The Doubly Green Revolution in Rice[1]

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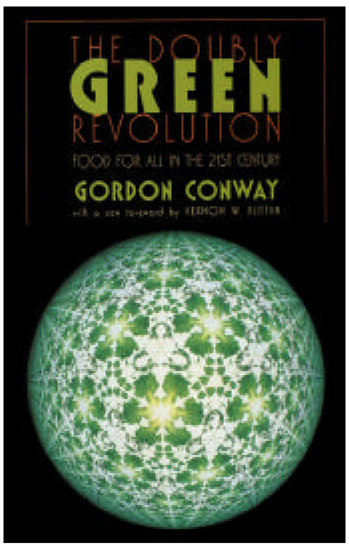
It is indeed a pleasure to be at this World Food Prize celebration here in Des Moines to participate in honoring this year's co-laureates, Dr. Monty Jones and Prof. Yuan Longping, two giants in rice research. How appropriate it is that we honor them this year—2004, the International Year of Rice. In Africa and Asia, respectively, they have both made remarkable contributions toward the eradication of hunger and poverty.



We're sure Dr. Jones and Prof. Longping will be building on their past successes toward even more achievements as we all stand ready to play roles in the coming "Doubly Green Revolution"—a concept put forth a decade ago (Conway et al 1994) by a small CGIAR-commissioned think-tank panel headed by Gordon Conway, who is here in the audience today. In his 1997 book of the same name, he put forth that the world needed a Doubly Green Revolution that would be even more productive than the first Green Revolution and substantially more "green" in terms of conserving natural resources and the environment (Conway 1997).

Today, we would like to suggest that—certainly in rice—the Doubly Green Revolution has commenced and significant progress has already been made. We'll be giving some examples about how IRRI and its partners in national agricultural research and extension systems (NARES) have already had noteworthy successes with environment-friendly technologies that are having positive impacts on rice productivity and poor farmers' lives.

The Green Revolution in Rice—Achievements and Lessons Learned

First, it is important to look back at the first Green Revolution—for our purposes today, in rice—not only to tick off some notable achievements on the one hand but also to look hard at some valuable lessons learned on the other. Dr. Conway wrote in his book that "the Green Revolution proved that poverty and hunger could be alleviated through the application of modern science and technology and, without it, the numbers of poor and hungry today would be far greater" (Conway 1997). In Asia, the Green Revolution in rice began with IRRI's release in 1966 of IR8, the first modern, high-yielding semidwarf rice

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variety (HYV). Since then, the global rice harvest has more than doubled, racing slightly ahead of population growth. This increased production and the resulting lower prices of rice across Asia have been the most important results of the higher yields that rice research and new farming technologies have made possible.

Around 1,000 modern varieties—approximately half the number released in 12 countries of South and Southeast Asia over the last 38 years—are linked to germplasm developed by IRRI and its NARES partners alone—a significant achievement indeed (Cantrell and Hettel 2004a). The person responsible for developing the hundreds of breeding lines that led to many of these varieties is in the audience today—Dr. Gurdev Khush (in photo below), IRRI's former principal plant breeder who retired in 2001 after an impressive 34-year career. These modern varieties and the resultant increase in production have increased the overall availability of rice and also helped to reduce world market rice prices by 80 percent over the last 20 years.

Poor and well-to-do farmers alike have benefited directly through more efficient production that has led to lower unit costs and increased profits. Poor consumers have benefited indirectly through lower prices. This has brought national food security to China and India, not to mention Indonesia and other countries.

However, as we all know, the job started in the first Green Revolution is not finished. Although it did stave off hunger to a significant extent on two continents, an estimated 800 million still do not have access to sufficient food to meet their needs (NAS 2000). And there is the daunting challenge in Asia to increase the current level of annual rice production of around 545 million tons to about 700 million tons to feed an additional 650 million rice eaters by 2025 (D. Dawe, IRRI, 2004, pers. comm.). We can only meet these challenges now and for the future if we heed some of the hard lessons learned in the first Green Revolution, which echo some of Dr. Conway's reasons as to why a new Doubly Green Revolution is the right course.

The Green Revolution is generally considered to have been a tremendous success in Asia and Latin America—success at the time being defined as production increases that staved off potential malnutrition, quite apart from concerns about the environment (Wu and Butz 2004). Millions of lives were at risk from hunger and starvation and results were needed fast—an increase in food production had to be the top Green Revolution priority in these two vast regions of the world (Pinstrup-Andersen and Schioler 2001). This view is re-enforced by Dr. Tom Mew, recently retired principal scientist at IRRI, who has stated: "There was a real danger of people starving back then, so we focused on increasing production, whatever it took. It was a tough choice, so we focused on high-input agriculture that would ensure that everyone got fed" (IRRI 2000).

