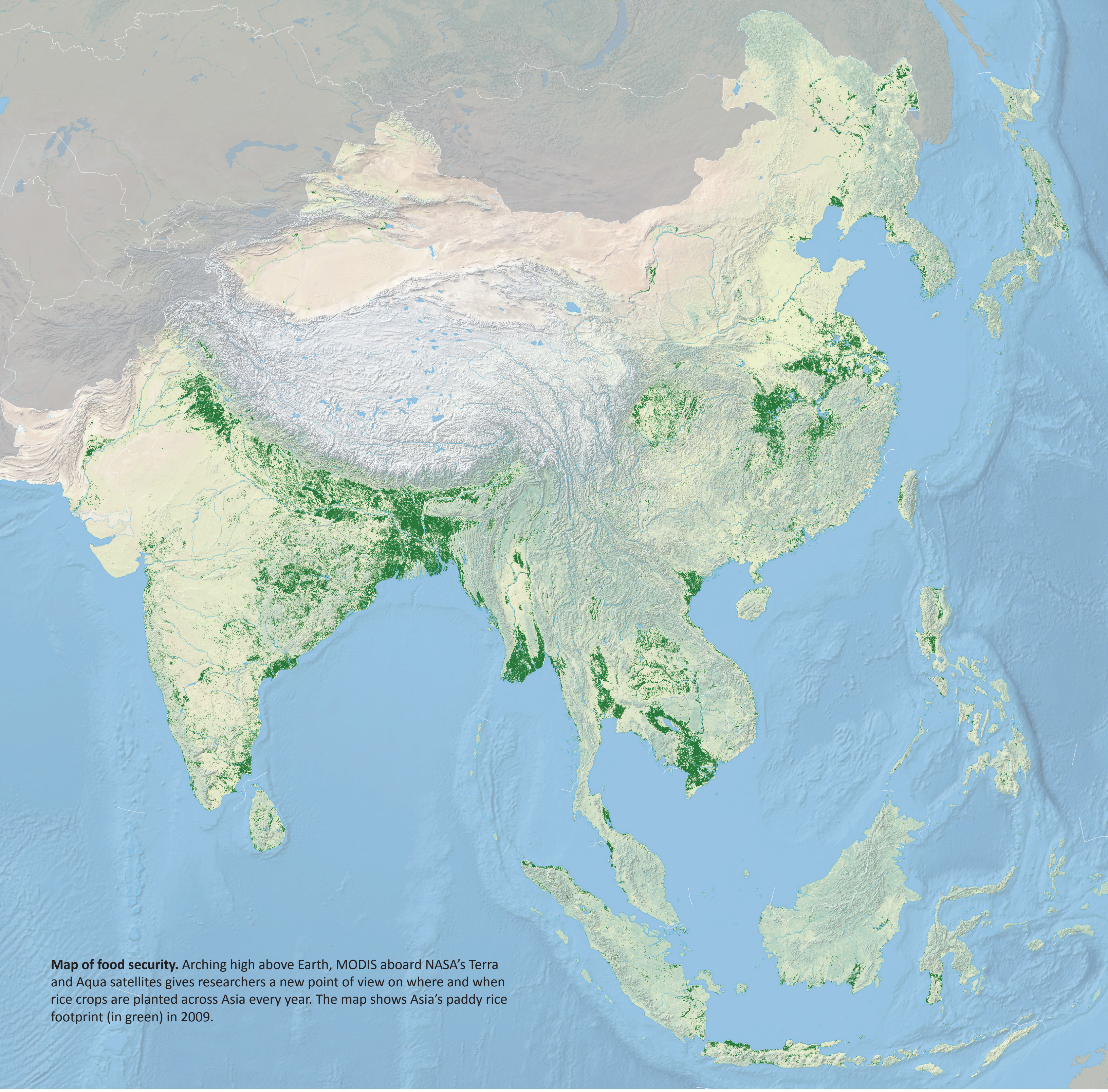
A spatial bird's-eye view

Knowing where and when rice is planted are key pieces of information that will feed into IRRI's Global Rice Information Gateway. Remotely sensed images from satellite platforms that pass over the entire Asian region daily can provide accurate and timely estimates of how much land is planted to rice and when it is planted.

"We first use on-the-ground observations to identify the time and duration of key stages of the paddy rice crop, such as flooding, transplanting, heading, and harvesting," Dr. Nelson explained. "The MODIS images that are most suitable for rice mapping are available every 8 days, or 46 times a year, so we can correlate the observed stages of the rice crop to this time series of surface reflectance. This provides us with a paddy rice signature. Any pixel in the remote-sensing image that matches that signature is classified as paddy rice, which results in a map of where and when rice is planted."

MODIS imagery is not detailed enough to detect individual paddy fields, but rice is often grown in larger homogeneous areas made up of many adjacent paddy

MAP BY CORNELIA GARCIA, SONIA ASILO, JORREL KHALIL AUNARIO, MURALI KRISHNA GUMMA, ANDY NELSON



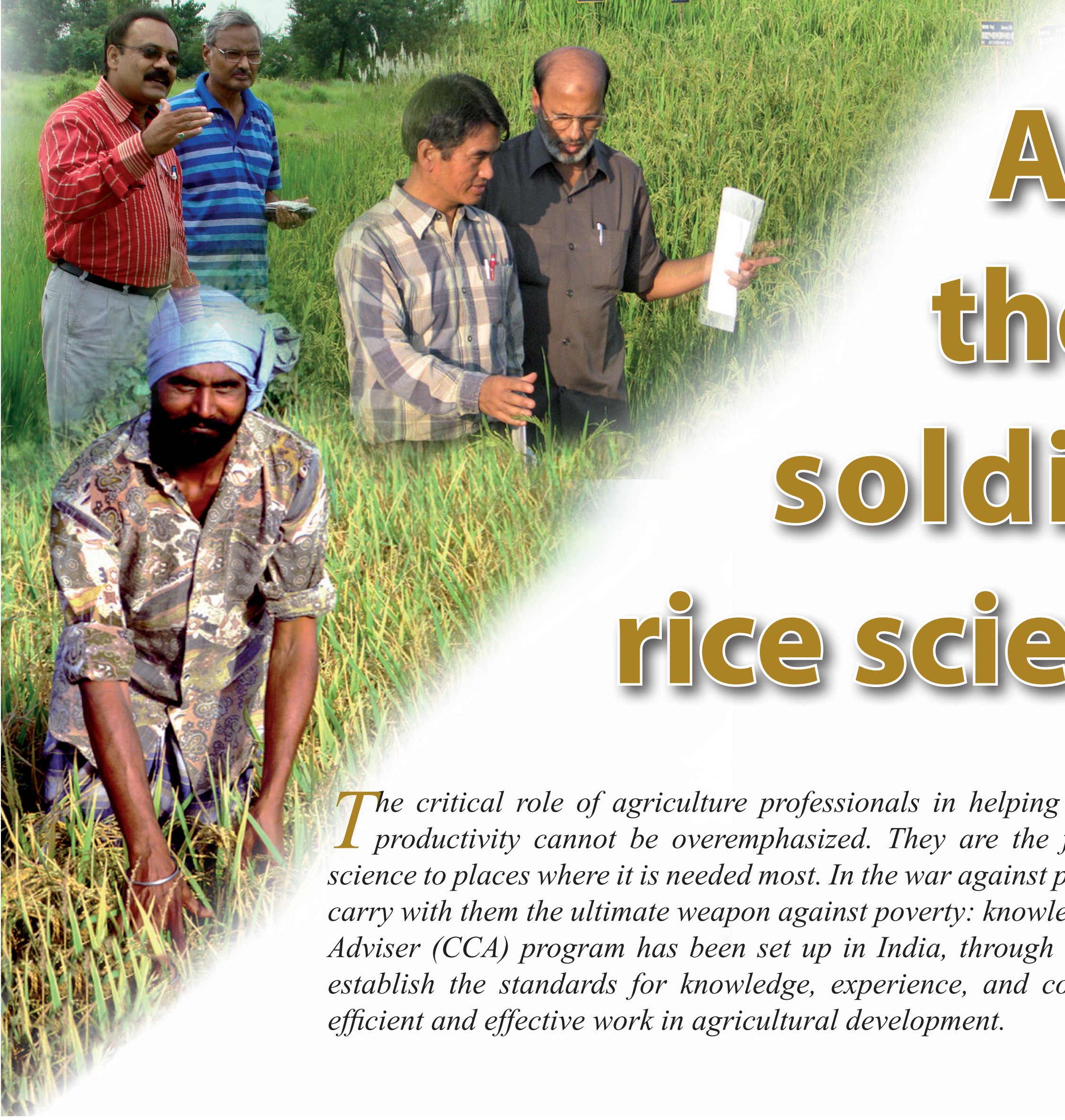
Map of food security. Arching high above Earth, MODIS aboard NASA's Terra and Aqua satellites gives researchers a new point of view on where and when rice crops are planted across Asia every year. The map shows Asia's paddy rice footprint (in green) in 2009.

fields, and it is these areas that are depicted. The map shows the paddy rice footprint of Asia in 2009 depicted in green—the physical area that was planted to rice during that year.

Mapping food production

"The archive of MODIS data that we use goes back to February 2000, though it will take some time to process all that information up to the present day," Dr. Nelson said. "But, as long as MODIS or similar sources of imagery remain available, these maps can be updated every year as a consistent and uniform assessment of where and when rice crops are planted across Asia."

Dr. Nelson's team, in collaboration with partner organizations, is also developing spatial models of rice pest and disease epidemics, and a spatial characterization of socioeconomic markets and mega-environments for rice in sub-Saharan Africa and Asia.



Arming the foot soldiers of rice science

The critical role of agriculture professionals in helping poor farmers increase their productivity cannot be overemphasized. They are the foot soldiers that bring rice science to places where it is needed most. In the war against poverty, these men and women carry with them the ultimate weapon against poverty: knowledge. Thus, the Certified Crop Adviser (CCA) program has been set up in India, through the catalytic role of IRRI, to establish the standards for knowledge, experience, and competency in agriculture for efficient and effective work in agricultural development.

South Asia is home to 40% of the world's poor and nearly half a billion people subsist on less than US$1 a day. But, a nagging question goes with this: How can they be helped to uplift themselves from abject poverty?

To meet this challenge, IRRI, in collaboration with the International Maize and Wheat Improvement Center (CIMMYT), International Food Policy Research Institute (IFPRI), International Livestock Research Institute (ILRI), IRRI Fund Singapore, and numerous public, private, and international partners, in 2009 launched the Cereal Systems Initiative for South Asia (CSISA), an umbrella program supported by the Bill & Melinda Gates Foundation and the United States Agency for International Development.

CSISA comes at a crucial time for key nations in the region to assist in their struggle to boost grain supplies in the wake of growing demand and strained natural resources. Building on past cereal research achievements in the public and private sector, CSISA has a clear target in mind: to produce an additional 5 million tons of grain per year and increase the income of 6 million poor rural households by at least $350 per year.

Strengthening the frontline

CSISA recognizes the critical role of frontliners—the agriculture professionals. They interact with farmers in the field, communicate the best technologies and management practices, and guide farmers in decision-making; hence, the birth of the CCA program in India.

CCA is a voluntary professional certification program, which was initially offered by the American Society of Agronomy (ASA) in the U.S. and Canada for field agronomists, extension agents, and crop consultants, among other agricultural practitioners.

India is the first country outside North America where this program is being extended, under the leadership of Dr. J.K. Ladha, IRRI principal scientist and representative for India.

Under CSISA, IRRI partnered with the ASA to establish an international CCA program in India through a memorandum of understanding (MOU) in March 2009.

Prior to this, Punjab Agricultural University, Ludhiana, had signed an MOU with the ASA and IRRI in February 2009 for technical and academic inputs to the India CCA program.

"IRRI's role was to facilitate and catalyze these innovative changes," said Dr. Ladha. "The vision has been for the CCA program to be self-sustaining. Thus, a local partner to carry out the program in India was needed."

After a round of consultations, the Indian Society of Agribusiness Professionals (ISAP) became that local partner. ISAP administers and implements certifications through a formal licensing agreement between the ASA and ISAP, and between IRRI and ISAP during the first quarter of 2010. Currently, IRRI is helping ISAP in its initial years to promote the program.

Eligibility to be a CCA

To become a CCA, a candidate must pass a comprehensive exam based on four core competency areas of agriculture: nutrient management, soil and water management, pest management, and crop management. Preferably, he/she must have a degree in agriculture (bachelor of science in agriculture) with two years' experience working with farmers. However, candidates with 10 years of basic education and 2 years in college can also take the exam as long as they have worked with farmers for at least 4 years.

