Program 3

Improving productivity and livelihood for fragile environments

More than 700 million of Asia's poor obtain 50–80% of their calories from rice grown in unfavorable rice environments—infertile uplands, rainfed lowlands subject to frequent droughts and submergence, and deepwater and coastal areas that suffer from flooding, strong winds, salinity, and other soil-related problems. Farmers in these fragile environments face drought and submergence, diverse pests and diseases, and poor soils. They minimize risk by limiting inputs, but this results in low yields—less than 2 tons per hectare compared with more than 5.5 tons per hectare in favorable irrigated lowlands. The benefits from rice science in these conditions have so far not been as great as those in the favorable environments. Because rice farming (the production of staple food) is the major economic activity at low levels of income, these ecosystems are characterized by low farm income and high incidence of poverty. These ecosystems account for about 55% of the rice lands and are home to the vast majority of the rural poor in Asia. New, higher yielding varieties that are tolerant of drought, submergence, and problem soils must also be comparable in quality with traditional varieties if farmers are to adopt them.

Stress-tolerant, better yielding varieties, along with efficient crop management practices, will help reduce the risk in rice cultivation that contributes to socioeconomic inequity and will help increase yield and farm income. The probability for success in research for

building tolerance for abiotic stresses into better yielding varieties was low in the past, leading to inadequate allocation of research resources to solve these problems. But, with recent advances in molecular biology for tagging and characterizing genes and their transfer to other species, the probability of success in this area appears bright. The environments are diverse and their domains vary across countries; hence, this research must be done in partnership with the national agricultural research and extension systems (NARES), drawing on local scientific expertise and farmers' indigenous knowledge. IRRI coordinates the Consortium for Unfavorable Rice Environments (CURE, Project 9) to develop and implement the research agenda to tackle problems in the unfavorable rice environments. The consortium places emphasis on developing and delivering technologies and knowledge to farmers, and working with them to adapt these to suit specific needs, conditions, and livelihood strategies.

The research and related activities are grouped into three projects, on genetic enhancement, natural resource management, and the activities of CURE, respectively.

PROJECT 7

Genetic enhancement for improving productivity and human health in fragile environments

The modern rice varieties developed for irrigated systems do not adapt well to unfavorable ecosystems and farmers obtain low and unstable yields and limited gains in profits when they adopt them. Risk reducers that offer more promise include enhanced seedling vigor, heightened tolerance or avoidance (through early maturity) of drought and submergence, improved ability to grow in soils with toxic levels of salt, iron, or aluminum or deficient in phosphorus or zinc, and strengthened resistance to pests and diseases, especially the blast fungus. The goal of Project 7 is to develop rice varieties that combine these traits with high and stable yields and consumer-preferred grain type.

Improving the efficiency and value of rice production in fragile areas promises immense gains in food security, human nutrition, poverty reduction, and environmental protection. In addition to providing more calories from higher yields, improved varieties have the potential to offer enhanced levels of vitamin A, lysine, iron, and zinc. Because rice is prominent in the Asian diet, inexpensive, and easily stored, it is an ideal vehicle for enhancing nutrition among the poor.

In recent decades, researchers have discovered potential answers to many of these problems and aspirations in the genes of cultivated and wild rice. Scientific advances in biochemistry, physiology, and biotechnology have already produced promising genetic material and clear breeding strategies that can now be tapped for genetic enhancement of varieties for fragile environments. High levels of iron, zinc, and provitamin A, and tolerance for drought, submergence, phosphorus deficiency, and saline soils, are traits with good prospects for breeding into different rice cultivars.

IRRI is uniquely positioned to bridge, on the one hand, the upstream research done in advanced research institutes and the private sector in industrialized countries and, on the other, the downstream research by NARES in developing countries to create varieties for rice farmers in highly diverse rainfed ecosystems.

Boosting the impact of this project are NARES-IRRI breeding networks, farmer participatory selection that recognizes the central role of women, and linkages with the International Network for Genetic Evaluation of Rice (in Project 1) and the Consortium for Unfavorable Rice Environments (in Project 9). The Asian Rice Biotechnology Network (in Project 2) facilitates the development and dissemination to NARES of germplasm and databases and the training of NARES scientists in new breeding, selection, and evaluation techniques. Animal and human nutritional studies on the bioavailability and food safety of micronutrient-rich rice are in progress.