The conventional wisdom of the time was that the environment was either insignificant or, at least, capable of being easily redressed at a future date, once the main task of feeding millions of hungry people was accomplished (Conway 1997). As Dr. Conway pointed out in his book, "there was also a strongly held view that a healthy, productive agriculture would necessarily benefit the environment. Certainly, good agronomy was good environmental management. Through the ages, traditional agriculture has usually followed ecological wisdom."

Unfortunately, this has not always been the case with the use of Green Revolution technologies over the last 40 years. The combination of pesticides and fertilizers with the HYV seeds was key to increasing food production (Pingali and Heisey 2001). All too often, these technologies turned out to have adverse environmental effects. For example, the heavy use of pesticides has caused severe problems. There is growing human morbidity and mortality while, at the same time, pest populations are becoming resistant and escaping natural control. In the intensively farmed lands of both developed and developing countries, heavy fertilizer applications are producing nitrate levels in drinking water that approach or exceed permitted levels (Conway 1997). So, because of, at least in part, the Green Revolution, the contribution of agriculture to global environmental degradation has grown, with potentially serious costs.

Truly, we have learned some important lessons over the last 40 years. IRRI, for one, believes that modern technologies can indeed be environmentally sensitive—if they are designed and used with the benefit of modern ecological knowledge. IRRI is committed to ensuring a cleaner, greener environment. The days of unsustainable high-input rice production will soon be a thing of the past. Our research strategy for rice in the 21st century, as spelled out by Cantrell and Hettel (2004b), is to couple our ongoing varietal improvement work using hybrids and the new plant type, for example, with finding new durable disease resistance and developing innovative sustainable crop production systems. These systems will be achieved, in part, through maintenance research (MR) that facilitates and encourages lower-input methods that are friendlier to the environment and enable farmers and their families to attain a better quality of life.

Jumpstarting the Doubly Green Revolution in Rice

Reducing—or even eliminating—chemical pesticide applications

A continuing challenge in agricultural MR is reducing chemical use on the farm (Dalrymple 2004). By the mid-1980s, the phrase "integrated pest management—or IPM" had been coined by scientists to describe the way they looked at any cultural strategy that could control pests and diseases. Over the past 10-20 years, IRRI scientists have been looking at scores of different ways to control rice pests and diseases, all with the aim of reducing—and in some cases even eliminating—chemical use.

To illustrate our environment-friendly focus, we will outline four ongoing MR projects with our NARES partners in China, Vietnam, Bangladesh, and other Asian countries. We believe that these projects, which are an integral part of our research strategy, are jumpstarting the Doubly Green Revolution in rice and perhaps providing models for other important food crops.

China. Crop biodiversity can play a key role in helping farmers improve their livelihoods while protecting the environment and their families' health. This is emerging from our latest research in China on the benefits of planting traditional rice varieties either alongside or in place of the modern, high-yielding Green Revolution varieties (see photo). Some farmers in China's southwestern province of Yunnan had traditionally planted different varieties of rice alongside each other to control pests and diseases.

Although exploiting biodiversity to protect crops is hardly new, researchers and farmers working together to use cutting-edge science to exploit the strategy to its maximum effect certainly is new (IRRI 2003a). In 1997, Dr. Mew and collaborators in Yunnan set out to learn which biodiversity techniques are most effective and how and why the process worked (Barclay 2004b). They saw great potential to improve control of the devastating rice blast fungus—a disease that can cost the rice industry there millions of dollars per year—while at the same time reducing pesticide applications.

The technology of interplanting spread from a mere 15 hectares in an initial experiment in Zhang Gui Zhai County in 1997 to 812 hectares in 1998, to 3,000 hectares in 1999, and to 43,000 hectares in 2000 (Leung et al 2003). This spread was facilitated by what we call the *Lighthouse Approach*, in which the "lighthouse" is a site where teams of researchers and extension specialists from various disciplines work jointly in planning and implementing pilot experiments. Farmers are involved in demonstrating practical application of the research findings and "radiating" research results to other sites with similar environments (Mew et al 2004).

It was during that second year when experiments spread to Jianshui County that things really took off. With the help of local government and extension officials, the IRRI-Yunnan research team worked with some 12,000 farm households in the two counties to interplant those 812 hectares with a modern blast-resistant hybrid and a traditional glutinous rice that fetched a good price but was highly blast susceptible.