Performance objectives

The keys to an effective CCA program are appropriate performance objectives (POs), which are composed of four indispensable modules of Indian agriculture: nutrient management, soil and water management, pest management, and crop management. These modules were further divided into different competency areas necessary for agricultural professionals to know in guiding farmers to increase productivity.

The PO document has been developed by a team of 33 experts. The ASA and IRRI provided all the support in finalizing the PO document during a 3-day workshop in New Delhi in May 2009. Each competency area has been validated by 45 professionals from agri-input organizations, academe, and among extension workers to ensure that the CCA exam truly tackles agricultural practices within the Indian context.

"Moreover, we want the PO document to be always on a par with innovations in crop science," said Dr. Ladha, who is the current and the first India CCA board chair. "So, it will be updated from time to time as need arises." The India CCA program is guided by a board, which comprises senior officials of the private and public sector, NGOs, and international organizations.

The first batch of CCAs

The pilot exam for the India CCA took place in August 2010 in New Delhi. Out of 22 candidates, 19 passed and were awarded certificates from the ASA. Then, another exam, in December 2010, was conducted at three locations—New Delhi, Hyderabad, and Chandigarh, where 85 candidates took the exam.

The CCA program is recognized by the public and private sector around the world as a tool to enhance and upgrade one's knowledge in agriculture. The certification not only prepares the extension work force to do its job more efficiently and effectively, but it also provides better job opportunities in multinational organizations.

And, most of all, CCA certification helps guarantee that this new breed of crop advisers has attained a level of knowledge and experience and is most qualified to work in the field with farmers, who are in dire need of the advisers' expertise. It is with great hope that the India CCA program translates into profitable productivity in farmers' fields and uplifts those farmers from abject poverty.

IRRI (2)

A spark of life without oxygen

Direct seeding of rice, in which seeds are sown dry or pregerminated directly in the soil, requires much less labor and sometimes involves using less water than the traditional way of cultivating rice. But, direct-seeded rice (DSR) has its Achilles' heel. Seeds cannot germinate and the young seedlings cannot survive while completely submerged under water. This makes heavy rainfall and flooding right after seeding a serious concern. IRRI scientists are now working to understand the mechanisms of anaerobic germination—the tolerance of flooding during germination—and develop improved varieties that could sprout and thrive in the presence of little or no oxygen.

For centuries, rice seedlings have traditionally been grown in standing water and then transplanted into the field. Transplanting is backbreaking work that requires 250–350 person-hours per hectare or 25% of the total labor requirement of rice production.

In recent years, direct seeding of rice has gained popularity in many regions, mainly because it is significantly less labor intensive. And, because it may require less water, direct seeding, which was traditionally used only on relatively small areas of upland and lowland rice production, is becoming more important in irrigated fields given the growing scarcity of water.

A crucial weak spot

However, direct-seeded rice (DSR) cannot germinate and survive while completely submerged in water. Heavy rainfall that leaves fields flooded immediately after sowing will drown the seeds. This occurs when fields have poor drainage or are not properly leveled. The result is poor crop establishment and, consequently, lower yield.

Also, flooding effectively suppresses weeds before they emerge. Farmers deliberately keep their fields submerged in water to prevent the growth of weeds that would otherwise compete with the crops for nutrition. Since fields recently sown with DSR cannot be flooded, weeds get a head start and become a major challenge. Farmers either resort to hand weeding, which is very laborious and essentially neutralizes the labor saved from direct seeding, or use herbicides that are expensive, environmentally risky, and useless against herbicide-resistant weeds.

In response, IRRI scientists are looking at this problem from various angles. Dr. David Johnson, weed scientist and coordinator of the Consortium for Unfavorable Rice Environments, and Dr. Bhagirath Chauhan, also a weed scientist, are tackling the major threat posed by weeds to the sustainability of DSR production. Dr. Elizabeth Humphreys, a scientist who specializes in water management, is developing better systems for using water specifically for direct-seeded rice.

Molecular mechanics and the rice engine

On the breeding side, IRRI is also developing DSR varieties that can germinate, elongate, and stay alive even while completely submerged in water in the presence of little or no oxygen (anaerobic germination).

Abdelbagi Ismail, a plant physiologist in IRRI's Crop and Environmental Sciences Division, has been working to understand the physiology of anaerobic germination. Dr. Ismail and his team screened thousands of rice varieties in the IRRI Genebank for varieties that can germinate under complete submergence, a trait that is hard to find in rice, and have successfully identified several traditional varieties with this special characteristic, such as Khaiyan

Neither heavy rains nor waterlogging. Anaerobic germination-tolerant direct-seeded rice can germinate, elongate, and stay alive even while completely submerged in water up to 10 centimeters. This trait is useful in areas where heavy rainfall and flooding can occur right after seeding.

from Bangladesh, Khao Hlan On from Myanmar, and Mazhan Red from China.

EMMANUEL PANISALES (3)

"Tolerance of anaerobic conditions during germination is an essential trait for direct seeding in both rainfed and irrigated areas," according to Dr. Ismail. "In rainfed areas, farmers abstain from direct seeding because they are not sure when the rain will come, and even showers that cause waterlogging are sufficient to prevent seed germination and crop establishment.

"In irrigated areas, tolerance is important as lands are rarely well leveled, resulting in a patchy crop after direct seeding," he added. "Besides, shallow flooding early in the season can effectively eliminate most of the serious rice weeds."

Having identified varieties capable of anaerobic germination, Dr. Ismail, along with plant breeders David Mackill and Endang Septiningsih, began exploring the genetic mechanisms of this trait by mapping the quantitative trait loci (QTLs) in a population derived from Khao Hlan On. QTLs are stretches of DNA that are closely linked to the genes responsible for useful traits such as anaerobic germination and QTL analysis has become a fast and powerful method for discovering highly desirable genes.

Dr. Septiningsih proceeded to develop near-isogenic lines (NILs), a set of plants that are genetically identical but with one or a few variations found in specific locations of a gene or DNA sequence on a chromosome. She and her team started to fine-map one of the major QTLs identified from Khao Hlan On and to identify candidate genes that may control the desired but missing trait in DSR. By working together with molecular biotechnologist Dr. Inez Slamet-Loedin, they are also trying to validate several candidate genes underlying the QTL.

Dr. Septiningsih and her team have also mapped QTLs from a population derived from Mazhan Red. A major QTL on chromosome 7 has been targeted for fine mapping and marker-assisted selection. Furthermore, they have also identified more varieties capable of tolerance of anaerobic conditions during germination and these have become potential sources of additional QTLs that could increase the ability of DSR varieties to germinate under water. Additionally, they have begun to develop NILs carrying different QTLs in the background of several elite cultivars.

Natural herbicide. Without manual or chemical intervention, direct-seeded rice plants grown under normal conditions often experience heavy weed infestation (left). With rice varieties that are capable of anaerobic germination (AG-tolerant lines), flooding the field right after sowing effectively suppresses weed growth.

MICHAEL THOMSON

Conventional wisdom and new technology

To complement the molecular work, a conventional breeding program has begun to develop improved breeding lines that are better suited to direct-seeded systems.

"Once the genes and alleles that confer the trait are identified and better understood, these can be combined through QTL pyramiding to develop rice varieties that can survive field flooding immediately after direct seeding," said Dr. Septiningsih. "This can be achieved through molecular marker-assisted breeding that is integrated with a conventional breeding program."

Keeping the spark alive

"Furthermore, this trait can be combined with other stress-tolerance genes, such as *SUB1* that enables rice to survive continuous flooding for up to 2 weeks," Dr. Septiningsih said. "This will allow us to develop DSR varieties that can withstand the challenges of extreme weather patterns that may increase due to global climate change.

"With the new advances in breeding technology such as high-throughput single nucleotide polymorphism marker genotyping, the time is ripe to take advantage of these basic scientific discoveries to develop a host of stress-tolerant rice varieties for the future," she added. In a world that seems to grow more challenging with time, farmers can look forward to IRRI keeping the spark of ideas alive.

For more information:

Angaji SA, Septiningsih EM, Mackill DJ, Ismail AM. 2009. QTLs associated with tolerance to anaerobic conditions during germination in rice (*Oryza sativa* L.). Euphytica 172:159-168.

Ismail AM, Ella ES, Vergara GV, Mackill DJ. 2009. Mechanisms associated with tolerance to flooding during germination and early seedling growth in rice (*Oryza sativa*). Ann. Bot. 103:197-209.

Double-
ri

GLENN GREGORIO

Soil salinity and flooding, especially under the threat of global warming and rising sea levels, are of exceptional importance in coastal deltas. In India and Bangladesh, they have a direct impact on the lives of around 130 million people. Rice fields in these areas are inundated with tidal surges driven by cyclones early in the wet season, followed by partial or stagnant flooding due to heavy monsoon rains later in the season. IRRI has already released rice varieties capable of surviving either one of the conditions but the ideal rice varieties for the harsh conditions in coastal areas really need multiple tolerance for better adaptability.

Too much salt

Using QTL (quantitative trait loci) analyses, powerful tools for the discovery of useful and important genes that regulate complex traits, IRRI scientists identified several QTLs for salt tolerance. One of these is *Saltol*, a major QTL on chromosome 1 found in Pokkali, a highly salt-tolerant landrace (a local variety that has developed largely by natural processes) from India.

"By means of conventional breeding as well as marker-assisted backcrossing (MABC), we can transfer different tolerances into popular rice varieties and elite breeding lines," said Glenn Gregorio, senior rice breeder and deputy head of IRRI's Plant Breeding, Genetics, and Biotechnology (PBGB) Division.

MABC is routinely used in breeding programs for gene introgression or the introduction of a gene from one gene complex into another to shorten the breeding cycle. "Through MABC, *Saltol* was successfully introgressed into popular varieties such as IR64, BRRI dhan28, and BRRI dhan11," said Abdelbagi Ismail, senior plant physiologist of the Crop and Environmental Sciences Division (CESD). "And, additional varieties are being introgressed with this QTL."

Since salinity tolerance in rice is controlled by multiple but mostly independent mechanisms, the long-term goal of plant breeders is to identify and combine multiple genes and QTLs, each controlling different tolerance traits, for higher salt tolerance in high-yielding rice varieties. These are combined in what is known as gene pyramiding.

Too much water

Meanwhile, a substantial milestone in developing flood-tolerant cultivars was achieved after the cloning of *SUB1*, the major QTL for submergence tolerance located on chromosome 9 of FR13A, a landrace from Orissa, India, that is able to survive flooding for more than 2 weeks. *SUB1* controls about 80% of the tolerance of this line.

"MABC was successfully used to introgress *SUB1* into eight popular varieties within 2–3 years," Dr. Ismail said. "Several of these varieties such as Swarna-Sub1, IR64-Sub1, and BR11-Sub1 were released in South and Southeast Asia." These varieties consistently showed a yield advantage of 1 to 3 tons per hectare following submergence in farmers' fields compared with intolerant

-trouble
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Rice farmers in low-lying coastal deltas face two daunting challenges. Because their lands are practically at sea level, they have to deal with soil salinity from rising sea levels and flooding from excessive rainfall. IRRI scientists have already developed flood-tolerant and salinity-tolerant rice varieties. Now, they're taking things one step further: rice varieties that can handle the double trouble coastal rice farmers face.

varieties that had similar yields in the absence of submergence.

The next step is developing rice varieties that combine tolerance of salinity and submergence through two strategies. In the first approach, conventional and MABC methods were used in crossing salt-tolerant donors and submergence-tolerant varieties with *SUB1.* The progenies of these crosses were then tested and selected for salinity and submergence tolerance. Molecular markers were also used to determine the presence of both *Saltol* and *SUB1*. The selected lines were then advanced several generations, and tested and evaluated by farmers for yield and other agronomic traits.

In the MABC method, *Saltol* and *SUB1* were first introgressed separately into one variety, in this case, IR64, to produce IR64-Sub1 and IR64-Saltol. Then, the two introgression lines were crossed and lines combining both genes were selected after one more generation.

"The latter method was faster and more precise in recovering the background of the original variety," Dr. Ismail explained. "It is now being pursued with a few varieties, including IR64 and BRRI dhan11."

Some finished products of rice elite lines that can withstand the double trouble demonstrated encouraging results. "Combining *Saltol* and *SUB1* in one genetic background showed no apparent negative impacts on agronomic and quality traits, and this will help develop more resilient varieties adapted to coastal zones," Dr. Gregorio confirmed.

