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Twenty Years of Plant Pathology at the IRRI

Rice is an ancient cultivated crop, and today it is the primary source of food for nearly half of the world's population. More than 90% of the world's annual harvest is produced in Asia on 89% (125 million ha) of the cultivated rice area (Table 1). Because rice is predominantly an Asian crop, the International Rice Research Institute (IRRI) has focused its efforts primarily in Asia and to a lesser extent in Latin America, Africa, and the Middle East.

Rice is produced under diverse environments ranging from tropical to subtropical to temperate at elevations from sea level to 2,000 m. Cultivation may be classified into four broad categories: upland, irrigated lowland, rainfed lowland, and deepwater, depending on water management. More area is devoted to rainfed rice cultivation than to any other; this includes all rice dependent on rainfall, whether bunded or not. Irrigated lowland rice is bunded and normally flooded throughout the growing season; this system results in the most stable and highest yields. Deepwater rice accounts for only a small portion of the total production, with relatively low yields.

Each cultivation system with its associated subsystems results in general environmental conditions that affect the development of diseases. Each system can then be categorized by the diseases most likely to occur and the ones that will do the most damage.

Increasing rice production through agronomic as well as varietal improvement

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Aerial view of the International Rice Research Institute. The Department of Plant Pathology is housed in the Laboratory Training and Conference Center building (left center).

Table 1. World rice area and production, 1974–1976[a]

Region	Production		Area		Yield
	10^3 t	%	10^3 ha	%	(t/ha)
East Asia	150,701	43.8	40,047	28.5	3.8
South Asia	91,764	26.7	52,266	37.3	1.8
Southeast Asia	68,843	20.0	32,328	23.0	2.1
Latin America	13,316	3.9	7,199	5.1	1.8
United States	5,111	1.5	1,057	0.7	4.8
Europe	3,790	1.1	881	0.6	4.3
All other	10,309	3.0	6,502	4.8	1.6
World	343,834	100.0	140,280	100.0	2.5

[a] From A. C. Palacpac, World Rice Statistics, IRRI, 1978.

Viruliferous leafhoppers that have fed on virus-infected rice plants are being transferred to healthy seedlings in test tubes by E. R. Tiongco, senior research assistant, under the supervision of Dr. K. C. Ling, virus disease research leader.

programs is an ancient Asian practice. Around the year 1000 the Chinese introduced into the Fukien area a relatively early maturing, drought-tolerant variety from the Indochina state of Champa. The area of rice production immediately doubled and eventually increased severalfold. Selections of the 'Champa' rice were introduced from Fukien into the lower Yangtze and Huai areas in 1012. Many improved variants, some presumably resulting from natural outcrossing, are known to have been selected and propagated as varieties (3). It is reasonable to assume that Asian rice cultivators were selecting improved variants long before historians recorded the fact. These Asian farmers undoubtedly selected disease-free plants or those with less disease, probably resulting in the accumulation and conservation of disease resistance genes in modern rice.

IRRI's Objectives and Goals

At the close of World War II, Asia, Africa, and Latin America—net grain exporters before the war—found themselves deficient in grain production (1). Postwar reconstruction efforts in Asia, especially in Japan, were concentrated on increasing rice production. The use of fertilizers to improve soil and increase yields was widely adopted.

Increased use of fertilizers and improved management, the model that worked so well in the temperate climates, proved inappropriate for rice production in the tropics. Yields in some cases actually decreased. When fertilized, the tall, traditional rice varieties produced grain heads too heavy for their stalks to support; the plants lodged or fell over and the grain rotted in the paddy or was eaten by rats and birds.

In the late 1950s, the static or slowly increasing food supply contrasted with a rapidly increasing population in Asia prompted the Ford and Rockefeller foundations to explore a novel approach to agricultural research. They envisioned a new kind of agricultural research institute, one truly international that could devote its research efforts to improving a single crop, rice.