The results were dramatic—in the traditional variety, blast incidence dropped to a mere 5 percent from an average of 55 percent farmers had seen in monoculture (Zhu et al 2000). In 1999, farmers reported an average of US$280 more income per hectare compared to growing hybrids alone. In 2000, The *New York Times* described this project as one of the largest agricultural experiments ever—with stunning results (Yoon 2000). Today, eager farmers across 10 Chinese provinces are interplanting nearly 1 million hectares (T. Mew, IRRI, 2004, pers. comm.).

The IRRI-Yunnan research team found that not only do rows of hybrids block the transmission of the blast fungus between rows of glutinous rice, but the presence in the field of susceptible rice plants appears to lengthen the useful life of improved, resistant varieties. Dr. Mew surmises that the susceptible plants provide refuge to pathogens, thus reducing selective pressure on them to overcome plant resistance. Farmers across the region are now achieving better plant protection with minimal fungicide use and preserving popular traditional varieties, once endangered outside of genebanks, as profitable field crops.

Going hand-in-hand with this type of biodiversity work in China are the continuing efforts to find new durable and broad-spectrum resistance to diseases and insects. At IRRI, we are now taking advantage of the availability of new information coming out of sequencing of the rice genome by setting up an allele "mining" operation at the International Rice Genebank (photo at left). We estimate that the bank contains more than 91,000 distinct accessions that carry a wide range of untapped traits for variety improvement.

We are using genomics tools to find new genes and mechanisms to provide broad-spectrum resistance to rice pathogens, such as the devastating rice blast. For example, we have put together five known blast defense genes in a rice cultivar from China, and we are getting good resistance across locations, presumably because of resistance to multiple races of the pathogen.

Vietnam. Hundreds of millions of farmers in the developing world continue to overuse pesticides despite the new IPM strategies for pest control (IRRI 2003b). While it has not been easy to wean rice farmers from their dependence on chemicals, IRRI researchers have achieved notable success in Vietnam (IRRI 2000). Our research there has been based on the premise that farmers' perceptions, rather than an economic rationale, are behind most of their pest management decisions. For example, we believe that farmers generally overestimate the seriousness of many pests and so spray too much.

First launched in 1994 in the Mekong Delta—long one of the great rice bowls of Asia—the IRRI-led partnership's research and subsequent campaign marked a milestone in rice production for two reasons. First, it clearly identified the damage caused by misapplied insecticides, which kill off insect predators and so encourage the pests they would otherwise help control. Second, it developed innovative and effective ways to communicate important scientific information to farmers.

Research results showed that spraying in the first 40 days after sowing was not necessary, so farmers were told it was a waste of money—not by foreign scientists—but through a unique and innovative communication campaign, which involved local radio dramas aired across the Delta and supported by leaflets, posters, and billboards. Eventually, this effort persuaded almost 2 million rice-growing households in the Mekong Delta to cut back on using harmful and unnecessary farm chemicals.

The effectiveness of the campaign was crystallized with the analysis in 1999 of some intensive surveys. Insecticide use had halved from an average of 3.4 applications per farmer per season to 1.7 applications. The number of farmers who believed that insecticides would bring higher yields had fallen from 83 to 13 percent. The number who realized that insecticides killed the natural enemies of rice pests had risen from 29 to 79 percent.

The team's long-running collaborative effort in Vietnam has been led by K.L. Heong, senior entomologist at IRRI; M.M. Escalada, a communications professor at the Philippine's Leyte State University; and Nguyen Huu Huan, the vice director general of Vietnam's Plant Protection Department. In 2002, the team won the $25,000 Saint Andrews' Prize for Environment in recognition of their success. The prize money has been used to initiate a pesticide reduction project in the Red River Delta in the north (IRRI 2003b). This was launched by the vice minister of agriculture and the UK ambassador to Vietnam during World Environment Day in 2003. The campaign has now already reached nearly 100,000 farm households in the initial project area of Quang Ninh Province. Within the next two years, the goal is to reach 3.5 million farm households in the Red River Delta.

Dr. Heong believes that insecticide use can be reduced by another 50 percent in the Mekong Delta, without affecting rice production, not to mention in countries such as Thailand and Laos, where the campaigns are just beginning. But he and his research partners also fear that insecticide use will creep up again if the campaigns are allowed to lapse. That's why the Rockefeller Foundation is supporting a 3-year effort to develop new radio soap operas in Vietnam—and Laos as well—to continue communicating the important message that misapplied pesticides pollute the environment and threaten the health of farmers and their families (IRRI 2004b, Nature 2004; www.irri.org/radio).