Plant breeders are looking at other traits, in addition to the ability to withstand soil salinity and flooding, associated with tolerance of other abiotic stresses common in coastal areas. For example, in most coastal areas, water stagnation of 20–50 cm for several months is a serious problem because modern rice varieties are sensitive to such conditions. However, reasonable genetic variations in tolerance of stagnant flooding have been observed in some rice varieties and plant breeders are now exploring the possibility of finding new genetic materials for this trait. Combining tolerance of salinity, submergence, and stagnant flooding, together with proper management strategies, could contribute substantially to increasing and sustaining rice production in these fragile areas.

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Making technology count. Simple water tubes help farmers check the water level in the rice field and ease into alternate wetting and drying, a water-saving practice.

Bridging the "GAP" makes farmers wealthier

Information is not knowledge, Albert Einstein once said. In South and Southeast Sulawesi, for instance, farmers' limited awareness of the proper way of using fertilizer and pesticides was proving to be more detrimental than helpful. By introducing good agricultural practices (GAPs) to the area, IRRI is helping maximize the impact of technology in the farmers' fields and their lives.

Indonesia is one of the biggest consumers of rice in Asia. On average, Indonesians consume about 130 kg of rice annually—exceeding the yearly consumption in Malaysia, the Philippines, and Thailand. This makes the availability of rice and the stability of its price of prime importance to this island nation with a population of 235 million people. Responding to the 2008 rice crisis, the Indonesian government took drastic steps to avert a crisis and launched a national program to increase the country's annual rice production by 5%.

The use—and misuse—of technology

In March 2008, Irrigated Rice Research Consortium (IRRC) scientists were commissioned by the Australian Centre for International Agricultural Research to lead a collaborative project with the Assessment Institutes of Agricultural Technologies and the Indonesian Center for Rice Research to raise rice productivity in South and Southeast Sulawesi because these provinces have high potential for increasing rice production.

But, as Donna Casimero, an IRRI project scientist who was based in Makassar, Indonesia, found out, farmers in the area were using technology but with limited information about it. For instance, rice farmers in Bendewuta in Southeast Sulawesi were using herbicides but were not aware that one type of herbicide does not work for all species of weeds.

"They were spraying their fields with herbicide for broadleaf weeds when the fields were actually infested with grassy weeds," Dr. Casimero said. "The farmers were clueless that they were actually losing 20–30% of their yield because of weeds alone while they continued to spend for and use herbicides."

Adding knowledge to information

Dr. Casimero, who is also an agronomist and weed scientist, introduced GAPs (good agricultural practices), which promote the importance of integrated crop management and worker welfare. GAPs also address environmental, economic, and social sustainability for

IRRC

Sharing the wealth. Dr. Donna Casimero (second from left) discusses the progress of field trials using good agricultural practices (GAPs) with partners. By filling in the knowledge blanks, GAPs make farmers both wiser and wealthier.

on-farm practices. She taught farmers the best practices to manage water, weeds, nutrients, and pests in four selected villages in the area.

"By educating the farmers about different herbicides, they now know the importance of using the right herbicides and have realized the major effect of weeds on their yield," she explained. "Farmers also learned that they need to lessen pesticide use because there are beneficial insects in the field that help control harmful insects and these need to be protected."

Before the intervention, farmers were more likely to apply too much fertilizer at the early stage of the crop—yet another expensive but wasteful practice resulting from insufficient knowledge. Through site-specific nutrient management (SSNM) in adaptive trials in farmers' fields, Dr. Casimero was able to show proof that a more diligent application of fertilizer resulted in higher yields than their current practice.

"I told them that feeding a young rice plant was similar to feeding a baby, and that it did not need that much milk," said Dr. Casimero. "This simple message made a mark in the farmers' minds, and they reduced their fertilizer application."

Wealth in wisdom

Farmers who tried alternate wetting and drying technology, a practice that reduces water use and pumping costs by allowing their plots to dry for several days, showed yield increases of 0.2–0.6 ton per hectare compared with yields of continuously flooded fields, which was their usual practice. They were also able to reduce the number of irrigation periods by 10–30%.

Having seen the benefits of these practices, farmers are now testing two or more of these technologies together in their fields. "We are happy," claims one farmer. "We got 3 tons per hectare in 2008 and 5 tons in 2010." Another farmer reported more than a 100% increase in rice yield. In 2010, farmers in four selected villages received a total of 1.8 million rupiah (US$204) more in net returns than farmers who did not try the practices.

Driven by the enthusiasm of the farmers and Indonesian partners, IRRI will continue to provide technical assistance to spread best practices to more districts, with funding from the Swiss Agency for Development and Cooperation. A little knowledge may indeed be a dangerous thing, but, by filling in the blanks with GAPs, IRRI is leaving farmers both wiser and wealthier.

DONNA CASIMERO (2)

Proof of GAPs. An extension worker weighs sample yields from field trials. Tangible benefits of good agricultural practices motivate farmers to quickly adopt new technologies.

"Cooler rice" for a warming planet

CHRIS QUINTANA

Rice plants are feeling the heat from global warming. In almost all cultivated rice varieties, heat stress, particularly during the flowering and ripening stages, produces empty grains and this threatens future food security. Curbing global warming may prove to be humankind's greatest challenge, but IRRI scientists are already developing rice varieties with higher limits of heat tolerance to prevent the problem from reaching its boiling point.

The effects of global warming on food production go beyond erratic weather, and too much or not enough rainfall. Typically yields become depressed when day temperatures exceed 35 °C during the flowering stage. When temperatures surpass this point, the heat begins to interfere with seed setting, which increases the incidence of empty grains in rice plants. For example, IR64, the most widely grown rice variety in the tropics, experiences a 50% drop in seed set if flowering occurs when daily temperatures peak at 37 °C compared with a peak of only 28 °C. Turn up the heat to 39 °C and this normally high-yielding variety fails to produce any grains.

The impact of higher temperatures is already being felt outside climate-controlled laboratories. A study conducted from 1992 to 2003 at the IRRI farm in the Philippines showed a coincident if not causative decrease in rice yields as nighttime temperatures increased. Generally, every 1 °C rise in nighttime temperature will have a corresponding 10% decrease in grain yield, according to the study.[1] In fact, this has been happening in India, the Philippines, China, Vietnam, and Thailand, as work conducted by IRRI scientists in collaboration with universities in the U.S. found out.[2] This yield loss occurs because higher night temperatures can speed up the plants' maintenance respiration. Maintenance respiration is essential for biological health and growth of plants but, at higher rates, and particularly during the night, the process depletes the plants' carbohydrate reserves—which would otherwise be directed to grain filling.

Higher daytime temperatures present additional worries. Although no systematic monitoring and evaluation of temperature stress–induced rice yield losses have occurred to date, recent information suggests that the 2003 heat wave in China damaged an estimated 3 million hectares of rice along the Yangtze River, resulting in a lower yield of about 5.18 million tons of paddy rice. In Pakistan, even IR6 and other high-performing hybrids well adapted to tropical conditions released in Pakistan experienced a 30% and 70% decline in yield, respectively, as an aftermath of a heat wave in 2007, according to Dr. Nihaluddin Mari, Rice Research Institute Dokri, Pakistan.

In 2009, IRRI, with funding from the Bill & Melinda Gates Foundation through the Cereal Systems Initiative for South Asia, took on the challenge of developing new rice varieties that could handle the hotter days and nights expected later this century.

Breeding rice for a warming planet

IRRI's breeding program for heat-tolerant rice follows two strategies, according to Edilberto Redoña, senior rice breeder in the Plant Breeding, Genetics, and Biotechnology (PBGB) Division, who began an international effort to produce varieties that can cope with higher temperatures resulting from climate change: "The first strategy is to develop varieties that will still flower normally and retain the ability to set seed even at temperatures above 35 °C." (See box.)

> Redoña ED et al. 2009. Identifying heat-tolerant rice genotypes under different environments. SABRAO J. Breed. Genet. 41(special suppl.). Published on CD (ISSN 1029-7073).

Dr. Redoña, along with Changrong Ye, a postdoctoral research fellow in PBGB, made significant progress in breeding heat-tolerant varieties. "We have mined the rice genebank for potentially heat-tolerant varieties, especially those coming from hot countries, and we are identifying suitable genetic donors," said Dr. Redoña.

So far, Dr. Redoña and Dr. Ye have field-tested N22, a variety from India, which has proven to be an excellent candidate for developing heat-tolerant rice. "It maintains 80–90% seed setting at 39 °C," Dr. Ye said. "In comparison, the seed setting of IR64 at that temperature is less than 5%."

"N22, along with other potential donors, is being heavily used in crosses with popular varieties such as IR64, PSB Rc18, PSB Rc82, and Super Basmati, among others, and we are beginning to identify promising materials," said Dr. Redoña. The field performance of these materials is being validated via a shuttle breeding program involving "hot" and vulnerable rice-growing regions of India, Pakistan, and Iran for faster varietal development.

Quantitative trait loci (QTLs) for heat tolerance are now being identified as well, Dr. Redoña explained. QTLs are stretches of DNA that are closely linked to the genes responsible for a particular trait. QTL analyses are powerful tools for the discovery of useful and important genes that regulate complex traits. Tagged with DNA markers, QTLs can be inserted into existing mega-varieties or new genetic backgrounds faster and more precisely than otherwise would be possible using conventional breeding strategies.

[1]Peng SB et al. 2004. Rice yields decline with higher night temperature from global warming. Proc. Natl. Acad. Sci. USA 101(27):9971-9975.

[2]Welch JR et al. 2010. Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. Proc. Natl. Acad. Sci. USA 107(33):14562-14567.

Tweaking the rice clock

"IRRI's second approach to mitigating the effects of the planet's increasing temperature is to change the rice flowering time to an earlier and cooler period in the day," Dr. Redoña said.

This is where Greg Howell, a plant physiologist in PBGB, comes in. "The world has changed considerably since the 1960s Green Revolution," Dr. Howell said. "Climate change has eroded the yield potential of the miracle rice varieties of that and subsequent eras. The environment is constantly changing and so too must the varieties grown in order to ensure food security.

"Elevated temperatures affect rice plants directly in a number of ways," he added. "All living things are fundamentally a complex series of chemical reactions and the rate at which these reactions proceed is governed by temperature.

"We know that extremely higher temperatures, particularly during the reproductive phase, and most importantly during flowering, are associated with low yields," Dr. Howell explained. "Most rice varieties experience peak flowering between 0930 and 1130 when the temperature is well on its way up. Even an hour's exposure to heat stress at this time can be sufficient to induce sterility.

"Abnormal physiological and developmental processes may appear when the temperature exceeds 36 °C," Dr. Howell said. It is reported that heat-affected anthers (male organs) fail to adequately dehisce (release pollen) just prior to the flower opening (anthesis). This results in inadequate pollination. Since these processes occur just before the flower opens, it has been proposed to develop varieties that flower earlier in the day so that any heat-sensitive reproductive processes occur before critical temperature thresholds are breached.

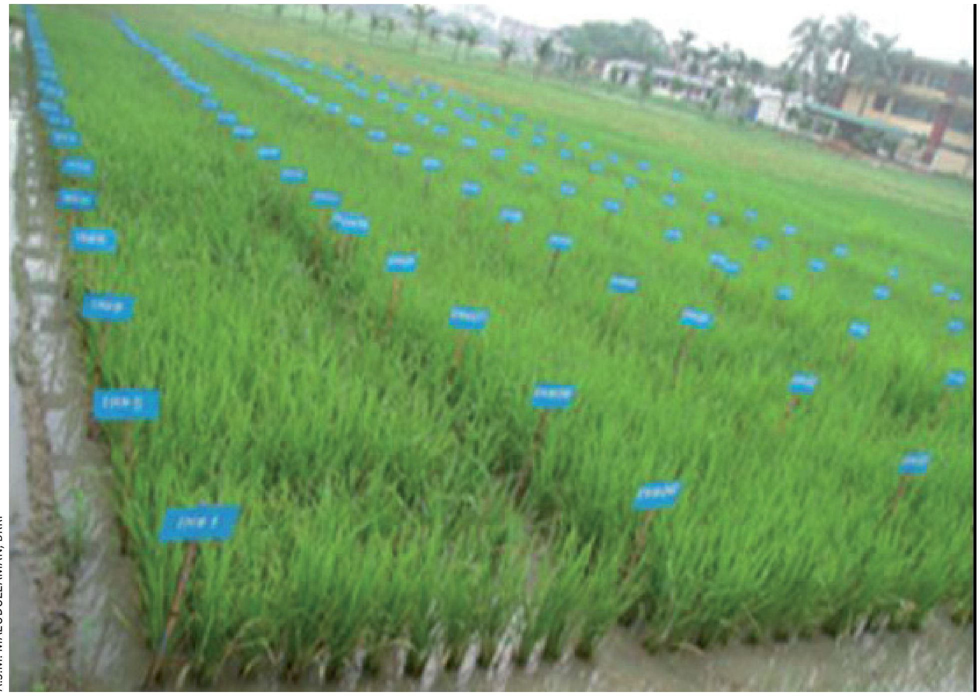
Much of IRRI's success arises from gene discovery and optimizing the most favorable genetic combinations because IRRI hosts the world's largest collection of domesticated rice and wild rice germplasm. Screening this vast collection for plants that flower earlier in the day is very labor intensive but it has shown that there is tremendous variation in flowering times.[3]

[3] Sheehy JE et al. 2005. Searching for new plants for climate change. J. Agric. Meteorol. 60:463-468.