The two privately funded philanthropic organizations pooled their resources and in 1960 established the International Rice Research Institute at Los Baños, Philippines, naming a world-renowned plant pathologist, Dr. J. George Harrar, chairman of IRRI's first board of trustees. By 1962 the physical plant was complete, a core staff had been hired, and IRRI began the research that was to transform rice production in Asia.

IRRI's goal was a simple one: increase world rice production through research. The strategies for achieving the goal were more complex: 1) improve the rice plant itself, 2) improve agronomic technology, and 3) develop appropriate machinery for the small farms typical of Asia.

The desirable rice plant characteristics for Asia were determined to be short stature, stiff straw, insect and disease resistance, photosynthetic efficiency, fertilizer responsiveness, and day-length insensitivity. Agronomic research was to concentrate on identifying crop production practices to optimize rice yields and on categorizing the production potential of rice soils.

A Department of Plant Protection, headed by Dr. S. H. Ou, was one of the first seven departments of IRRI. Ou established three research objectives for plant pathology and disease control: 1) to identify and describe major diseases of rice in Asia, 2) to locate sources of genetic resistance to the major diseases, and 3) to develop screening methods that could be used to incorporate multiple-disease resistance into improved plant types.

When IRRI was organized, the prevailing opinion among the world's rice scientists was that the major pathogens of rice were fungi; bacteria and especially viruses were considered relatively unimportant. Scientists and administrators alike generally agreed that host resistance was the only economical means of disease control available to Asian rice farmers. IRRI's total approach to disease control was the development of multiple-disease-resistant varieties.

Plant pathology research focused first on rice blast, the major disease of rice, caused by *Pyricularia oryzae*. Sources of resistance were identified and the blast nursery screening technology was perfected. Subsequently, research was begun on bacterial blight and bacterial leaf streak; IRRI plant pathologists began to study bacteriophages and phage typing to predict outbreaks of bacterial diseases in the tropics. Virus disease studies concentrated on developing methods to identify different viruses and the diseases they caused. The vectors involved and methods of transmission were determined, sources of resistance were identified, and screening methods were developed to use in the variety development program.

By the end of 1963 Ou and his coworkers had described the orange leaf, dwarf, tungro, and yellow dwarf virus diseases of rice and were studying a fifth, later named grassy stunt. In just 2 years IRRI had demonstrated that virus diseases of rice were of far greater importance than had been recognized.

Ou was the only senior plant pathologist at IRRI until 1965, when he was named head of the newly formed Department of Plant Pathology. That year he was joined by Dr. K. C. Ling, who took charge of rice virus disease reasearch. Seven years later Dr. Harold E. Kauffman joined the department and conducted the research on bacterial diseases of rice from 1972 to 1975. In each of these expansions, IRRI's disease screening activities were increased considerably (Table 2).

Since 1972 the department has consisted of three permanent senior scientists supported by a local staff of about 20 junior scientists and research assistants, plus 60 technicians and laborers. Visiting scientists, postdoctoral fellows, and research scholars supplement the research programs of the permanent staff.

The Green Revolution in Rice

IRRI made tremendous initial progress. By 1966 it had released its first named variety, IR8, to begin the green revolution in rice.

In yield trials at IRRI and at other Asian experiment stations in 1965 and 1966, IR8 yielded a minimum of 4 t/ha; maximum yields were over 8 t/ha, considerably more than double the yields of traditional varieties grown by farmers (2). Since 1966, IRRI has developed more than 100 varieties that have been released through various programs. All have common characteristics: short stature, nonphotoperiod sensitivity, high grain-to-straw ratio, upright or erect leaves, thick stems, high tillering ability, and yield responsiveness to nitrogen fertilizer. These varieties coupled with nitrogen fertilizer programs increased total rice production as well as yields per hectare beginning in the late 1960s and continuing through the 1970s.