The farm IPM radio drama premiered in Vinh Long, Vietnam, on 7 July and in Vientiane, Laos, on 22 July. Each drama will be broadcast twice weekly through July 2005. The serials are set in typical rice-growing households in Vietnam and Laos, detailing the family members' daily chores, frustrations, joys, relationships, and farming problems—with IPM principles woven seamlessly into each of the 104 episodes. Scientists and creative artists have worked closely together to develop simple stories illuminating such topics as biological pest control, the behavior of pests' natural enemies, and the toxic effects of pesticides on non-target animals, water quality, and human health.

***Bangladesh*.** Another success story in the battle to reduce—and perhaps, incredibly, even eliminate—chemical use in rice farming comes from Bangladesh. There, the government began getting rice farmers hooked on chemicals as far back as 1956 when it began doling out free insecticides, causing spraying to rapidly gain a firm foothold (Barclay 2004a). Subsidies continued—100 percent until 1974, then 50 percent—and the government even conducted campaigns encouraging farmers to spray. Indiscriminant insecticide use became so entrenched that, with the end of government handouts in 1978, poor farmers were still willing to shoulder the whole cost.

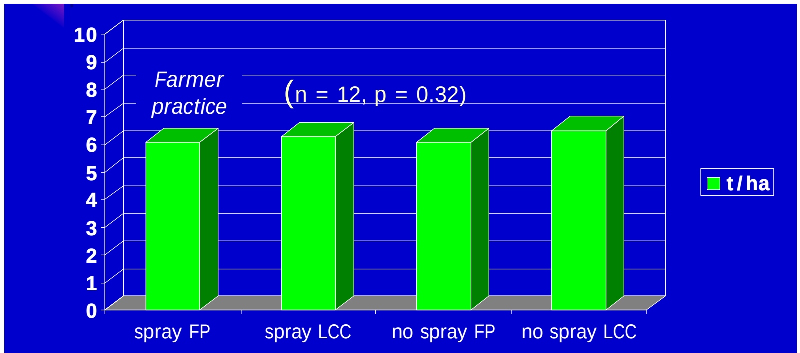
And now, after just 3 years of an IRRI-led project called Livelihood Improvement Through Ecology—LITE—there is an excellent chance that, with continued donor support, the next decade may see many of Bangladesh's 11.8 million rice farmers no longer using insecticides to any significant degree—the money saved then being available to help put children through school or buy grain to tide rice-deficit farm families over to the next harvest.

LITE—part of our project on Poverty Elimination Through Rice Research Assistance (PETRRA), funded for Bangladesh (**www.petrra-irri.org/html/index.asp**) by the UK's Department for International Development—set out to discover the exact cause of a drop that we assumed would occur in rice yield when farmers stopped spraying insecticide (IRRI 2004a). Working with the Bangladesh Rice Research Institute, local NGOs, extension agents, and farmers, our original aim was to identify safe alternatives to insecticides.

Imagine our surprise! When cooperating farmers stopped spraying, their rice yields didn't drop at all—this was in an experiment across 600 fields in two different districts, one in the southeast and one in the northwest of Bangladesh over four seasons (Barclay 2004a). LITE principal investigator and IRRI senior entomologist Dr. Gary Jahn is now convinced that the vast majority of insecticides that rice farmers use in the country are a complete waste of time and money. "If they don't spray, they lose nothing," he says, "but they gain a lot—money, a safer environment, and reduced risk to their health."

Most likely, spraying does not affect yield because 1) many supposed insect pests don't attack the parts of the plant that affect grain production, or the grain itself, under farm conditions — and so aren't pests at all; 2) many farmers use poor equipment to apply out-of-date or inappropriate insecticides at the wrong time; and 3) insecticides can kill the natural enemies of rice pests more effectively than the pests themselves, thus compromising natural pest control.

But it is not enough for a scientist to tell farmers these things. Dr. Jahn says an outsider, with all the best intentions in the world, won't be believed. And so this is why we have enabled thousands of Bangladeshi farmers to become—in a way—agricultural scientists themselves. The method we are using is known as "success case replication (SCR)." We are selecting lead farmers, identified as being more successful than their neighbors, and training them to perform on-farm experiments that prove they don't need to apply insecticides. These farmers then train other farmers in their own village, as well as successful farmers from surrounding villages, who become the next lead farmers. The new lead farmers do the same, and the process repeats. The number of trained farmers should grow exponentially each rice season.



No significant difference in yields without spraying, Rangpur, Bangladesh.