Racing mercury. IRRI scientists are rushing to bring "cooler rice" varieties to farmers' fields in time to offset the effect of hotter temperatures on food production. From these experimental plots in India and Bangladesh (next page), researchers are identifying potentially heat-tolerant varieties that will be used in breeding programs.

S. SHERYL

Many wild species of rice flower earlier in the day but strong interspecific hybridization barriers prevent gene flow from many wild species into domesticated lines. Furthermore, restoring fertility to hybrid lines and confirmation require multiple cycles of backcrossing and screening to incorporate any trait. Fortunately, ongoing research at IRRI has produced many lines with the desired alien introgession from wild rice species (e.g., *Oryza eichingeri, O. glaberrima, O. officinalis, O. minuta, O. longistaminata*) and screening of these has revealed some early-flowering lines.



A.S.M. MAZUDUZZAMAN, BRRI

The lack of a consistent performance of all the genotypes examined in the field and in enclosed greenhouse facilities suggests that regulation of time of day of flowering is controlled by something other than the perception of elapsed time since dawn. The opening of new walk-in controlled-growth facilities at IRRI in 2010 has made the task easier.

"Current experimental observations into the effects and interaction of light intensity, photoperiod, humidity, and temperature on time of day of flowering will, we hope, unravel this problem," Dr. Howell said.

Boosting the internal rice mechanism to beat the heat

Why do some rice varieties set seed even under high temperatures while others do not? This is the part of the puzzle that IRRI molecular biologist Sigrid Heuer and postdoctoral research fellow in PBGB Krishna Jagadish are trying to unlock by looking at pollination, pollen germination, and fertilization processes at the molecular level. So far, Dr. Jagadish, Dr. Heuer, and other researchers have closely examined nearly 20 varieties known to be heat tolerant.

"We identify the most sensitive organ in the process and use advanced physiological and molecular approaches to identify mechanisms and genes that are responsible for allowing varieties to withstand temperatures greater than critical thresholds," Dr. Jagadish said. "Once we fish out those genes, we then confirm that they really are the ones worth investing our time in. Then we use a well-established molecular marker platform at IRRI to transfer the gene or chromosomal region to the sensitive variety preferred by farmers to enhance its tolerance of high temperature."

The particular gene from a heat-tolerant variety is transferred into popular but heat-sensitive varieties such as IR64. The resulting plants are exposed to high temperatures to observe the different physiological processes leading to seed set and to find out whether the gene is really inducing higher tolerance of heat.

Once the importance of a gene is confirmed, IRRI scientists use advances in molecular markers to facilitate introgression of the heat-tolerance genes into different varieties suited for particular regions. These varieties are then handed over to NARES partners for field evaluation and ultimately for use as materials in their own breeding programs.

"Many signs indicate that rice cultivation in the tropics and the subtropics is at risk of catastrophic collapse if immediate and sustained efforts to stem the effects of rising global temperatures are not made," Dr. Jagadish said. Through its multiple approaches, IRRI scientists are rushing to bring heat-tolerant rice varieties to farmers' fields in time to turn the impending climate of despair into one of hope. (See box below.)

Jagadish SVK et al. 2010. Temperature effects on rice: significance and possible adaptation. In: Advanced technologies for rice production for coping with climate change: "No regret" options for adaptation and mitigation and their potential update. Proceedings of the joint workshop organized by the Food and Agriculture Organization and the International Rice Research Institute, Los Baños, Philippines. Los Baños (Philippines): IRRI. p 19-25.

Squeezing the most out of flood-proof rice

Because flooding affects 15–20 million hectares of lowland rice fields in Asia each year, it is a major contributor to the food insecurity and widespread poverty in these areas. In recent years, IRRI scientists incorporated the SUB1 *gene into popular local rice varieties collectively known as "scuba rice." Scuba rice varieties, which can survive up to 2 weeks of being under water, are now used by millions of farmers and serve as their first line of defense against flooding. Add good management to the mix and scuba rice varieties can deliver even higher yields, giving farmers a bigger fighting chance against the elements.*

Flood-prone areas are underexploited but they hold enormous potential for food production. The key to higher and more sustainable agricultural productivity in these areas is using a combination of flood-tolerant scuba rice varieties with the best management practices suited for the conditions of the lowland environment. Best management practices not only help scuba rice seedlings recover faster once floodwaters have receded, they also enable farmers to earn more by increasing their cropping diversity and intensity.

Sowing good genes

Through the introduction of good rice varieties and their proper management, IRRI's Consortium for Unfavorable Rice Environments (CURE) has helped farmers in flood-prone environments get decent harvests almost every year compared to the regular crop failures they have previously experienced.

Production and management practices for flood-prone areas include seed selection, proper seedling management, good practices for transplanting seedlings in the field, and taking the proper steps after flooding has occurred.

Field of promises. Swarna-Sub1, a popular flood-tolerant or "scuba" rice variety in India, helps farmers get decent harvests even after flooding during the kharif or monsoon season. Scuba rice varieties, which can survive up to 2 weeks of being under water, are now used by millions of farmers and serve as their first line of defense against flooding.

Before preparing the rice nursery, farmers are urged to use good-quality seeds of the scuba rice variety of their choice. Sowing good-quality seeds ensures better chances of crop establishment and realizing the full potential of a variety.

Helping good genes work even better

Once the seeds have been selected, proper nursery management helps farmers raise healthy and vigorous seedlings. Aside from having a big impact on survival and recovery after flooding, healthy seedlings can also produce up to 40% more paddy rice even if complete submergence takes place during the vegetative stage. Using lower seed rates is also recommended because higher seed rates lead to thinner and weaker seedlings that are likely to be damaged by early floods.

Following proper land preparation, and water and pest management, the seedlings are then transplanted in fields at 35–45 days old when they are stronger and tall enough to keep more leaves out of the water. They should be transplanted as soon as they are uprooted from the nursery. It is recommended to plant 2–3 seedlings per hill and use closer spacing between hills if high levels of standing water are expected since prolonged flooding will reduce tillers or the branches that develop from the lower stalks of the rice plants.

Initial studies have also shown that adequate nutrient management after floodwaters recede helps rice plants recover more quickly and yield more.

Season of plenty

"Some of the farmers who tried the new flood-tolerant varieties along with validated management practices said they had their first good harvest in 15–20 years," according to Abdelbagi Ismail, head of the CURE working group on submergence problems and flood-prone areas.

"For instance, by planting early-maturing scuba rice varieties, farmers can increase their lands' productivity since they are able to plant and harvest earlier," Dr. Ismail explained. "They can then plant another batch of rice or other crops when enough moisture is still available.

"The changes within one season may appear small but, when farmers move from one season to multiple seasons, the change in their system productivity can be enormous," he added. "Increasing their cropping system intensity to two crops per year allows farmers to at least double their annual productivity."

"This is very important since it helps farmers reduce their dependence on the unpredictable flood-prone wet season and get some income from the dry season," said Dr. Stephan Haefele, who also works on submergence problems.

GENE HETTEL

Flexible farming systems. To get the most from their lands, farmers can raise freshwater fish or prawns alongside scuba rice during the wet season when there is too much fresh water. In the dry season in places where salinity is too high, they raise shrimp instead, and grow rice during the wet season.

The best from any situation

IRRI also recommends flexible systems that farmers can adopt to help make their rice farms not only more productive but also sustainable at the same time. For example, farmers in areas that have too much water during the wet season can opt to raise freshwater fish or prawns alongside the rice. Farmers living in places where salinity is too high during the dry season can raise shrimp instead, and grow rice during the wet season.

Together with national agricultural research and extension systems and the CURE network, IRRI continues to test and validate good management strategies to get the most out of flood-tolerant rice varieties and flood-prone areas and give farmers a better prospect for eventually lifting themselves out of the mire of poverty.

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Turbocharging

As the world is pushed toward the nearly impossible position of feeding an increasing population even as its resources are being depleted by the minute, IRRI and its partners are turning to one of the most audacious scientific undertakings of recent years: supercharging photosynthesis in rice. The "Apollo 11" of rice research is now in motion in the laboratories of IRRI and its partners across the globe and it just may be the break humanity needs for sustainable food security.

Photosynthesis is arguably the most important process in the cycle of nature. Without it, there could be no life on Earth. Plants use photosynthesis to convert carbon dioxide into organic compounds using energy from sunlight. But, different plant lineages have evolved to use the sun's energy more efficiently.

Rice, wheat, and most other cereals all use conventional C_3 photosynthesis (so called because the first stable product produced is a 3-carbon compound). C_3 photosynthesis works very efficiently under normal light and cool, moist conditions. Around 25 to 35 million years ago, as concentrations of carbon dioxide in the atmosphere started to drop, some plants, such as maize and sorghum, adapted to the new environment by evolving a new way of producing food: C_4 photosynthesis. C_4 plants manufacture food more efficiently than C_3 plants, producing higher yields while using less sunlight, nutrients, and water.

Turbocharging the rice engine

Because of the typical environment where rice crops are grown, researchers know that rice's C_3 nature renders it inefficient in converting sunlight into plant food, making it relatively less productive. This presents a yield barrier that is difficult to breach. But, cutting-edge rice research has brought scientists to the very doorstep of a milestone of epic consequences.

The C_4 Rice Project—an ambitious scientific endeavor that pulls together the world's elite in the science of photosynthesis—seeks to incorporate C_4 photosynthesis in rice. However, C_4 rice is so revolutionary that it has been likened to supercharging a car's engine by fitting a new fuel injection system and scientists say its development may take many years.

"But, if scientists successfully develop C_4 rice, its enhanced photosynthetic ability would eventually translate into fewer inputs and higher yields," said William Paul Quick, coordinator of the C_4 Rice Project. "C_4 rice is predicted to produce 50% more grains than what is currently possible."

the evolution of rice

RAYMONDPANALIGAN

Reconfiguring rice for the future. Converting rice plants from C_3 to C_4 photosynthesis for more efficient use of energy from the sun is an ambitious and long-term scientific endeavor. But here, in the low-CO_2 screening chambers in the C_4 Rice Project plant growth facility, the future of rice has begun.

A revolution in evolution

IRRI scientists are now trying to assemble the necessary knowledge and technology to pursue C_4 rice. The C_4 Rice Project, which started in 2008, has already established the infrastructure and trained the personnel, and is currently developing the scientific skills required to meet its goal. Early results have shown promising indications that researchers are on the right path in establishing the genetic and mechanistic bases of C_4 photosynthesis in rice. “At this stage, IRRI and its global partners are in the process of discovering the genes for C_4 photosynthesis that can drive yields higher while using less nitrogen and water,” Dr. Quick said.

Scientists are creating populations of plants that exhibit characteristics that may lead to the discovery of new genes responsible for the components of C_4 photosynthesis. Using a “high-throughput screening” facility, which became fully operational in 2010, IRRI scientists are able to test some 72,000 plants per week. Plants that satisfy the scientists’ parameters will be sent to IRRI partners in the C_4 Consortium for further gene discovery studies.

The future of rice

The 2008 food crisis was a wake-up call to the importance of attaining global food security. It clearly showed the need for greater investments in agriculture and other measures to improve land quality, water management, and sustainability. The C_4 Rice Project, which is funded by the Bill & Melinda Gates Foundation, is looking further down the road for an innovative solution to the problem.

“IRRI and its partners are leading the way in unraveling one of nature’s most important biochemical processes and improving the ability of the rice plant to produce food from sunlight and water,” according to Dr. Quick. Making C_4 rice a reality will create a major route for rice yield improvement and that would truly be a giant leap for humankind as well as for rice.

Women of war,

Women were among the ex-combatants left without livelihoods in the wake of the disarmament policy in the Republic of Burundi. But, eligibility requirements excluded most of them from postconflict programs designed to reintegrate ex-combatants socially and economically into the community. IRRI, CARE Burundi, the University of Burundi, and other groups are training these former warriors for their new role in a time of peace.