During the early years of IRRI, the Department of Plant Pathology developed numerous breeding lines in which multiple-disease resistance to blast, bacterial blight, tungro, and grassy stunt were incorporated. These lines were later utilized as parents in the development of IR30, IR32, IR38, and IR40. Other multiple-disease-resistant lines generated by the department were used as parents to develop IR28, IR34, IR36, IR42, and IR48. With the release and widespread cultivation of these varieties, disease losses in the Philippines and elsewhere in Asia decreased significantly.

More area is planted to IR36 than to any other variety of any crop. Moreover, multiple-disease-resistant breeding lines and varieties have been used extensively in rice breeding programs throughout the world. China grows hybrid rice on more than 5 million ha; the pollinator parents

Research assistants Casiana Vera Cruz (left) and Renato Reyes using the clipping method to inoculate healthy rice plants with bacterial blight.

Table 2. Number of rice varieties and lines screened for resistance to 13 diseases at IRRI in 19 years

	Diseases												
Year	**Blast**	**Leaf scald**	**Cercospora leaf spot**	**Helminthosporium leaf spot**	**Bakanae**	**Sheath blight**	**Sheath rot**	**Stem rot**	**Bacterial blight**	**Bacterial leaf streak**	**Tungro**	**Grassy stunt**	**Ragged stunt**
1962	2,000	···	···	···	···	···	···	···	···	···	···	···	···
1963	6,000	···	···	···	···	···	···	···	···	···	···	···	···
1964	4,368	···	···	···	···	···	···	···	360	···	603	···	···
1965	6,600	···	···	···	···	···	···	600	3,275	···	2,611	···	···
1966	24,586	···	···	···	···	504	···	···	3,676	···	3,636	···	···
1967	14,475	···	···	···	···	···	···	···	3,324	44	3,895	···	···
1968	11,429	···	···	···	···	···	···	···	607	672	3,556	2,591	···
1969	17,088	···	···	···	···	···	···	···	1,163	···	2,301	4,040	···
1970	8,188	···	···	···	···	···	···	···	30,739	···	3,235	2,543	···
1971	25,276	···	···	···	···	688	···	···	51,527	···	1,886	4,584	···
1972	10,339	···	···	···	···	1,000	···	···	21,970	···	2,485	1,030	···
1973	11,862	···	···	···	···	1,130	···	···	37,739	···	4,599	481	···
1974	25,001	···	···	···	···	6,670	···	···	46,500	···	9,634	4,846	···
1975	49,461	···	···	···	···	7,777	···	···	50,000	64	8,847	7,746	···
1976	72,892	60	10	···	···	14,687	···	···	58,000	83	12,951	7,110	···
1977	66,248	4,459	373	···	···	7,564	···	···	73,000	93	11,470	5,348	···
1978	62,637	1,545	437	···	···	10,719	244	···	50,000	···	13,436	5,751	481
1979	98,878	292	161	89	270	6,574	85	···	78,238	···	9,688	5,395	8,986
1980	80,371	810	118	90	122	4,781	106	150	72,009	···	8,100	4,961	9,116
Total	597,699	7,166	1,099	179	392	62,094	435	750	582,127	956	102,933	56,426	18,583

for most Chinese hybrids are IRRI-developed, multiple-disease-resistant varieties.

Assistant scientists J. M. Bandong (left), B. A. Estrada (center), and F. L. Nuque recording disease readings in the IRRI blast nursery.

Types of Training Programs

The successful development of multiple-disease-resistant breeding lines required basic information on disease cycles and life cycles of pathogens, on epidemiology, and on efficient screening techniques. Much of the necessary information was generated by graduate students through formal training programs.

From its inception, IRRI conducted training programs for scientists from rice-producing countries of the world. The Department of Plant Pathology programs range from informal, short-term, intensive training in one facet of rice pathology to formal, long-term, research and education programs administered through the University of the Philippines at Los Baños (UPLB).

Short-term informal training is conducted within the department. Through these training programs IRRI maintains close ties with rice pathologists throughout the world. There is a continuous two-way flow of information between IRRI and other countries; this mechanism keeps rice pathologists abreast of problems and progress in rice disease control.