Dr. Jahn says that more than 2,000 trained farmers have reduced their insecticide use by 99 percent! Even in the control villages, where no farmers conducted the experiments, the proportion of farmers using insecticide dropped from 80 percent to 55 percent—largely because of casual contact with participating farmers. Our initial goal was to have 10 percent of the farmers in the target villages reduce their insecticide use. The result is beyond our wildest dreams. Given continued support, we are hopeful that LITE and its benefits will ripple and radiate across Bangladesh's rice fields in what could be a major battle won in the Doubly Green Revolution.

Optimizing fertilizer use with SSNM

Many of the nutrients a rice plant requires for growth and sustenance come from soil, crop residues, and irrigation water. However, these naturally occurring, indigenous nutrients are typically insufficient to meet the needs of rice grown for high yield, which must receive additional nutrients to overcome the deficit (Buresh 2004).

And so, as we mentioned earlier, chemical fertilizer application has been a key element of Green Revolution technology. The challenge for farmers has always been to know when to apply chemical fertilizers. Through collaborative research in the IRRI-coordinated Irrigated Rice Research Consortium (www.irri.org/irrc), we have found from our on-farm evaluations across Asia that many farmers of irrigated rice apply excess nitrogen during early crop growth, when crop demand for N is low, and then insufficient N at later growth stages such as panicle initiation, when crop demand for N is high (Buresh 2004).

After about 10 years of development and study, we are now promoting a technique we call site-specific nutrient management (SSNM), which enables farmers to "feed" the rice plant with nutrients only as and when needed, with optimal use of existing indigenous nutrient sources, including crop residues and manures, and timely application of fertilizer (Wang et al 2004).

According to Roland Buresh, senior soil scientist at IRRI, SSNM provides two approaches for improved N management using a leaf color chart—or LCC. In a "real-time" approach, farmers monitor the color of rice leaves and apply N fertilizer whenever they become too yellow. In a "fixed-time/adjustable-dose" approach, the time for N fertilization is pre-set at a critical growth stage, and farmers adjust the dose of N up or down based on leaf color.

Rice yields and the effectiveness of N use are often comparable for the two approaches. The fixed-time/adjustable-dose approach saves time and so is preferred by farmers who have profitable alternative activities, as often is the case in China and southern Vietnam. The real-time approach is generally preferred when farmers lack sufficient understanding of the critical stages for optimal timing of N fertilizer.

At the two Bangladesh SSNM sites, net return with real-time N management, compared with that of the farmers' practice, was on average US$41-65 per hectare better per season across five seasons. The real-time approach is being promoted and demonstrated through the distribution of about 66,000 leaf color charts to Bangladeshi farmers in 2004 as part of the PETRRA and LITE projects mentioned earlier.

The benefits from SSNM multiply when improved management of phosphorus (P) and potassium (K) is thrown into the mix with improved N management. In conjunction with local extension workers and farmers, our researchers initially developed the SSNM approach on about 200 irrigated rice farms at eight sites in Asia. Since 2001, the on-farm evaluation and promotion of SSNM have increased dramatically. Today, SSNM is being evaluated by extension workers and farmers at some 20 locations in eight tropical and subtropical Asian countries (Bangladesh, China, India, Indonesia, Myanmar, Thailand, Philippines, and Vietnam), each location representing an area of intensive rice farming on more than 100,000 hectares with similar soils and cropping systems.

Improved management of N, P, and K fertilizers through SSNM is now increasingly being shown in Asia to reduce disease and insect damage (Buresh 2004, Jahn 2004, Wang 2004)—yet another avenue on which to enhance the Doubly Green Revolution's agenda to reduce the need for pesticides.

Other elements needed to achieve "revolutionary" success

No matter how good the science and knowledge-intensive technologies may be, the success of the Doubly Green Revolution—like the first Green Revolution before it—will depend on the commitment of people—people in national and local governments, people in local universities and extension and research organizations, and the farmers themselves. We've learned this important lesson from two Green Revolution maestros who are in the audience today—Norman Borlaug and M.S. Swaminathan. Forty years ago, they knew that the people's inherent resistance to change had to be overcome. They had to be won over; otherwise, the new technologies would stay on the shelf.

This winning over of hearts and minds was not easy. Dr. Borlaug (pictured at right) relates that, during his early days as a wheat breeder in Mexico in the 1940s, the animosity of the Mexican farmers toward anyone who was involved with the agricultural sciences was very high (Borlaug 1995). And, Dr. Borlaug often had to go head-to-head with the political establishment. When en route to the wheat plots at local experiment stations, he would stop by the palaces and offices of governors, prime ministers, and presidents in places such as Pakistan and India. He had to convince them—sometimes in what amounted to a shouting match—to adjust government policies on such things as fertilizer regulations and guaranteed wheat pricing to give the Green Revolution technologies a fighting chance to win farmer acceptance.