War is hell. For many ex-combatants, the nightmares continue long after the revolution they fought in has ended. Often separated from their families and permanently scarred by physical and mental traumas, many are unable to find employment after the war.

The United Nations and other organizations work with governments to reintegrate them into society during the transition period from conflict to peace. But, in Burundi, a strict "one man, one gun" eligibility requirement for Disarmament, Demobilization, and Reintegration (DDR) and an eligibility test based on proficiency in handling weapons excluded many women and girl ex-combatants from formal DDR programs jointly run by the government and the World Bank.

Replacing bullets with skills

In 2009, through the Howard Buffett Foundation Rice Pilot Project, IRRI, CARE Burundi, Survivor Corps, Council on Integrated Development Burundi (CONSEDI), CEDAC,[1] and the University of Burundi started a holistic approach to give women ex-combatants economic and social empowerment. CARE, Survivor Corps, and CEDAC focused on the psychosocial aspects of their reintegration while CONSEDI provided vocational training for the participants' economic development.

MARITES SAUCELO

IRRI's role was in improving their income by teaching them how to grow rice and introducing new technologies for rice production. During the pilot phase, IRRI worked in Mubone and Mugerero on the Imbo Plain, Akagoma in Ngozi, and Muramba and Kireka in Kirundo.

"In Mubone, IRRI and CARE organized about 400 ex-combatant women into 10 groups to grow rice on 10 hectares of land," said Joseph Rickman, regional coordinator for the East and Southern Africa (ESA) IRRI-Africa Program. "The project supplied the necessary start-up finance for renting land, seed, and fertilizer while the women provided the labor. Each group was visited by the project team on a weekly basis to provide the necessary training."

Using the farmer field school (FFS) approach, IRRI and CARE provided advice and assistance from land preparation through to harvesting. Different planting techniques and fertilizer studies were conducted with the women's groups.

IRRI also conducted participatory variety selection (PVS) trials and other on-farm trials in each group's fields for collaborative research purposes. In the PVS trials, local varieties were compared with IRRI varieties. A number of new varieties are being prepared for release from these trials. The results from the on-farm trials are also being used to expedite the varietal registration process for the new varieties.

Students from the University of Burundi also conducted a number of variety comparison trials using local and new varieties in the same locality. The long-term goal of this project is to have these women's groups produce seeds for the newly released varieties.

Rebuilding lives from the ground up

"Through this project, all the women's groups were able to successfully grow rice crops and rent their own land for the second crop in 2010 using income generated

[1]Le Centre d'Encadrement et de Développement des Anciens Combattants (Center for the Training and Development of Former Combatants).

JOSEPH BIGIRIMANA

women of peace

from their first crop," Mr. Rickman reported. "They also paid for other inputs such as seed and fertilizer.

"This pilot phase showed a widespread global interest in the special needs of women ex-combatants," he added. "Within months of the project beginning, both news service IRIN and the BBC interviewed the project participants."

Sisters of change

In all agricultural sectors of Burundi, women are the main labor source for food production. But, women are proving to be agents of change, too, through their participation in the project's other research activities.

On the Imbo Plain, IRRI and the participating women's groups undertook varietal resistance studies for rampant plant diseases in all varieties currently being grown. Multilocation regional trials using two of the best varieties from each of the other six ESA countries are also being implemented. Another 158 varieties were tested for salt tolerance, a major problem in many of the poorly drained areas in the irrigated scheme in the area.

In the higher elevation areas at Akagoma, Ngozi, varieties were tested for cold tolerance, blast, sheath rot, and iron toxicity. At Muramba and Kireka, Kirundo, more than 160 new varieties and 86 pedigree lines were tested for their adaptability to the soil, climate, and other limitations of the region, including cold, blast, and sheath rot disease.

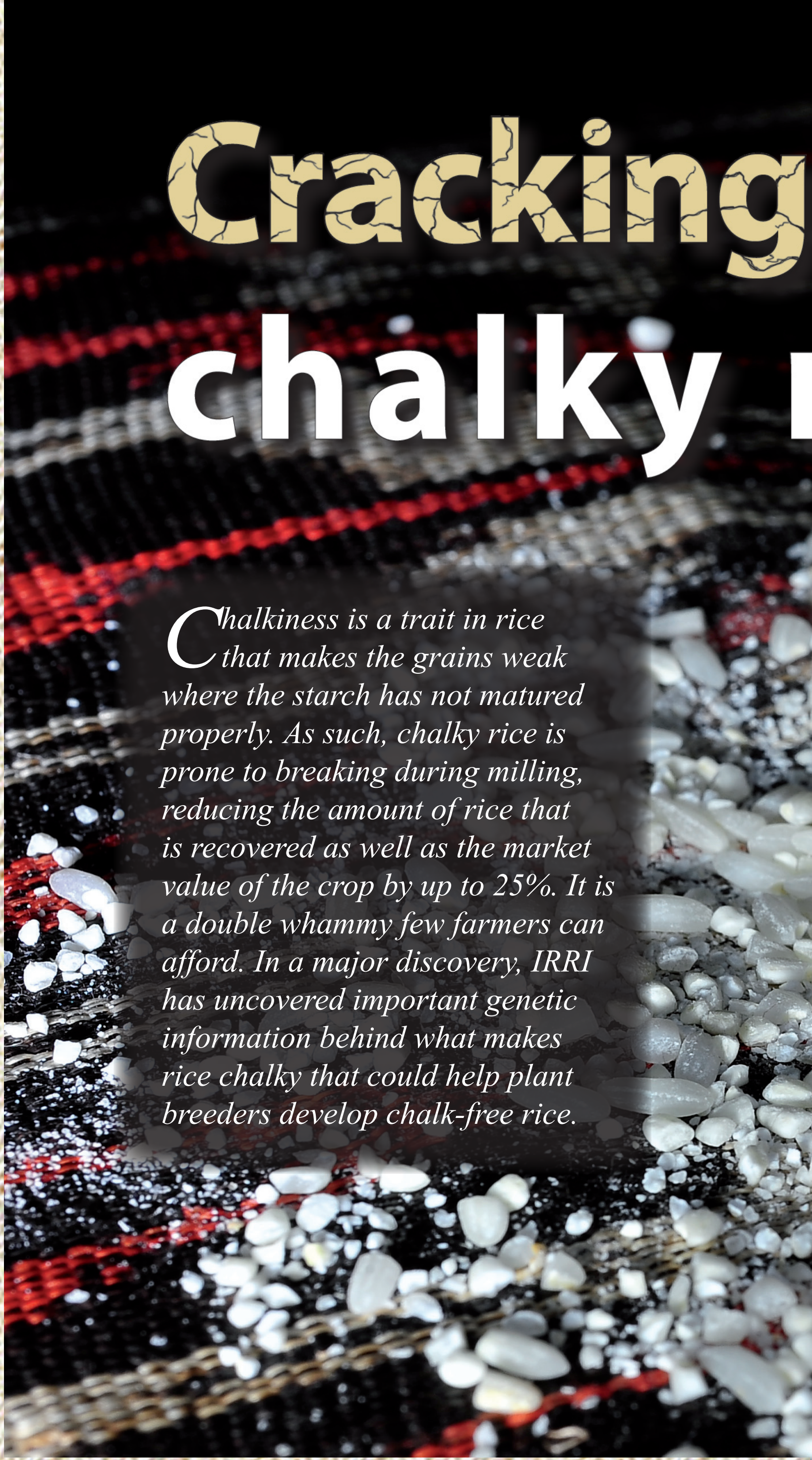
Giving women and peace a chance

Actor-activist George Clooney said that peace, like war, must be waged. Building from the lessons learned and the technologies introduced in the pilot phase, IRRI, CARE, Survivor Corps, CEDAC, and CONSEDI plan to expand their drive for peace into the other rice-growing regions in Burundi.

The organizations are looking for future funding to continue the project that will help change the policy environment through its advocacy on the prevention of sexual and gender-based violence and other issues affecting these women and other marginalized groups. This will also help restore communities by ensuring that both the local farming community and returning ex-combatants have livelihood options in rice production or in off-farm employment.

"Those who hammer their guns into plows will plow for those who do not." As Burundi transitions from conflict to peace, many ex-women combatants find themselves isolated and without any means of livelihood. By teaching them how to grow rice, these former soldiers get a chance to socially and economically rejoin the community.

Cracking chalky



MARITES SAUCELO

Chalkiness is a trait in rice that makes the grains weak where the starch has not matured properly. As such, chalky rice is prone to breaking during milling, reducing the amount of rice that is recovered as well as the market value of the crop by up to 25%. It is a double whammy few farmers can afford. In a major discovery, IRRI has uncovered important genetic information behind what makes rice chalky that could help plant breeders develop chalk-free rice.

Chalky rice occurs when part of the grain is whiter than the rest because this is where the starch has not developed properly and is a point of weakness. When chalky rice is milled, it is more likely to break, thus reducing the amount of rice that is recovered following milling. Also, because chalkiness is an unfavorable trait, chalky rice is downgraded in quality assessment ratings—reducing its value and returns for farmers. Chalkiness and the presence of whole grains are the two characteristics that both domestic and international rice markets base their grading on.

A tough genetic challenge

Two things known to cause chalkiness in the grains are the genetics of the rice variety and higher growing temperatures. Unfortunately, since farmers cannot manage their rice crops to reduce grain chalkiness, nor can they do anything to change temperatures, they must rely on growing varieties less susceptible to chalkiness. But, over the years, eliminating this trait has proven to be a difficult challenge for plant breeders.

For more than 15 years, in Australia and at IRRI, grain quality researcher Melissa Fitzgerald has been working to understand why grain becomes chalky to try to find a way to prevent or reduce its occurrence.

In an attempt to find out more about the genetics and biochemistry of chalkiness, Dr. Fitzgerald's team, including Dr. Zhao Xiangqian, Dr. Adoracion Resurreccion, Ms. Venea Dara Daygon, and Mr. Ferdinand Salisi, worked with many lines of rice with different chalkiness properties to try to find out why it has been so difficult to eliminate chalk from rice improvement programs.

A break in the case

In 2010, results came in from field tests in eight different countries where the different lines were grown. Three groups of rice were identified: rice that was always chalky, rice that was chalky when exposed to high temperatures at critical growing times, and rice that exhibited extremely low chalking. Only a few lines were in the extremely low chalk rice group.

These lines were further analyzed using genotyping tools that allow rice scientists to associate genetic information with a trait or property—such as chalkiness—and they were able to identify several key regions of the rice genome responsible for chalkiness.

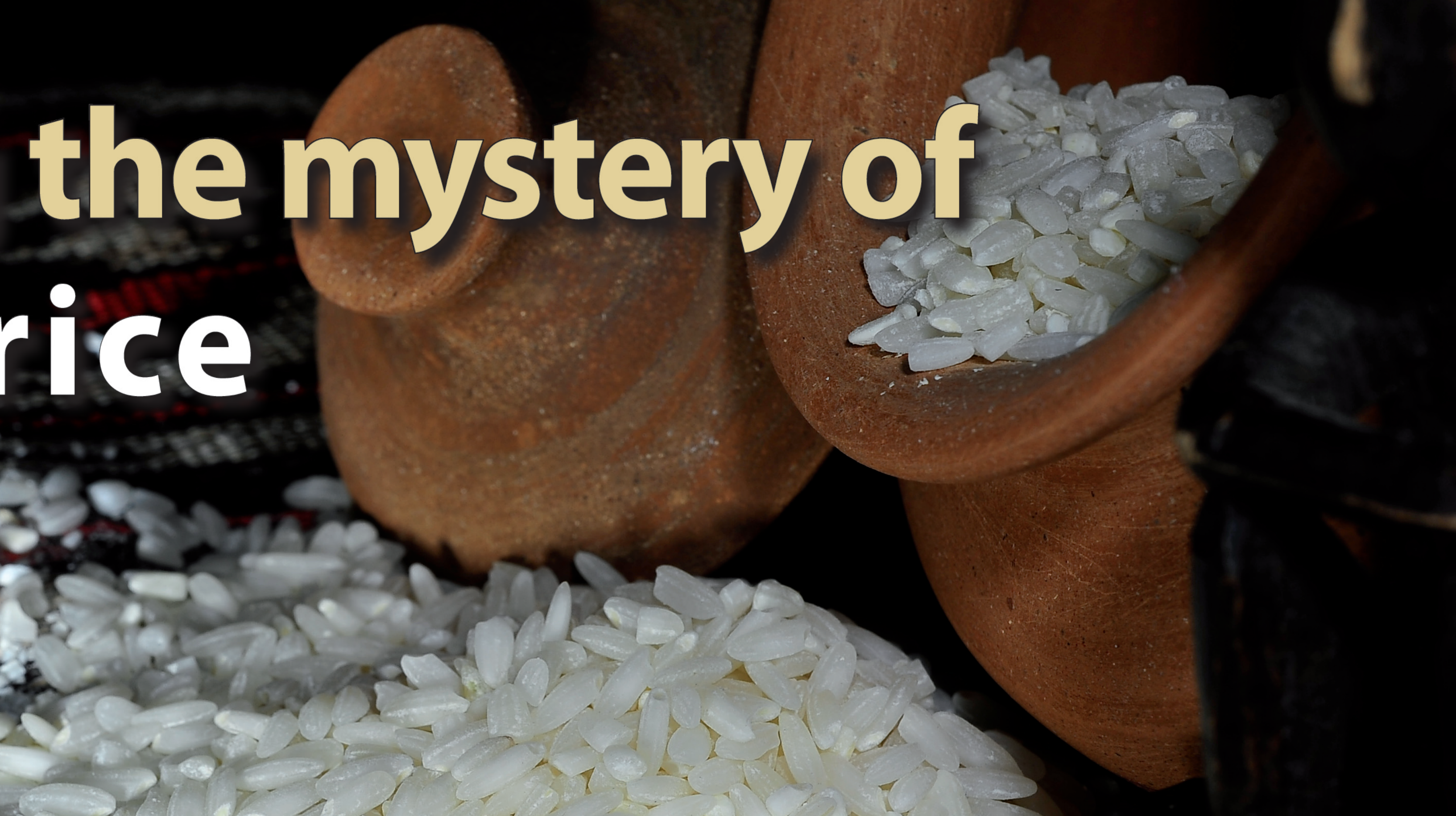
"Until now, rice scientists did not know where in the rice genome the genes for chalkiness resided," Dr. Fitzgerald said. "This made it hard to use accurate and rapid modern breeding techniques to develop chalk-free rice varieties."