Output 1: Superior germplasm for rainfed lowlands developed

A high-quality, blast-resistant version of the popular and highly valued Thai jasmine rice (KDML 105) with short duration, developed by IRRI in collaboration with the Thailand Department of Agriculture, was proposed for release in Thailand in 2005 (Output 6). This variety significantly reduces the risk of blast disease, which is endemic in northeastern Thailand. Also, its early maturity permits the crop to escape late-season drought, and will help small farmers in drought-prone areas to stabilize their yields. The new variety is likely to be rapidly adopted by farmers in affected areas. Equally important, the methodology serves as a model for developing high-quality, resistant varieties elsewhere.

Other blast-resistant lines that differ in only one gene (monogenic lines) are being evaluated in Thailand and the Philippines. These monogenic lines, which are useful for identifying different strains of blast disease and the genes that confer resistance, have been

distributed to more than 30 institutions in 15 countries for identification of the blast strains and application in breeding.

We are developing superior rice hybrids for farmers in moderately drought-prone lowlands. So far, we have produced (cytoplasmic male) sterile lines for breeding hybrids for drought-prone rainfed lowlands. Results from India suggest that yields are at least 1 ton per hectare higher than with varieties presently in use. The sterile lines will next be crossed with elite lines adapted to rainfed lowlands to produce suitable hybrids.

Rice yield under moderate to severe lowland drought stress is a heritable trait. This finding, the result of years of trials at IRRI and the Indira Gandhi Agricultural University, Raipur, India, will enable breeders to confidently apply selection techniques that will lead to the development of varieties combining high yield and improved drought tolerance in farmers' fields. Thirty-seven useful lines have been identified using these techniques and their superiority has been confirmed in tests in India. Next, we will apply the approach to IRRI's lowland rice populations and support national programs in institutionalizing drought screening in managed-stress conditions for cultivar development.

Output 2: Superior germplasm for flood-prone areas and infertile lowlands developed

Evaluation of salt-tolerant lines selected by farmers in a participatory rice breeding project in Bangladesh continued. Four selected lines for the boro season in coastal wetlands were compared in farmers' fields to decide which varieties to release and seeds were submitted to the Seed Certification Agency. The evaluation will continue in the aman season. Other breeding lines were being evaluated for salt tolerance in India. We will continue to send material to all participants in the Challenge Program on Water and Food for testing at each site and to other collaborators in research networks.

Research begun in 2003 on the mechanisms of submergence tolerance is now bearing fruit. Tolerance involves vigor, quick germination, higher activity of the enzyme amylase, and the generation of higher levels of ethylene. The findings mean that new fast screening techniques can be established based on these target traits. We now have 27 tolerant lines that show far greater survival (more than 60%) than do nontolerant varieties (9% for IR64). We will continue to look for any other physiological traits that may be involved. Work on marker-aided selection to speed up the incorporation of submergence into high-yielding varieties is also ongoing.

A key mechanism of tolerance for zinc deficiency in rice was identified: plant roots produce organic acids that make zinc more available for uptake. Existing mapping populations show variation in this trait, so we can rapidly move to map the regions on the chromosomes that control organic acid production. A new greenhouse screening method that simulates zinc-deficient field conditions now allows large-scale screening for traits associated with tolerance as well as a means for rapid phenotyping to identify the genes or groups of genes concerned.

Output 3: Superior germplasm for infertile uplands developed

The search for genetic markers involved in upland drought tolerance has not led to the identification of a few genes with large effects. Thus, tolerance in these populations is probably controlled by many genes and selection of phenotypes remains the best approach to improving upland drought tolerance in the short term, while we continue to seek the underlying genetic basis. Indeed, from trials at IRRI in 2004, we now know that yield under this kind of stress is a heritable trait (as found in lowland stress). Two promising high-quality, short-duration lines, developed by direct screening under drought conditions, are currently being evaluated in drought-prone areas of eastern India. An IRRI-India drought breeding network based on direct selection for yield under stress is beginning.

In seeking better breeding strategies for low-input upland systems, our analyses of trials from India and Lao PDR have shown that, contrary to expectation, improved upland cultivars perform better than traditional varieties under low-input and high-input management. However, because trial results exhibit high variability, extensive testing in different environments will be needed to make yield gains.

IRRI scientists successfully incorporated five candidate genes for blast resistance into selected elite lines. High levels of resistance to seedling and neck blast were demonstrated by these lines in an area of high disease pressure in Almora, India. Success of the technique means that we can combine several chromosomal regions, each providing a different type of resistance, in different varieties to provide partial blast resistance in blast-prone areas. Markers for tracking effective versions of genes (alleles) on small regions of the chromosomes in advanced breeding lines are now available. Next, we need to track and recombine these alleles in additional populations.