By demonstrating to local farmers that the new technologies had the capacity to increase yields, "the grass roots were set afire," as Dr. Borlaug described it, and then the politicians had to pay attention and "get out of the way" or risk getting booted out of office (**www.agbioworld.org/biotech_info/topics/borlaug/political.html**).

In the various Doubly Green Revolution projects we discussed earlier, we have borrowed a page out of Dr. Borlaug's "playbook." For example, sensing the same farmer skepticism that Dr. Borlaug experienced a half century ago in Mexico, Dr. Jahn in Bangladesh knew that farmers don't believe something just because a foreign scientist says it is so. That is why the "success case replication" method, in which farmers teach farmers to conduct experiments and record data, is working so well in the Bangladesh LITE project to convince farmers they don't have to apply insecticides and that they can adjust their timing of nitrogen fertilizer application using LCC technology.

Farmer skepticism was rampant in the early days of the "Don't Spray for 40-Days Campaign" in Vietnam as well (Hettel 1995). Here, early successes—on which to build later—depended on some brave and committed Vietnamese agricultural officials. They had the courage to urge farmers not to spray when visual inspection of preliminary insect damage in the rice crop suggested to worried farmers that it was time to bring out the sprayers—as their neighbors were doing.

The people-oriented aspect of the Doubly Green Revolution is especially exemplified in the Vietnam work, where farmer participatory research (FPR) was first introduced in the region. In Vietnam, more than 500,000 farmer experiments have been conducted in parallel with the media campaigns. The successes of FPR in Vietnam have helped to perpetuate the technique across Asia, where—as we have pointed out in this paper—it has become an indispensable standard tool in the crop biodiversity work in China, the LITE insecticide reduction project in Bangladesh, and the SSNM work across eight countries in South and Southeast Asia, not to mention its use by many other NARES partners across the continent.

Dr. Heong adds that the positive impact on Vietnamese agriculture would not have been possible without the vision, hard work, and commitment in the multi-stakeholder partnerships that involved farmers, extension agents, researchers, local government officials, NGO representatives, TV and radio personalities, and news reporters. In short, the project is Vietnam's success because the people there have had the political will to achieve "revolutionary" progress in such a relatively short time.

Dr. Mew also echoes this sentiment regarding the recent successes in China using crop biodiversity to improve the livelihoods of farmers. Because there is no national extension system in China, progress happened so quickly on such a large scale in Yunnan Province due largely to the commitment of local extension, provincial, and party officials who worked diligently with the international researchers and local farmers.

IRRI's Environmental Agenda

During the course of this paper, we have acknowledged the impact that agriculture has—and will continue to have—on the environment. We see the projects that we discussed here as truly "jumpstarting" the Doubly Green Revolution in rice as we look for cleaner, greener, and more efficient ways to increase rice production.

And now, to assure that environmental sustainability will always be central to our research projects, as well as to our day-to-day operations at our research campus headquarters in the Philippines, IRRI is about to codify its longstanding commitment to environmental protection and sustainable rice production. In just a few days, during the upcoming World Rice Research Conference (**www.irri.org/wrrc2004**) in Tokyo, Japan, 4-7 November, the Institute will formally launch its *Environmental Agenda*.

To take the environmental approach in this more holistic way, to consciously commit to conserving the environment and achieving sustainable development, and to package it in this way, we think, is something unique among the Future Harvest Centers of the CGIAR. Our *Environmental Agenda* identifies seven key environmental areas of concern (Barclay 2004c):

- Poverty and environment;
- Farm chemicals and residues;
- Land use and degradation;
- Water use and quality;
- Biodiversity;
- Climate change; and
- Use of biotechnology.

Our research is placing emphasis on fragile ecosystems by developing strategies to maximize biodiversity to build rice systems that will be more resistant and resilient to environmental changes. To make rice research more relevant under rainfed conditions, it is necessary to conduct the research on-site—like the SSNM work described earlier—in a wide range of environments that present specific constraints to production. This is why the people-oriented Consortium for Unfavorable Rice Environments (**www.irri.org/cure/cure.htm**) has been set up to serve as a platform and forum for identifying and prioritizing the rainfed research needed to generate impact in farmers' fields (Cantrell and Hettel 2004b).