With the discovery of these major regions—also called QTLs or quantitative trait loci—they now have a much better idea. This discovery means that the team is now one step away from identifying the actual genes involved in chalkiness, because they know that the genes will reside somewhere within these regions. If they can pinpoint the exact genes responsible for chalkiness, it will make breeding chalk-free rice even easier.

Chalk-free rice on the horizon

The bonus result of the team's research is that one of the extremely low chalky lines actually contains all of these

the mystery of rice



ACIAR

Old problem, new science. Dr. Melissa Fitzgerald and her team use genotyping tools to solve the mystery of chalky rice, an unfavorable trait that reduces farmers' profits.

QTLs and therefore, presumably, all the genes that make rice chalk-free. This breeding line has higher yields than other currently grown and popular rice varieties such as IR64 and has excellent quality characteristics.

"The development and release of chalk-free rice varieties will help improve the amount of rice that farmers have available to sell, and its quality," according to Dr. Fitzgerald. "Farmers could get higher returns for their produce while more high-quality rice will be available for consumers."

This research is supported by the Australian Centre for International Agricultural Research.

Rice with a vision

Hundreds of millions of children and pregnant women across the world suffer from vitamin A deficiency, a condition that can cause blindness and can lower people's ability to fight infections. Vitamin A deficiency is also a ferocious killer. An estimated 670,000 children under five die annually from the lack of this nutrient. IRRI scientists and their partners are working to reduce vitamin A deficiency by developing and evaluating a new variety of rice containing beta carotene—the same substance found in carrots and other vegetables—that the body converts into vitamin A.

Many people in the developing world, particularly in Africa and Southeast Asia where the staple diet is starchy, or nutritious food is scarce or too expensive, do not get enough vitamin A or beta carotene. In 2009, the World Health Organization estimated that 190 million children and 19 million pregnant women were affected by vitamin A deficiency, which is the leading cause of preventable blindness in children and can put them at higher risk of death from certain common infections. Vitamin A deficiency also causes night blindness in pregnant women and may increase the risk of maternal mortality.

To reduce the widespread mortality and health problems associated with vitamin A deficiency and complement existing interventions, IRRI and its partners are looking at rice as a way of supplying adequate vitamin A to the most susceptible segment of the population. Rice is not only the staple food crop for more than half of the world's population, it is also affordable. The only problem is that rice contains no vitamin A. That is, until Golden Rice came along.

Golden Rice is unique because it contains beta carotene, giving it a golden color, which the body converts to vitamin A as needed. According to research published in the *American Journal of Clinical Nutrition* in 2009, eating about a cup of Golden Rice every day is enough to supply 50% of the Recommended Daily Allowance of vitamin A for an adult. Because rice is widely produced and consumed, Golden Rice has the potential to reach people who do not have regular access to or cannot afford other sources of vitamin A.

ISAGANI SERRANO

Grains of innovation. Golden Rice gets its rich yellow color from beta carotene that the body converts to vitamin A.

A new partner in health

"We have been working on Golden Rice for about 10 years to develop a safe and effective way to address vitamin A deficiency, prevent blindness, and save lives," said Gerard Barry, Golden Rice Network coordinator and IRRI's Golden Rice project leader. "Our latest stage of work is now supported by the Bill & Melinda Gates Foundation and will bring in Helen Keller International (HKI), a new partner from the nutrition sector, to further understand how well Golden Rice can reduce vitamin A deficiency."

HKI is a leading global health organization that has been advocating the elimination of vitamin A deficiency for more than 40 years by working with governments and other partners. In 2010, it joined the Gates Foundation-funded partnership with IRRI, the Philippine Rice Research Institute (PhilRice), the Bangladesh Rice Research Institute (BRRI), and other partners to reduce blindness and prevent malnutrition worldwide.

Keeping farmers' seeds in sight

Developed by Professor Ingo Potrykus, then of the Institute for Plant Sciences, Swiss Federal Institute of Technology, and Professor Peter Beyer of the University of Freiburg, Germany, Golden Rice was conceived as a gift to resource-poor farmers in developing countries. Through genetic modification, the rice contains genes from maize and a common soil microorganism that produce beta carotene in the grains. Since 2000, scientific research and international collaboration on Golden Rice have been supported by funding and in-kind support from the private, public, and philanthropic sectors.

From research laboratories, the precious gift is now a step closer to its intended beneficiaries. Dr. Parminder Virk, IRRI senior rice breeder, worked closely with PhilRice and BRRI breeders on the groundbreaking crosses to transfer the Golden Rice trait into many Asian mega-varieties of rice. Scientists bred the Golden Rice trait into multiple lines of PSB Rc82, the most popular farmer variety in the Philippines, and BRRI dhan29, the most widely used variety in Bangladesh during the productive growing season.

At the end of 2010, IRRI established a confined field test of Golden Rice in the popular rice variety IR64 and in other leading Philippine and Bangladeshi varieties. Screenhouse and field evaluations of Golden Rice are critically important because they help determine how well Golden Rice grows in conditions similar to farmers' fields. They are also used to develop Golden Rice varieties that are suited to different areas.

"We are conducting our breeding carefully to make sure that the new Golden Rice varieties retain the same high yield, pest resistance, and excellent grain and eating qualities while helping to address the pervasive problem of vitamin A deficiency in the Philippines," said Antonio Alfonso, chief science specialist and Golden Rice team leader at PhilRice. Initial trials indicate that the Golden Rice trait has no measurable effect on the performance of the rice varieties in the field and these varieties are ready for transfer to PhilRice and BRRI.

This research will also include cooking and taste tests to help make sure these qualities of Golden Rice meet consumers' needs. In addition, Golden Rice is expected to cost farmers and consumers the same as other rice.

Golden opportunities ahead

Building on previous funding from the Bill & Melinda Gates Foundation, the Rockefeller Foundation, and the U.S. Agency for International Development, the US$10.3 million grant to IRRI in 2010 will fund the further development and evaluation of Golden Rice varieties for the Philippines and Bangladesh. The new funding will be used in part to establish the safety of Golden Rice. Safety research and other evaluations will be done by IRRI, PhilRice, BRRI, and other partners in field tests in both the Philippines and Bangladesh.

Results of the field tests will be assessed by regulators according to internationally accepted guidelines for food, feed, and environmental safety as part of the approval process for Golden Rice before it can be released to farmers or made available to consumers. PhilRice and BRRI plan to submit all safety information to their respective national government regulators as early as 2013 in the Philippines and 2015 in Bangladesh.

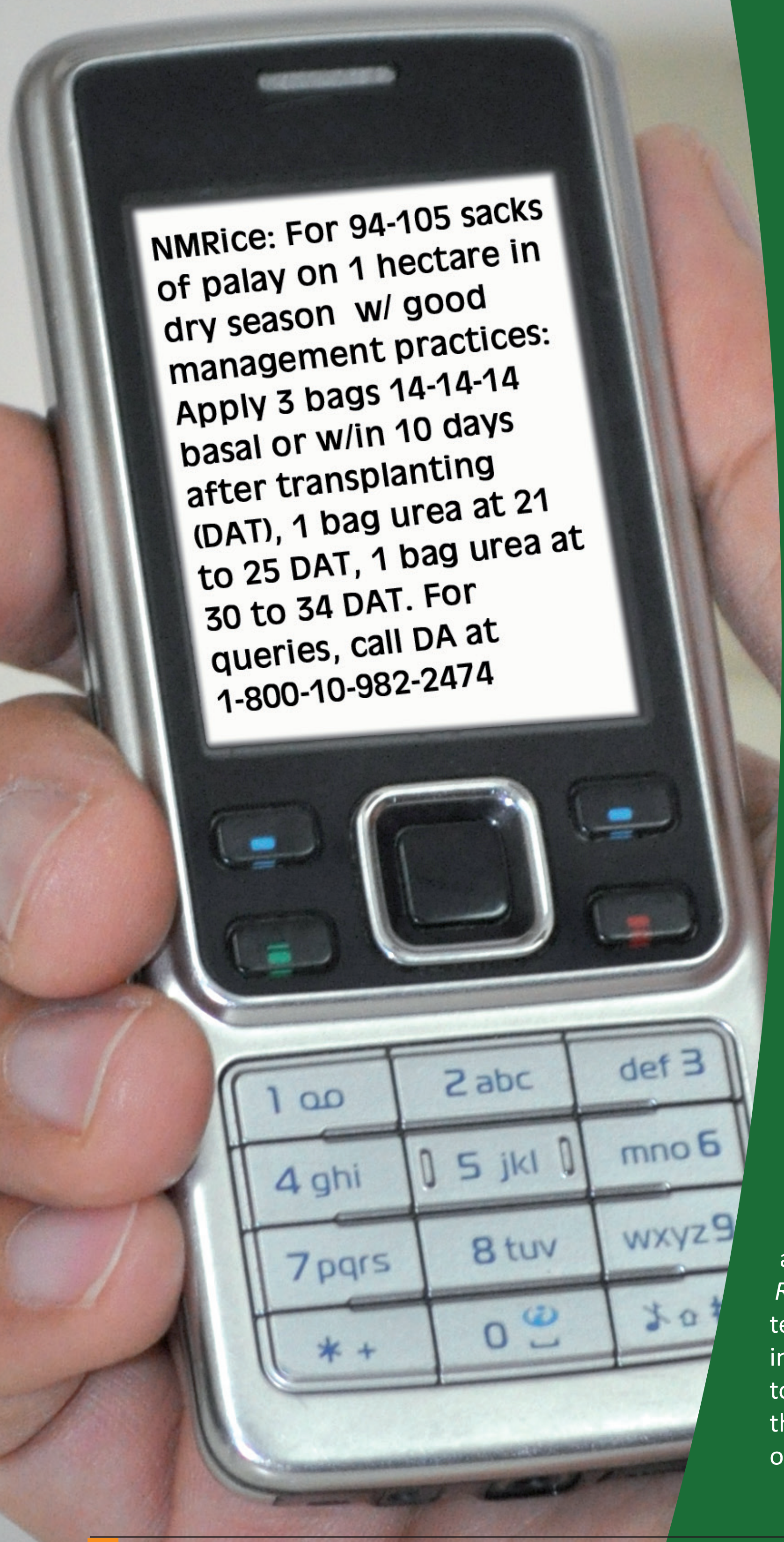
Once the safety of Golden Rice is confirmed, HKI, the University of California at Davis, and local partners will conduct studies to determine the effectiveness of Golden Rice in improving vitamin A status among vitamin A-deficient women in the Philippines. The trial will compare the efficacy of daily consumption of Golden Rice and white rice with a vitamin A supplement for 90 days. The organizations will also design and test a delivery program to ensure that Golden Rice can reach farmers and consumers in the Philippines and Bangladesh, especially those who need it most, in a sustainable manner.