Long-term research-oriented training programs are undertaken in cooperation with UPLB. Research scholars take course work at UPLB and conduct their thesis research at IRRI on problems of mutual interest. UPLB is the degree-granting institution. IRRI senior staff hold joint appointments at UPLB; they are uncompensated, participating members of the graduate faculty.

Each year, five to seven scholars do research in the Department of Plant Pathology at IRRI. Many IRRI/UPLB alumni have become leading plant pathologists; some hold key positions at research institutions in Asia, Africa, and Latin America.

Screening for Disease Resistance

Predictability is a characteristic of epidemic rice diseases. The normal progression of disease in rice is some damage noted the first season of appearance, then more widespread losses the second season, followed by often severe or catastrophic losses in subsequent seasons. Widespread rice disease epidemics were relatively rare until the improved varieties were uniformly cultivated over large areas.

IRRI's strategy has been to conduct extensive disease screening programs and to develop multiple-disease-resistant varieties to replace those with a so-called breakdown of resistance due to the evolving pathogen population adapting to these varieties.

The management of massive screening programs (Table 2) for disease resistance evaluations was a significant accomplishment in rice research. IRRI's successful screening programs to identify sources of resistance have been extended into many rice-growing countries through the International Rice Testing Program (IRTP).

Annually, IRTP assembles about 20 nurseries grown at about 450 sites in 40 countries of Asia, Africa, and Latin America. Disease ratings, especially those for the major diseases in a particular area or country, are routinely recorded by the cooperating scientists. In three special disease nurseries, promising rice varieties and breeding lines are evaluated for disease resistance to blast, sheath blight, and tungro. All disease ratings are based on a standard evaluation system for rice that was jointly developed by national and IRRI scientists. Results from each nursery are computerized at IRRI and summaries are sent to each cooperating scientist well before succeeding nurseries are formulated.

IRRI's disease screening program is the world's largest. From it numerous other breeding programs have made significant advances in rice disease control through host resistance.

Impact of Changes on Pathogens

For optimum production, plants of IRRI varieties must be spaced closer together. Because of their tillering ability, a dense canopy exists at the soil level as well as at the top of the plants, a characteristic lacking in traditional varieties. Rice farmers were quick to learn that with some of the earlier maturing IRRI varieties they could annually grow two crops instead of one, or three crops instead of two. As double- and triple-cropping rice production practices gradually spread through Asia, rice production increased even more. The increased tillering characteristic and the agronomic practice of close plant spacing coupled with year-round rice cropping in the tropics created an optimum environment for disease development.

The impact of the change in plant type and cropping practices on Asian rice pathogen populations was not immediate. Changes in pathogenicity in rice blast populations were observed early, but the breakdown of resistance to other diseases was not so readily obvious. Generally, IR8 yields at IRRI have steadily declined since 1966. The highest yield of IR8 ever obtained on the IRRI farm was 10.3 t/ha in 1966, the year of its release. In the 1978 IRRI yield performance and nitrogen response trials, where insects were not a problem, the lowest yield for IR8 was 1.8 t/ha and the highest was 3.4 t/ha. In similar trials of IR8 in farmers' fields, the minimum yield was 2.0 t/ha and the maximum was 4.4 t/ha (4).

Overall yields of rice, however, have not declined at IRRI or in Asian farmers' fields. Yields have increased because plant breeders and plant pathologists at IRRI and at numerous other sites in Asia and Latin America have steadily generated varieties that are locally adapted and better equipped genetically to resist the new populations of pathogens and pests evolving when a new variety is released and cultivated over a wide area.

Rice pathogen populations and rice varieties are mutually dependent. The genes for pathogenicity (ability to incite disease) and virulence (severity of disease) within the pathogen population depend on the specific genes for resistance and for tolerance in the rice population being cultivated.

The interaction between genes for pathogenicity and genes for resistance are qualitatively expressed on a gene-for-gene basis. If the appropriate gene(s) for resistance is in the rice varieties being grown and the complementary gene(s) for pathogenicity is not in the pathogen population, disease does not occur. Disease will develop in the converse system, however. Climatic conditions have little effect on the *expression* of disease.