IRRI scientists made progress during the year on two major upland problems for rice farmers—phosphorus deficiency and blast. Lines that we confirmed in 2003 to have superior phosphorus uptake (with the gene concerned [*Pup1*] finely mapped; see Project 2, Output 3) were crossed with blast-resistant lines. Third-generation data are now being analyzed. We will screen blast-resistant lines for incorporation of the *Pup1* gene and evaluate selected materials in further generations until the lines are stable, when field testing can begin. Combining quantitative blast resistance and tolerance for phosphorus deficiency with tolerance for drought will be the next task.

Output 4: Aerobic rice germplasm for water-scarce tropical environments developed

We now have a composite picture of aerobic adaptation: rapid growth in the vegetative stage; and maintenance of panicle elongation, spikelet fertility, and harvest index under moderate stress in the reproductive stage. The work involved deriving lines with high aerobic adaptation by crossing the elite aerobic variety Apo with various lowland varieties, followed by four seasons of selection for yield under aerobic conditions. Advanced backcross lines are also being developed and their genotypes determined. Next, we will assess allele frequencies in the aerobic-adapted progeny of aerobic × irrigated crosses to identify the chromosomal regions that confer an advantage in aerobic rice systems.

Elite aerobic lines from upland × lowland crosses are being evaluated by breeding networks in Yunnan Province of China, India, Lao PDR, and the Philippines.

Hybrid rice is showing potential in aerobic conditions also. We plan to evaluate large numbers of rice hybrids under aerobic rice environments.

Output 5: Micronutrient-enriched rice to combat malnutrition in fragile environments developed

The year has been a busy and productive one in joint IRRI-NARES micronutrient research. IRRI distributed 10 elite iron-dense lines for evaluation by NARES in five countries (Bangladesh,

China, Indonesia, the Philippines, and Vietnam). NARES partners also identified elite lines with enhanced iron content, which will be shared among them and IRRI for evaluation. The evaluations are to confirm the elevated iron content and its distribution in the grain. (An earlier IRRI study, in which 300 women consumed high-iron rice, showed that the iron was bioavailable; the diet improved blood iron levels in nonanemic women.)

Transgenic rice plants that incorporate genes for beta-carotene synthesis and for enhanced levels of iron and protein in milled grain are now in place at IRRI. We are investigating varietal differences in expression of the incorporated genes, how these genes affect yield, and the effect of fertilizer on their expression. Although there has been concern about the use of such plants in some countries, they are well accepted in others. We will also continue to develop farmer-preferred cultivars incorporating these traits.

Output 6: NARES-IRRI partnerships in rice breeding enhanced

There is a need to integrate effective, low-cost methods of plant varietal selection (PVS) into breeding programs. Involving farmers is key to this. We found, for example, in experiments in India and the Philippines, that farmers' preharvest yield ratings and postharvest reports were similar to researchers' quantitative data. Farmers' experience, as both producers and end users, adds value to field trials. In collaboration with NARES, we produced a draft manual of PVS techniques to expand awareness of them among NARES. The techniques have already been incorporated in the Indian rainfed shuttle breeding networks and in the Lao PDR upland and rainfed lowland programs. Training materials on PVS will be upgraded for the NARES and we will continue to promote the methods in breeding programs.

Ideally, all the shuttle breeding groups collaborating with IRRI should use the International Rice Information System (IRIS), both to trace pedigree and evaluation information and to input their data for sharing with all users of the system. Breeders are enthusiastic to use the system. However, coordinating data input remains problematic, an issue we are now examining.

To complement IRIS, we produced software in 2004, now freely available, for the design of field trials in low-input and drought-stress environments. The previous lack of convenient software precluded the design and analysis of sophisticated trials needed for an efficient breeding program in these environments. We will provide training in use of the software.

The Eastern Indian Rainfed Lowland Shuttle Breeding Network (EIRLSBN) is a collaborative NARES-IRRI network of rainfed rice breeding programs targeting flood-prone lowlands in eastern India. The network produced two varieties developed by the Narendra Deva University of Agriculture and Technology (Faizabad, Uttar Pradesh) and derived from IRRI crosses, which were recommended for release in 2004. One of them, NDR 8002 (IR67493-M2), was recommended for national release by the All-India Coordinated Rice Improvement Project (AICRIP), and the other, NDR 96005 (IR66363-10-M-1-1-1-1), was recommended for release by the state of Uttar Pradesh. In addition to these releases, 41 lines developed by this network were under advanced national AICRIP testing in 2004.