Our agenda recognizes that environmental concerns act both ways; while IRRI strives to reduce the impact of rice farming on the environment, the changing environment also affects rice farming. For example, global warming and other environmental trends are already having an impact on rice production (Peng et al 2004, Sheehy 2005), and this impact will increase. Rice producers all over the world need to understand the implications of environmental change. For IRRI to help the NARES of rice-producing countries, we need to continue to develop technologies that can be used to cope with this change.

IRRI's development over the past 40 years of high-yielding rice varieties has helped double average rice yields from the pre-Green Revolution level of less than 2 tons per hectare. Without this intensification, current rice production would need twice as much land as is currently sown to rice. IRRI research aims to continue to raise rice productivity in favorable environments, thereby reducing the pressure to extend farming into marginal lands. At the same time, the Institute seeks to ensure that farmers who must grow rice in fragile environments do so using environment-friendly technologies.

Agriculture accounts for about 70 percent of the water drawn from freshwater sources worldwide (**www.waterforfood.org**). In Asia, this figure is 90 percent, and more than half of that is used to irrigate rice. Recent years have seen widespread deterioration of water quality and stiffening competition for often-depleted water resources from domestic and industrial users. The resulting higher water costs make irrigated rice less economically sustainable. By 2025, more than 30 million hectares of Asian irrigated rice lands will suffer physical or economic water scarcity. IRRI's modern rice varieties possess up to 3 times the water productivity of traditional varieties, and the Institute's integrated approach seeks to develop rice plants and production practices that use water even more efficiently (**www.irri.org/ipswar/about_us/ipswar.htm**).

Billions of people from poor countries depend on rice for most of their nourishment. Today, IRRI's efforts to develop more nutritious rice, through both conventional breeding and biotechnology, promise further public health improvement by combating hidden hunger for the essential micronutrients iron, zinc, and vitamin A.

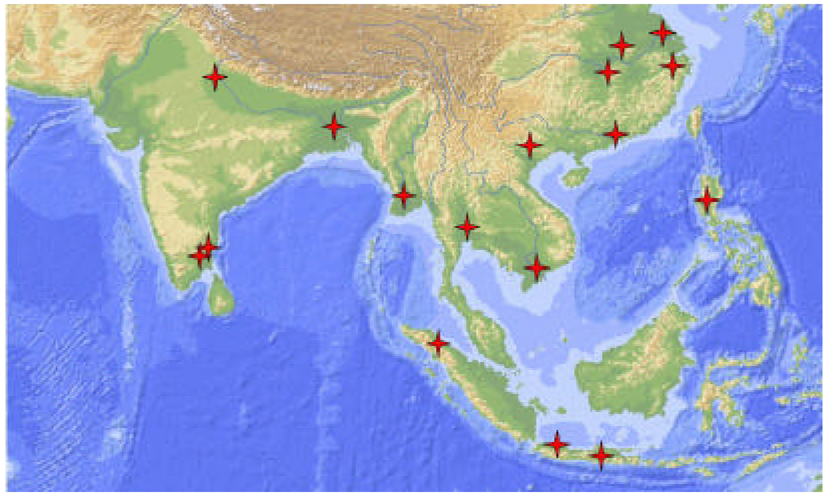
IRRI's research program promises to extend the benefits of the *Environmental Agenda* to the farthest corners of Asia and beyond. As we have already discussed in this paper, these benefits include stemming farm-chemical pollution by promoting technologies that reduce and optimize their application. More broadly, IRRI's work to improve the health, nutrition, and livelihood of poor rice farmers and consumers directly addresses the rural poverty that is the most intractable threat to the environment.

Conclusion—the Doubly Green Revolution Has Begun

As was already pointed out, the MR projects discussed in this paper are a critical and integral part of our overall strategy for rice research in the 21st century (Cantrell and Hettel 2004b). The Doubly Green Revolution in rice will thrive only if we link the MR work and improved crop production systems with the superior modern varieties resulting from our hybrid, new plant type, and genomics research. We are cognizant of the fact that there will be no successful Doubly Green Revolution without carefully integrating the other components of our research strategy, which include:

- Renewing and invigorating our efforts to close the yield gap in rice;
- Using cutting-edge tools—such as genomics for gene discovery (see Cantrell and Hettel 2004b)—to enhance strategic thrusts to break the yield barrier and face head-on the twin crises of impending global warming and water shortages; and
- Employing research consortia, such as CURE and the IRRC mentioned earlier and others such as the Rice-Wheat Consortium (**www.rwc.cgiar.org/rwc**), and the International Rice Functional Genomics Consortium (**www.iris.irri.org/IRFGC**), wherever possible to enable our researchers to work with both scientists from

advanced research institutes and NARES partners in collaborative research and farmers themselves in participatory research.