The interaction between genes for virulence and genes for tolerance is expressed on a genes-for-genes basis. The interaction results in disease and is the expression of two quantitatively inherited genetic systems. This interaction may result in horizontal resistance where disease *severity* is highly responsive to environment.

Both types of host-pathogen interactions operate with various rice diseases. It is highly unlikely that plant breeders will be able to produce another breakthrough to increase rice yields (as was done with IR8) until effective disease control and management schemes have been identified.

The major battle plant breeders have fought since the release of IR8 has been to maintain the yields the plant type was capable of producing while incorporating more and more genes for resistance and tolerance to disease. Increasingly more resistance genes are required because the pathogen populations continue to evolve, adapting to the new varieties by accumulating genes for pathogenicity and virulence.

Rice diseases that are being or can be controlled with host resistance through variety development and disease screening programs are grassy stunt, bacterial blight, Cercospora leaf spot, sheath rot, and blast. Bacterial leaf streak, leaf scald, and Helminthosporium leaf spot may also be in this category. These diseases are typically expressed as gene-for-gene interactions in which physiologic races of the pathogen normally occur. Host resistance is relatively easy to manipulate in the breeding program but requires considerably more research before it can be effectively deployed in farmers' fields to result in stable and high yields.

Tungro and ragged stunt are rice virus diseases that for the most part may be controlled through variety development programs. Ragged stunt is the most recent rice virus disease identified and described at IRRI (6). In controlled inoculation experiments, no variety escapes these diseases. Both viruses are obligately transmitted by insect vectors. Disease development can be accurately predicted on the basis of epidemiological criteria. The incomplete resistance that has been incorporated into recent varieties is adequate to prevent epidemics from occurring in some environments, but in environments favoring disease development, vector control is required to prevent epidemics.

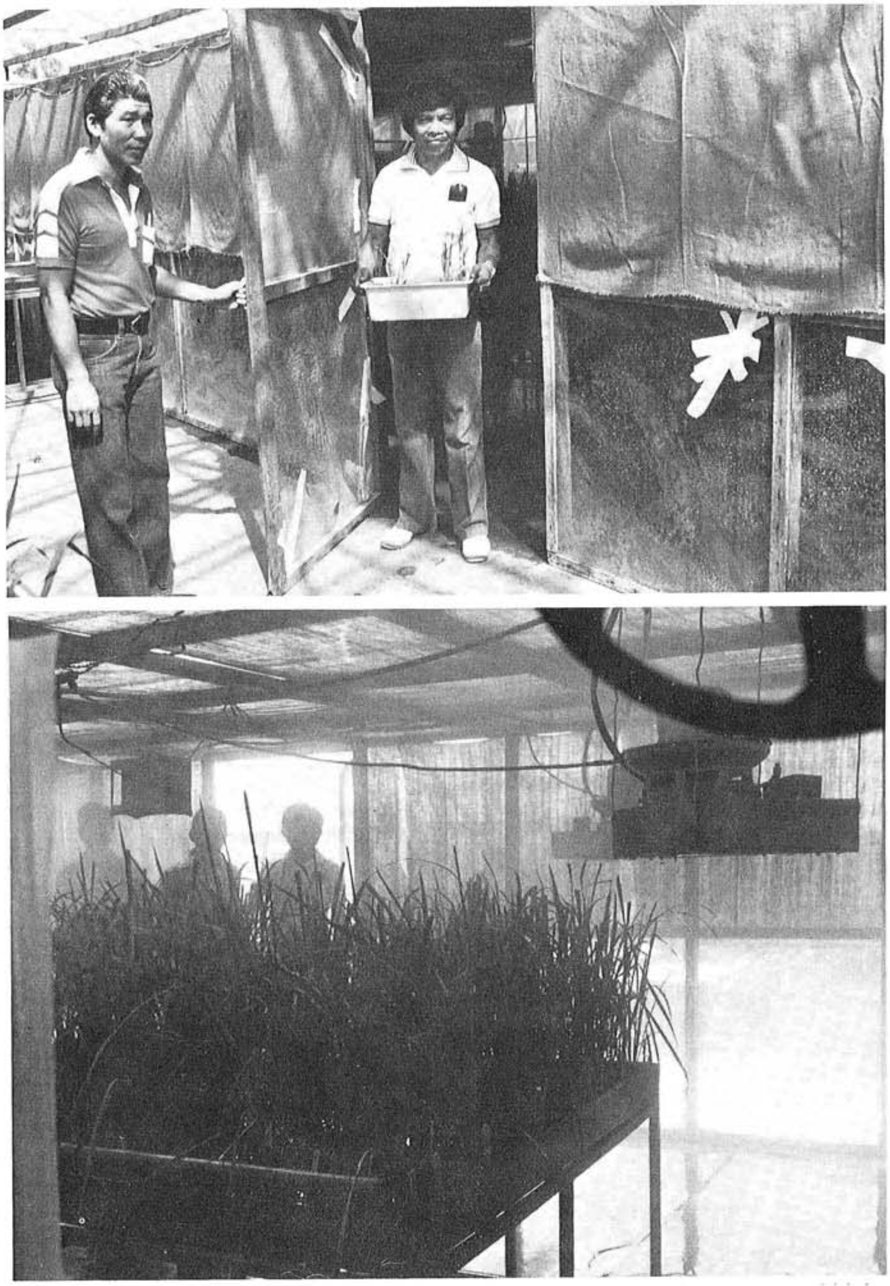
IRRI's basic strategy of disease control through host resistance (5) has been modified since it was learned there are no effective sources of resistance to certain diseases. For these diseases, the only effective control is with chemicals. Sheath blight is a prime example.