In Thailand, collaboration between IRRI and the Department of Agriculture resulted in the development of two short-duration, blast-resistant jasmine rice varieties. These varieties were evaluated by farmers across northeastern Thailand in a large-scale IRRI-Department of Agriculture participatory varietal selection program in 2003 and 2004, funded in part by the Rockefeller Foundation. The short-duration varieties performed very well in the severe drought conditions of 2004 in the Khon Kaen area, and one is proposed for release to farmers in 2005. Responsibility for the advanced backcross program for short-duration jasmine rice was transferred to the national breeding program, which will also oversee the participatory testing and release of blast-resistant varieties of longer duration.

Project leader

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PROJECT 8

Natural resource management for rainfed lowland and upland rice ecosystems

The farm families who live and work in unfavorable rice environments are among the poorest people in the world. Rice yields in these difficult ecosystems, where 80 million families farm a total of 60 million hectares, are low and unstable. Erratic water supplies, crop diseases and pests, and problem soils cause risk that discourages farmers from investing in improved rice-production and resource-management techniques. Unsustainable farm practices degrade the natural resource base, condemning communities to ever-deepening poverty. Many inhabitants of these areas, especially the highlands, belong to socially and politically marginalized ethnic minorities. Project 8 seeks to overcome these problems by improving crop and natural resource management practices.

Output 1: Crop and natural resource management practices for improved livelihood in rainfed lowlands developed and evaluated

Ways to improve yield and sustainability in direct-seeded rice areas of Karnataka, India, were identified. The suggested resource management practices could help to improve the livelihoods of poor farmers. The state agricultural department is keen to demonstrate the practices, which may result in more farmers changing from transplanting to the direct-seeding method. We will investigate whether improvements can be made in Sri Lanka, where nearly all rice is farmed by this method, and in areas with similar agroclimatic conditions in other parts of South Asia.

Improved nutrient management strategies developed at IRRI for flood-prone areas were tested successfully at sites in Bangladesh and India, where yields improved by more than 1 ton per hectare. Low seeding rates (75 grams per square meter) in nurseries resulted in seedlings better capable of surviving flooding than those seeded at the normal rate (150 grams per square meter).

Survival of seedlings in the cold temperatures of the early boro season in Bangladesh was enhanced by placing nurseries under polyethylene covers, and further improved when combined with other improved nursery and nutrient management regimes.

In salt-affected areas, the earlier finding that application of excess calcium and phosphorus substantially improves seedling survival and growth was confirmed; the two nutrients act synergistically. We found that zinc oxide root dipping in saline areas improved grain yield by more than 1 ton per hectare, a finding that will next be tested in farmers' fields in collaboration with the Narendra Deva University of Agriculture and Technology (Faizabad, Uttar Pradesh).

IRRI's crop model ORYZA2000 has been evaluated for the first time in

rainfed conditions, using a standard procedure that we developed. The model worked satisfactorily in a wide range of rainfed lowland rice conditions in Central Java. Although some parameters are yet to be incorporated, we can begin to use the model to explore management options to improve rainfed rice productivity and stability.

Nutrient management recommendations for rainfed lowlands in Lao PDR were evaluated on-farm. We found that fertilizers have considerable potential to increase productivity but farmers lack knowledge on their use. Production of a poster to help farmers make decisions on where and when to use fertilizers has been delayed. An evaluation of nutrient recommendations in northeastern Thailand's rainfed lowlands showed that there seemed to be little potential for gain with the varieties in use there and a re-evaluation of the research strategy is needed.

Output 2: Crop and natural resource management practices for improved livelihood in upland rice systems developed and evaluated

The widespread *bolon* system in Bangladesh (photo above), which involves double transplanting of rice to avoid submergence in heavy flooding, is expensive in terms of labor and has low productivity. Research is continuing on the reasons for low productivity, socioeconomic issues, and overcoming constraints to improving the system. One result to date is an improved bolon system using tillers for double transplanting in second lowland fields and single transplanting on higher lands.