HELEN KELLER INTERNATIONAL

Gift of sight. Golden Rice aims to reduce vitamin A deficiency, which is the leading cause of preventable blindness in children and can put them at higher risk of death from certain common infections.

If, at the end of this project, Golden Rice is proven to be safe, effective in reducing vitamin A deficiency, and accessible to those who need it the most, IRRI's partners will expand efforts to promote it in the Philippines and Bangladesh. The experiences of developing and launching the product in these two countries will be invaluable for efforts to combat vitamin A deficiency in the rest of the world.

Fertilizer recommendations at farmers' fingertips



Fertilizers constitute the second-largest cost for rice farmers. But, when applied too much, too little, or at the wrong time, this expensive agricultural input fails to increase crop yield and farmers' income. Now, using interactive voice response technology, Nutrient Manager for Rice (NMRiceMobile) *allows farmers to receive advice via their mobile phone on what, when, and how much fertilizer should be applied to their rice crop.*

The use of agricultural inputs, in particular fertilizer, is widely recognized as a major key to food security. Fertilizer promotes dramatic growth in crop yields and generates high returns while its low use has been proven to cause stagnation in productivity.

In Asia, where 90% of the world's rice is produced and consumed, rice receives about one-third of all fertilizers used in the region. Although rice farmers generally recognize the importance of fertilizer for supplying crops with essential nutrients needed for sustaining high yield, they often do not apply fertilizer at the right time and in the right amount to get a high return on their investment.

Making the right call

In partnership with the Department of Agriculture (DA) in the Philippines, IRRI developed and launched a mobile phone application of *Nutrient Manager for Rice* (*NMRiceMobile*) using interactive voice response technology. *NMRiceMobile* is designed to help farmers increase their production and profit by allowing them to receive advice via their mobile phone on applying the right type of fertilizer in the right amount and at the optimum time, thereby reducing fertilizer waste.

EMMANUEL PANISALES (2)

“Crop management practices must be tailored to location-specific needs in order to produce sufficient food at affordable prices for consumers and with higher profitability for small-scale farmers,” explained Roland Buresh, IRRI’s nutrient management expert and lead developer of *NMRiceMobile*. “The same holds true for applying nutrients to cereal crops like rice.

“This is because optimal amounts and sources of nutrients to meet crop needs can vary even across short distances within or among fields,” he added. “If the application of nutrients as fertilizers is too little or at the wrong time, there can be a loss in yield and profit. On the other hand, applications beyond the crop’s needs not only reduce profit but can also increase risks to our environment.”

A direct line to information

NMRiceMobile incorporates the principles of site-specific nutrient management (SSNM) for rice already well established in Asia’s major rice-growing areas. SSNM is available through an online decision-making tool called *Nutrient Manager for Rice*, which is tailored to the particular rice-growing conditions of a country. It enables extension workers, crop advisors, and farmers to rapidly determine the best fertilizer management practice for specific areas. Online applications of *Nutrient Manager for Rice* are now available for the Philippines, Indonesia, and Guangdong Province of China.

“*Nutrient Manager for Rice* was first made available on CDs in 2008 in the Philippines using local languages, but it was slow in reaching farmers because of the time required for distributing the CDs,” said Dr. Buresh. Moreover, the DA wanted to put *Nutrient Manager for Rice* easily within the grasp of Filipino farmers and their extension workers. “Many Filipino farmers don’t have ready access to a computer,” Dr. Buresh said. “But most have access to mobile phones, so it made sense for the DA to pursue mobile phones as a way to communicate with the farmers.”

Fertilizing by numbers

Farmers and extension workers can now dial a toll-free number and hear a voice instruction in English or their preferred local language of Tagalog, Cebuano, or Ilocano. The instruction will prompt them to use their keypad to answer 12 to 15 questions about their rice crop. After answering all the questions, the caller receives a text message with a fertilizer recommendation customized for his or her rice field and rice-growing conditions. The use of a toll-free number from a mobile phone greatly increases access to *NMRiceMobile*.

“It’s so fast and easy to understand,” said Mamerto Jimenez, a farmer from the province of Isabela in Northern Luzon. Romeo Pangan, also from Isabela, says he no longer has to guess the amount of fertilizer his crops need because he can now rely on accurate information provided by *NMRiceMobile*.

Meanwhile, development of Internet applications of *NMRice* is under way in Bangladesh, India, Vietnam, and Africa. Mobile phone applications of *NMRice* are planned in 2011 in Indonesia and Bangladesh.

The DA together with the Swiss Agency for Development and Cooperation, the International Plant Nutrition Institute, the International Fertilizer Association, and the International Potash Institute have supported the development of *NMRiceMobile*.

For more information:

Buresh RJ. 2010. Precision agriculture for small-scale farmers. Rice Today 9(3):46.

Buresh RJ. 2010. Nutrient best management practices for rice, maize, and wheat in Asia. In: Gilkes RJ, Prakongkep N, editors. Proceedings of the 19th World Congress of Soil Science; Soil Solutions for a Changing World; ISBN 978-0-646-53783-2; Published on DVD; www.iuss.org; Division Symposium 3.2; Nutrient best management practices; 2010 Aug 1-6. Brisbane, Australia: IUSS. p 164-167.

Buresh RJ, Pampolino MF, Witt C. 2010. Field-specific potassium and phosphorus balances and fertilizer requirements for irrigated rice-based cropping systems. Plant Soil 335:35-64.

Resizing rice's carbon footprint

The effects of global warming such as hotter days and nights, flooding, drought, and soil salinity pose serious threats to rice production. On the other hand, rice farming gives off methane, one of the greenhouse gases that acts like a warm blanket around the planet, holding in the heat, and causes erratic and extreme weather conditions. IRRI is attempting to break this cycle by exploring potential technologies that will cut down on the greenhouse gas emissions from rice production.

Most people associate greenhouse gases such as carbon dioxide and nitrous oxide with heavy industry and other activities powered by fossil fuels—but certainly not with rustic rice fields or organic fertilizers.

Lowland farmers commonly keep rice fields continuously flooded because this has several benefits. For instance, it effectively suppresses the growth of weeds, thus eliminating the need for herbicides. It also promotes the rapid decomposition of organic matter, which increases soil fertility without using chemical fertilizers. Therein lies the rub. Under flooded conditions, the decomposition of organic materials such as decaying rice roots, leaves, and straw or organic fertilizer consequently leads to the production of methane, a gas that is 25 times more effective in trapping heat in the atmosphere than carbon dioxide.

Testing for greener technologies

As early as the 1990s, IRRI started looking at ways to lessen the environmental footprint of rice farming through technologies and management practices that cut down on carbon dioxide, methane, and nitrous oxide emissions as well as water-saving techniques. One of these ways is treating organic materials first using a biogas plant or transforming rice straw into black carbon ("biochar") before adding them into the soil. These pretreatments substantially reduce methane emissions compared with simply mixing fresh organic residues into the topsoil.

Another technology evaluated was aerobic rice production, in which lowland rice is grown without continuous flooding using varieties developed for nonflooded and well-drained fields. During the wet and dry seasons of 2008, IRRI compared seasonal changes in heat, water vapor, and carbon dioxide fluxes in lowland and aerobic rice environments using an eddy covariance (EC) system installed at the IRRI farm. EC is a standard micrometeorological method that measures carbon dioxide and heat exchange over a large area. The EC system at IRRI is the first of its kind in the Philippines. Powered by a solar panel, the system consists of a sonic anemometer that senses wind direction, an open path CO_2/H_2O infrared analyzer, as well as sensors for radiation, temperature, and humidity.

Balancing the pros and cons

On the basis of findings in the study, lowland rice fields take up more carbon dioxide from the atmosphere than aerobic rice fields. "Flooded rice fields have higher capacity to convert carbon into organic compounds via photosynthesis," said Reiner Wassmann, IRRI's climate change expert and coordinator of the climate change research program. "This carbon uptake leads to storage of carbon in the soil, a process called sequestration, which is a positive feature of flooded rice fields.

"In turn, converting from flooded rice production to an aerobic rice system to conserve water would mean less stored organic carbon in the soil," Dr. Wassmann added. "This effect must be taken into account to determine the net global warming potential of an aerobic production system."

This complex interaction of intertwined cause-symptom relationships can be seen as typical for responses to climate change for which plugging one hole may cause another one to burst open. This shows that we need to find a balance in the management of our land-use systems—including rice fields. The effects of new crop management techniques on climate change must also be considered as they present a future challenge of attaining equilibrium between ensuring food security and slowing down global warming.

EMMANUEL PANISALES (2)

Measuring rice footprints. Using a highly sophisticated eddy covariance setup at the IRRI farm, climate change expert Maricar Alberto checks and collects data on wind, temperature, humidity, and CO_2 emissions of aerobic rice production.

In the past few decades, Bangladesh has made remarkable progress in agriculture, particularly in rice production, through mechanization and modernization. Modern irrigation systems, using shallow tube wells (STW) and deep tube wells (DTW) to extract groundwater, have led to an increase in the country's cultivation of boro rice. In fact, boro rice constitutes about 60% of the national rice production and plays a vital role in ensuring the country's food security.

But, the significant increase in the operation and maintenance of STW and DTW, coupled with the low efficiency of irrigation water use, could threaten the country's hard-earned food self-sufficiency. Additionally, the presence of arsenic in groundwater is becoming a major health and environmental concern in Bangladesh. The source of the toxic element has been traced to pyrite minerals that are being drawn up to the surface with the extraction of groundwater.

Easing the pressure on water

IRRI, through the Irrigated Rice Research Consortium (IRRC), has been working with the Bangladesh Rice Research Institute and other organizations in promoting and testing a technology that could help farmers save on water. Instead of continuous irrigation, alternate wetting and drying (AWD) technology allows farmers to let their fields go without irrigation from 1 day to more than 10 days before flooding them again.

After irrigation, the depth of water in the field will gradually decrease. With the use of perforated *pani* ("water" in Bangladeshi) pipes inserted into the ground, farmers are able to determine the right time to re-flood the rice field. When the water has dropped to 15 cm below the surface of the soil, irrigation is applied to re-flood the field with 5 cm of water. From 1 week before to 1 week after flowering, water is maintained at 5-cm depth. After flowering, during grain filling and ripening, the water level can drop again to 15 cm below the surface before re-irrigation.

Spreading the wise use of water

In 2007, the Bangladesh Agricultural Development Cooperation, Barenda Multipurpose Development Authority, and the Department of Agricultural Extension (DAE) established AWD demonstration plots in farmers' fields in different ecological zones in Bangladesh. Practical Action, a nongovernment organization (NGO), conducted AWD demonstrations with 400 farmers, while Syngenta, a private company, worked with 50,000 farmers. DAE and other private agencies and NGOs disseminated AWD over 50 districts in 2010, covering more than 120,000 hectares of boro rice.

Early impact and benefits

A study commissioned by IRRI, in collaboration with the Advisory Service on Agricultural Research for Development (BEAF) of German Technical Cooperation (GTZ), measured the level of adoption and short-term impacts of AWD in Rajshahi and Rangpur divisions. IRRC's agricultural anthropologist Flor Palis and Water-Saving Work Group leader Ruben Lampayan provided technical support in planning and designing the study.

"Positive economic benefits were reported by Bangladeshi farmers who adopted AWD," Dr. Lampayan

RUBEN LAMPAYAN

A plug in the drain. Using a simple perforated tube, Bangladeshi farmers can monitor the water level in their fields and determine when to stop and re-start irrigation. AWD can significantly increase their water-use efficiency without affecting their harvest.

The continuous supply of good-quality water is an essen food security of Bangladesh. Through its groundwater i country achieved self-sufficiency in food grain productio of dry-season or boro rice. But boro rice production req extraction of groundwater, a costly process because a va are powered by diesel. Alternate wetting and drying (AW water-saving technology, allows farmers to reduce their significant yield loss.

Managing liquid asse

LANIE C. REYES

reported. "The cost of irrigation was cut by 20% due to a reduction in the number of irrigations, and yet there was a yield increase of about 10%."

Thirsting for water-saving technology

Although early adopters have proven AWD's potential for conserving water among Bangladeshi farmers and conserving the energy required to extract it, many of the various public, private, and nongovernment organizations involved in the validation and dissemination of the technology have not gone far beyond the "piloting and validating" stage.

"Because dissemination efforts started only in 2007, the study concluded that the dissemination and adoption of AWD are still in the early stage," Dr. Lampayan said.