Sheath blight was a minor disease of rice when IR8 was released in 1966. Today it probably causes more loss than any other fungus disease of rice, especially in the lowland tropics. All of the 60,000 entries that have been screened at IRRI (Table 2) are susceptible. Sheath blight evolved to its present importance in Asia and the Americas in only a few years because of changes in the plant type as well as in rice production cropping systems. Sheath blight is a factor—quite possibly the major one—now limiting yields of IR8.

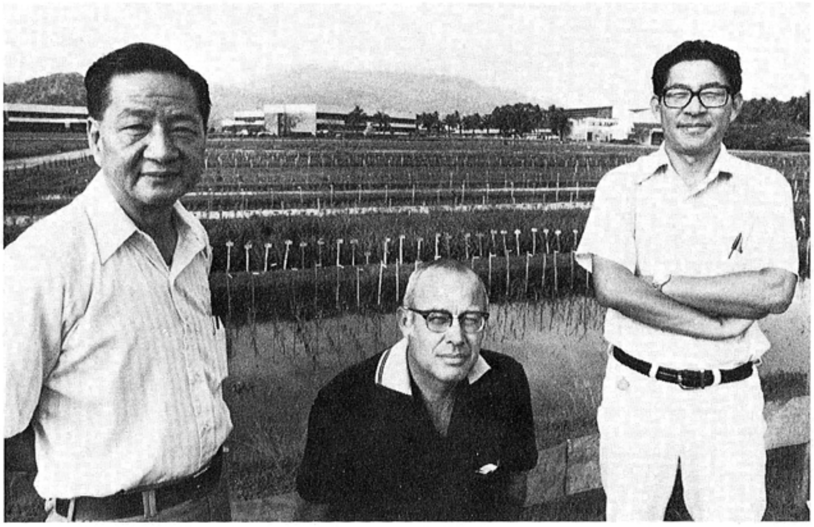
There is little doubt that the sheath blight pathogen will continue to evolve by accumulating more genes for virulence, thus becoming a progressively more serious problem in rice production. There is no effective resistance to sheath blight, and chemical control offers the only immediate solution.