Management options suitable for smallholders in upland areas infested with the perennial grass *Imperata cylindrica* are being explored through field experiments. Options include sowing various legumes and forage grass, combined with flattening the *Imperata* with a drum or plank to allow the replacement species to establish. The use of a herbicide (glyphosate) was included as an option in the experiment to provide a comparison. The trial was established in the wet season of 2004. However, seed shortages meant that a replicated design was not possible and this is planned for 2005. Initial results suggest that the use of one legume (pigeon pea) may be an attractive option for farmers and that glyphosate addition prior to rice provides excellent control of the weed with very little regrowth. The work on improved fallow species builds on previous studies in Laos.

Project leader

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PROJECT 9

Consortium for Unfavorable Rice Environments (CURE)

In unfavorable rice environments that produce low rice yields, poverty and population density are high in both rural and urban areas. Rice productivity gains have so far been meager because of variable and difficult conditions and the absence of a well-structured strategic research approach to address key constraints. The continuing challenge in unfavorable rice environments is to increase and stabilize rice productivity, and so improve farmers' household food security and livelihood, while sustaining the resource base. Success demands that we work with our partners in the national agricultural research and extension systems (NARES) at sites representing these highly diverse environments and use a multidisciplinary approach to technology development and dissemination.

The Consortium for Unfavorable Rice Environments (CURE) is the framework to address these concerns and to foster cooperation in research and development between NARES and IRRI, who jointly identify strategic problems through collaborative research at NARES sites. CURE came about in 2002 with the restructuring and consolidation of the Rainfed Lowland Rice Research Consortium and the Upland Rice Research Consortium into a single entity. NARES in CURE at its establishment were from Bangladesh, India, Indonesia, Lao PDR, the Philippines, Thailand, and Vietnam. The research activities are described in projects 7 and 8.

Working groups' progress

NARES membership in the consortium formally expanded to 10 countries in 2004, with the inclusion of Cambodia, Myanmar, and Nepal. The steering committee, at its third meeting, held at the Ubon Rice Research Center, Thailand, 2-3 June, reviewed research progress and issues raised by the six working groups, each of which focuses on one of the unfavorable rice environments.

Drought-prone lowlands. Rice farmers in these areas generally still use old technologies rather than new ones recommended by national programs. Researchers conducted participatory varietal selection in order to select farmer-preferred rice varieties. Preference analysis was conducted with men and women farmers, and agronomic data were collected. Experiments conducted in Thailand during 2003-04 resulted in the development of the first short-duration KDML backcross derivatives, now handed over to the national program.

Submergence-prone lowlands. There has been enough crop-establishment research in this environment. Ways to scale up adoption of research findings and to identify new priority research areas are now needed.

Salt-affected environments. The main progress here has been in develop-

ing criteria for identifying representative sites for future research. Participatory varietal selection methods were used for screening advanced lines to identify farmer-preferred varieties for coastal areas in Bangladesh and eastern India. Experiments have also yielded nursery and crop establishment techniques that make seedlings more robust to withstand salinity stress, which is most severe at the start of the growing season.

Shifting rotational upland systems. Seed production was found to be important in ensuring seed availability for upland farmers. A case study on intensive upland rice systems in Yunnan Province of China was conducted to learn ways to improve productivity and livelihoods for upland systems in the Greater Mekong Subregion. In Lao PDR, IRRI social scientists organized training on socioeconomic and policy analysis, involving lectures, hands-on exercises, and case studies.

Drought-prone plateau uplands. After several years of trials, promising varieties of aerobic rice were identified for adoption in lands at the upland-lowland interface.

Intensive uplands with long rainy season. In Indonesia, interplanting experiments were conducted with susceptible and resistant traditional and improved varieties to reduce the yield losses from blast and reduce the use of pesticides for blast control. The results suggested that neck blast on the susceptible variety could be reduced more effectively by mixing seeds rather than by interplanting in rows.

Special research projects

New proposals for special projects under CURE were approved by donors for funding on the development of technologies to improve rice productivity in salt-affected areas of the Indo-Gangetic, Mekong, and Nile river basins (under the Challenge Program on Water and Food); technology validation and accelerating the adoption of technologies to improve livelihoods on the rainfed Gangetic Plains (funded by the International Fund for Agricultural Development, IFAD); and comparative analysis of food security and economic transition in uplands of the Greater Mekong and Hindu-Kush Himalayan subregions (funded by IFAD).

Project leader

Twng Wah Mew, principal scientist, plant pathology; program leader, Improving Productivity and Livelihood for Fragile Environments; and coordinator, CURE; Mahabub Hossain, head, Social Sciences Division, economist, and program leader, Improving Productivity and Livelihood for Fragile Environments, from June 2004, m.hossain@cgiar.org