"Thus, there is a strong need to push, improve, and institutionalize the dissemination process further in the country, considering the high demand and benefit of the technology, especially for the boro season," he noted.

To ensure policy support, policymakers should be involved early. Extension agencies should also form strategic partnerships and take the lead at the initial stages of technology dissemination. "The end-users, specifically the farmers, should be partners in the process of developing, validating, and disseminating new technologies," he added. "The farmers, after all, are the ones who stand to benefit from any development."

A team approach to rice health

Crop health problems—caused by diseases, insects, and weeds—surprisingly do not draw the amount of attention they deserve. Tropical and subtropical Asia regularly lose up to 200 million tons of rice every year to poor crop health management. At best, the pest-by-pest approach used in the past led only to partial solutions. Holistic approaches, however, can bring together plant protection specialists, social scientists, agronomists, breeders, and geographers to tackle the mounting problem of crop health management in times of global and climate changes.

Tropical and subtropical Asia regularly lose 120 million to 200 million tons of rice every year to poor crop health management. This amounts to a double penalty: first, loss of potential harvest, and, second, loss of labor, land, water, seeds, and inputs invested in the crop. This double penalty is not borne by farmers alone, but by rural communities, consumers, and societies as well.

Reinventing crop health management

Several studies have shown that a pest-by-pest approach used in the past led only, at best, to partial solutions. Instead, plant protection specialists are advocating a systems approach in which crop health is considered as a whole.

"This reasoning is guided by the same philosophy that good physicians follow when advising patients and prescribing a healthier way of life," said Serge Savary, a plant pathologist and head of the Crop Health Work Group of the Irrigated Rice Research Consortium at IRRI. "Imagine being a doctor in the UK in the 1800s during the Industrial Revolution," he explained. "Biology was just emerging. Many diseases were being discovered, many of them related to the way of life, the quality of nutrition or water, and working conditions. A medical doctor then faced dramatic, often widespread, public health situations.

"Today, doctors in the UK face completely different situations," he added. "They have a better understanding of social systems, health of elderly people, and the psychological effects of health.

"What plant protection specialists are facing today is similar," he concluded. "We need to understand this co-evolution between crop health and 'production situations,' which include biophysical and socioeconomic factors."

Managing pests using information

IRRI has been using a two-pronged approach to address the variation in crop health in response to shifting "production situations." The first, a part of the Cereal Systems Initiative for South Asia, is field-based and heavily uses a field-tested "survey portfolio" that has been instrumental in many rice-growing countries, including those of South Asia. The data gathered from this portfolio help diagnose the relationships between production situations and crop health. The approach has been used in Bangladesh, Nepal, India, and Pakistan, and it still generates new data.

The second approach is based on close collaboration between IRRI and the Directorate of Rice Research (DRR) of India.

In both approaches, various national agricultural research and extension systems play critical roles in generating data, gaining access to existing information, and sharing methods and results so that these data enter the public domain. Geographic information systems, combined with simulation modeling, are another avenue to make use of this invaluable information, especially with respect to global and climate changes.

From temporary eradication to long-term management

For example, information was analyzed from 129 Indian districts on five groups of injury patterns, four production situations such as biophysical and socioeconomic conditions where agriculture takes place, and three different kinds of rice plant materials collected as part of the production-oriented surveys conducted by DRR in 2005. The analysis showed a link between crop health in the context of production situations and the type of plant material used (i.e., inbred or hybrid).

Dr. Savary was able to statistically associate false smut, a fungal disease, with patterns of cultivation of certain varieties in hybrid rice-growing areas. This highlights the need for research on the biology and the causes, distribution, and control of this disease in order to develop suitable management tools.

According to Dr. Savary, several hundred farmers' fields were surveyed in 2009 and 2010 for production situations and crop health and these data are being processed.

"These data not only inform us about the current situation in farmers' fields, especially with respect to emerging crop health problems," Dr. Savary said. "They also help predict future pest infestations through the use of statistical tools."

IRRI

Surveys and stats. Data gathered using farmers' field surveys for production situations and crop health provide useful information on emerging health problems allowing experts to rtake proactive solutions.

Financial support from donors

Summary of financial support to IRRI's research agenda In 2010 and 2009 (US$000)

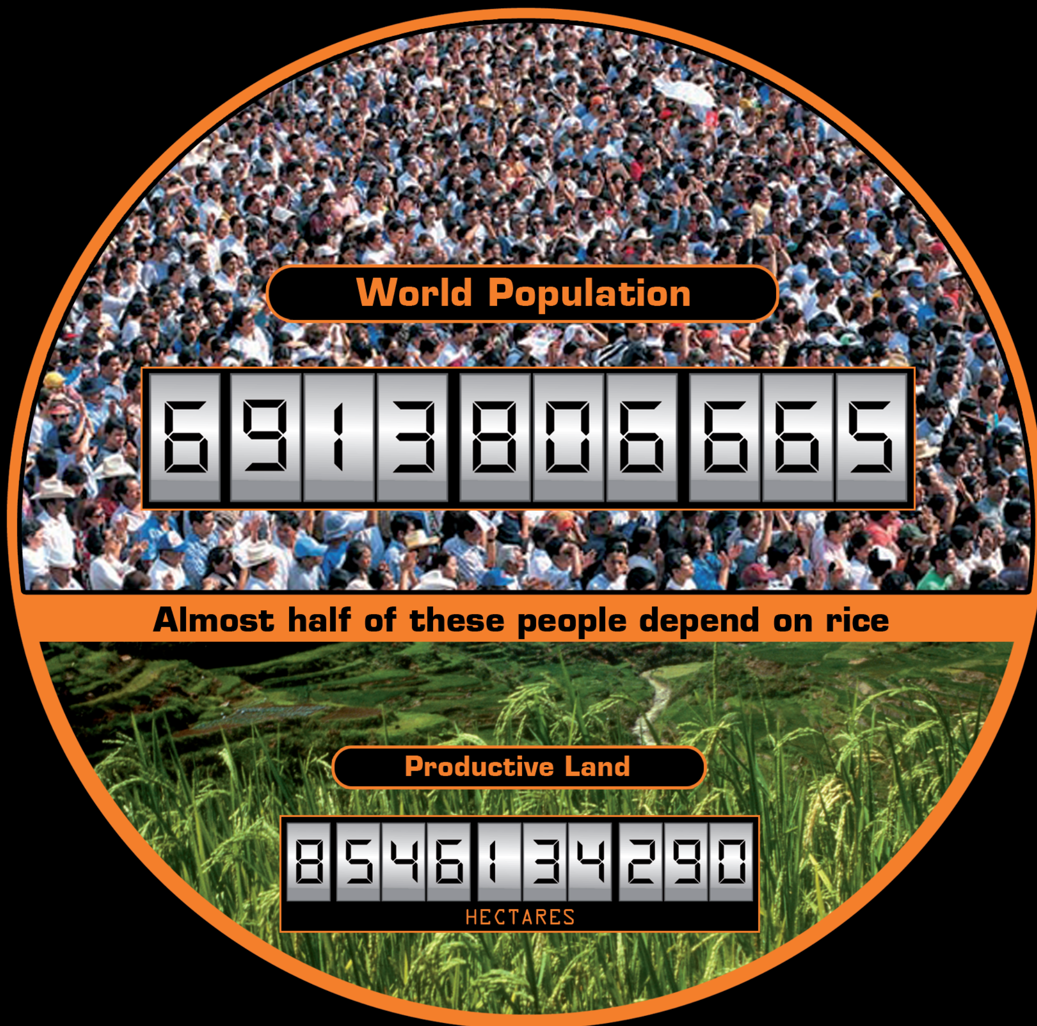
	2010	2009
Asian Development Bank	871	1,614
Australia	2,866	1,415
Bangladesh	100	105
Bayer CropScience AG	88	
Bill & Melinda Gates Foundation	16,838	15,103
Canada		
Canadian International Development Agency	1,273	1,191
Challenge Programs		
Generation	1,011	1,397
HarvestPlus	1,047	614
Water&Food	88	245
China	223	202
Chinese Academy of Agricultural Sciences	1,245	905
Consultative Group on International Agricultural Research (CGIAR) centers and Secretariat		
AfricaRice	13	
Bioversity International	68	68
CGIAR/Systemwide Genetic Resources Program/		
Special Program for Impact Assessment	46	403
International Center for Agricultural Research in the Dry Areas	23	74
International Crop Research Institute for the Semi-Arid Tropics	331	212
International Food Policy Research Institute	88	12
Cornell University	292	114
European Commission	1,526	1,421
Food and Agriculture Organization of the United Nations	35	40
France	491	549
Germany		
Federal Ministry for Economic Cooperation	612	853
Federal Ministry for Economic Cooperation/German Agency for Technical Cooperation	476	419
Global Crop Diversity Trust	271	234

	2010	2009
Grand Challenges in Global Health through Albert-Ludwigs University of Friedburg	389	483
Hybrid Rice Development Consortium	324	302
India	479	468
International Atomic Energy Association	1	27
International Fertilizer Industry Association, International Plant Nutrition Institute, International Potash Institute	122	103
International Fund for Agricultural Development	997	952
Iran	48	92
Japan	5,681	4,141
Kellogg Foundation	50	20
Korea	824	748
Malaysia	14	17
Norway	409	294
Nunhems BV	5	13
Philippines	562	159
Plan International Cambodia	6	27
Pioneer Hi-Bred International	234	207
Portugal	169	90
Rockefeller Foundation	929	376
Sweden	547	508
Switzerland	2,001	1,652
Syngenta Asia Pacific Pte. Ltd.	93	60
Thailand	80	40
United Kingdom	2,533	2,143
United States of America	6,738	5,073
Vietnam	70	15
World Bank	2,766	2,458
World Vision, Inc.	93	87
Others	742	310
Total	56,828	48,055

For complete information, view IRRI's Audited Financial Statements for 2010 on the attached DVD.

Selected acronyms (in print and DVD versions)

ACIAR Australian Centre for International Agricultural Research
ADB Asian Development Bank
ARI advanced research institute
ASL Analytical Service Laboratories
AfricaRice Africa Rice Center
ASA American Society of Agronomy
AWD alternate wetting and drying (technology)
BMGF Bill & Melinda Gates Foundation
BMZ The German Federal Ministry for Economic Cooperation and Development
BOT Board of Trustees
BRRI Bangladesh Rice Research Institute
CAAS Chinese Academy of Agricultural Sciences
CCA certified crop adviser
CESD Crop and Environmental Sciences Division
CGIAR Consultative Group on International Agricultural Research
CIAT International Center for Tropical Agriculture
CIMMYT International Maize and Wheat Improvement Center
CIRAD Centre de coopération internationale en recherche agronomique pour le développement
CPS Communication and Publications Services
CSISA Cereal Systems Initiative for South Asia
CURE Consortium for Unfavorable Rice Environments
DA Department of Agriculture (Philippines)
DDR Disarmament, Demobilization, and Reintegration
DDG-OSS Deputy Director General for Operations and Support Services
DDG-R Deputy Director General for Research
DRR Directorate of Rice Research (India)
DSR direct-seeded rice
DTW deep tube well
ES experiment station
ESA East and Southern Africa
EVO Events and Visitors' Office
FFS farmer field school
GAP good agricultural practices
GCP Generation Challenge Program
GIS geographic information systems
GQNPC Grain Quality, Nutrition, and Postharvest Center
GR Golden Rice
GRC Genetic Resources Center
GRiSP Global Rice Science Partnership
HKI Helen Keller International
IFAD International Fund for Agricultural Development
IFHK IRRI Foundation Hong Kong
IFPRI International Food Policy Research Institute
IFS IRRI Fund Singapore
ILRI International Livestock Research Institute
INGER International Network for Genetic Evaluation of Rice
IRD L´Institut de reserche pour le développement
IRRC Irrigated Rice Research Consortium
JIRCAS Japan International Research Center for Agricultural Sciences
LDS Library and Documentation Services
MABC marker-assisted backcrossing
MODIS Moderate Resolution Imaging Spectroradiometer
MOU memorandum of understanding
NARES national agricultural research and extension systems
NGOs nongovernment organizations
NILs near-isogenic lines
NM Nutrient Manager for Rice
PBGB Plant Breeding, Genetics, and Biotechnology (Division)
PhilRice Philippine Rice Research Institute
PO performance objective
PVS participatory varietal selection
QTL quantitative trait locus
SDC Swiss Agency for Development and Cooperation
SHU Seed Health Unit
SMTA Standard Material Transfer Agreement
SSD Social Sciences Division
STW shallow tube well
TC Training Center
UPLB University of the Philippines Los Baños



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ISSN No.: 0074-7793