Research Emphasis in the 1980s

IRRI has become the model for international agricultural research centers. Today it is one of 13 such centers supported by the Consultative Group on International Agricultural Research (CGIAR), an informal association of



Rice plants are artificially inoculated with blast fungus in a specially constructed high-humidity chamber (top) that maintains free water on the leaves. (Bottom) Fogging device inside the chamber.



Pat Crill

Dr. Crill, head of the Department of Plant Pathology and fungus disease research leader at the International Rice Research Institute in Manila since 1978, is shown on the Experimental Farm with Dr. K. C. Ling (left), virus disease research leader at IRRI since 1965, and Dr. Tom Mew (right), in charge of bacterial disease research since 1975.

governments, international and regional organizations, and private foundations. In 1979 CGIAR established an ambitious 5-year plan to double the resources it devotes to international agriculture. The plan contemplates only modest increases in real funding for the "mature" institutes, such as IRRI, and accelerated growth of some of the newer centers to their intended size.

The implementation of the CGIAR plan will in the long run certainly strengthen agricultural research worldwide, but it has serious implications for the disease control research program at IRRI. IRRI's program requires a significant expansion of effort, particularly in disease screening and the search for genetic sources of disease resistance, rather than a shift in emphasis that could be accommodated with a level funding scheme.

This is not a unique IRRI problem. The very nature of plant diseases dictates that the compelling need for disease control research comes at a time when the centers are considered to have made their maximum contributions—when disease-resistant, high-yielding, uniform varieties have been introduced and adopted over a wide area. Plant diseases never reach epidemic proportions and rarely are limiting factors in crop production until that requirement is met.

In 1973 the president of the World Bank (one of the major sources of CGIAR funds) concluded there had been a maldistribution of income in many developing countries. The incomes of people in mining, industry, and government had increased while productivity and income of the small farmer had stagnated. He concluded very high priority should be given "to strengthen that type of research which will benefit the small farmer—research to produce low-risk, inexpensive technology that he can put to immediate use" (7).

Plant pathologists are keenly aware there are no low-risk, low-cost technologies that can be used by farmers to control diseases. Resistant varieties represent a low-cost but high-risk technology to the farmer unless supplemented with basic research programs. Resistant varieties require significant research expenditures to develop and even more to manage properly if epidemic losses are to be avoided with disease resistance. Much research remains to be done before farmers can be assured of avoiding the high risks associated with disease-resistant varieties as they increase and intensify rice production. Chemical control is neither low risk nor low cost, but it can assure farmers of stable, high yields when disease resistance fails. The present knowledge of disease control in rice is totally inadequate to extend to Asian rice farmers as a low-risk, low-cost technology.

As we enter the 1980s, we may find there is little difference between the small and the large farmer when it comes to disease control. Host resistance was exclusively pursued in the developing world in part because chemical control was considered too expensive for the small, subsistence farmer. His counterpart in the developed nations may ultimately find the cost of. chemical control prohibitive—if the chemicals themselves are not regulated out of existence. Farmers in both developing and developed nations are likely to become equally more dependent on genetic resistance for disease control.

Funding and social restraints force research priorities to be established without adequate results and information. This increases the chances to make mistakes in establishing research priorities. Correct decisions have so far outnumbered wrong ones, or rice production would not have increased at all.

It is inevitable that a major rice disease epidemic will occur in the near future. If it occurs in one of the agriculturally less developed countries of Asia, the consequences will probably be catastrophic. In a more developed country, such as Japan or Taiwan, the consequences would be much less severe. Even the 1978 rice blast epidemic in Korea produced severe political, economic, and agricultural upheaval that drastically altered the country's economic development plan.

Future emphasis at IRRI in rice disease control research should be on the management of disease resistance as it is incorporated into improved varieties and used by farmers. The pathogens that cause rice diseases can be managed to insure high, stable rice yields, but considerable basic research remains to be done. The use of chemicals to control rice diseases on small farms in developing countries needs to be further explored, not necessarily as a primary control but as an alternative to protect farmers against epidemic losses.

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