To reiterate—and provide evidence—that the Doubly Green Revolution in rice is indeed already well under way with significant activities and results, let's briefly revisit the four projects discussed in this paper.

SSNM. From small beginnings just a few years ago, SSNM is now being evaluated by farmers at some 20 locations across tropical and subtropical Asia, as shown on the map (some stars represent more than one location). In these diverse areas where intensive rice farming is being carried out on locally similar soils using comparable cropping systems, the momentum is great for SSNM to spread rapidly across more than 2 million hectares in these areas.

With oil prices at near US$50 per barrel—and what this implies for higher fertilizer costs—and no decrease in sight, the interest in SSNM and its dissemination are increasing rapidly among NARES in these countries (R. Buresh, IRRI, 2004, pers. comm.). Recommendations for blanket (e.g., proportional) reductions in fertilizer use do not provide assurances that less use of fertilizers will result in optimal productivity without loss in crop production. Instead, farmers require simple decision-making approaches that can be used to optimize the use of increasingly expensive inputs across a myriad of soil types, seasons, cropping systems, and markets (represented by the stars on the map above). The principles of SSNM, once accurately understood and implemented, can fortunately provide this simple decision-making approach.

China. From a very modest initiation with a 15-hectare experiment in Yunnan, nearly 1 million hectares across 10 provinces (as shown on the map) are now sporting the distinctive pinstripes of varietal interplanting of traditional rice and modern hybrids—sometimes as far as the eye can see in Sichuan Province, where 500,000 hectares are being interplanted (T. Mew, IRRI, 2004, pers. comm.). The original IRRI-Yunnan research team is now looking beyond China to spread the biodiversity approach to other countries, such as in the Philippines to quell outbreaks of tungro virus.

Dr. Mew says that interplanting or mix-planting modern improved varieties and traditional high-quality varieties is certainly an important thrust in the Doubly Green Revolution, but, he adds, in conjunction with this, farmers must also be encouraged to use good-quality seed for planting, proper methods for seed storage, and wise crop management practices such as SSNM. He adds, and we agree, that healthy seeds, a healthy crop, and a healthy soil all go hand-in-hand to achieve a healthy ecosystem that will keep the environment doubly green.

Vietnam. There is one more success in Vietnam to mention involving the media approach. Radio, television, posters, and leaflets are being used to motivate farmers to not only reduce pesticide applications, but seeding and fertilizer rates as well. The popular program aptly called "Three Reductions" has—in just 12 months—been rapidly extended to more than 1 million farmers across a three-province region of the Mekong Delta. Farmers who are adopting the three-reductions practices are increasing their income as much as US$85 per hectare—a big sum of money in Vietnam—per season without reducing yields. We are happy to report that the Ministry of Agriculture and Rural Development of Vietnam attributed the bumper harvest success of the recent winter-spring crop to the Three Reductions Program and awarded the team of IRRI and local scientists who developed the idea the 2003 *Golden Rice Award for Best Agricultural Innovation*" (**http://vietnamnews.vnagency.com.vn/2004-07/12/Stories/02.htm**).

Bangladesh. And finally, we think it is appropriate to close with the enthusiasm we are seeing in Bangladesh. Just a few months ago in the district of Comilla, 80 kilometers southeast of Dhaka, more than 3,000 farmers gathered to celebrate their successful reduction of chemical inputs in their rice fields (pictured here). They displayed

a “revolutionary” fervor perhaps not seen since the heady days of the 1960s when the Green Revolution technologies were first making their impact. One can be sure that the political establishment and the research institutions are taking notice! As the farmer enthusiasm spreads and with appropriate donor and local government support, the goal of making Bangladesh essentially free of insecticides in rice well within the next decade seems reachable!

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And so, as farmers across the rice-producing world join us in the Doubly Green Revolution, by availing of such technology-spreading techniques as the "lighthouse" in China and "success case replication" in Bangladesh, we are confident that food security will be improving significantly for millions of impoverished people.

IRRI will be doing its part with smart research, as outlined in our strategy for rice in the 21st century, carefully managed according to the environmental principles now enshrined in our *Environmental Agenda*. This will keep us on target as we work with our partners—including Dr. Monty Jones and Prof. Yuan Longping, the eminent scientists whom we are honoring today—to help the world's rice farmers grow their crop in an environmentally sustainable way.

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