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RICE
RESEARCH & TRAINING in the 70's

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Foreword

This publication reports a conference on rice research and training in the 1970's held at the International Rice Research Institute (IRRI), Los Baños, The Philippines, from September 30 to October 3, 1969. The conference sought:

- to identify major unresolved problems of tropical rice production and marketing;
- to explore the impact of probable agricultural developments in tropical rice-producing countries in the 1970's;
- to assess national progress in developing improved capabilities in rice production, research, and training;
- to discuss programs that may merit greater attention by scientists, educators, trainers, and administrators.

Throughout the conference there was a particular interest in the past, present and future roles of IRRI. The contributions of the Institute in promoting greater production were stressed and much discussion was centered on its future role. This emphasis, of necessity reflected in this report, does not imply that the conference was unaware of the vital role that other institutions have played and must increasingly play in solving world rice problems.

Findings and issues highlighted by the conference are reported in Part 1 of this publication. Although an earlier draft was reviewed by the conference, the report is a synthesis of the discussions and it must not be inferred that the views expressed here are in fact those to which individual participants would necessarily subscribe.

Part 2 of this publication is a discussion paper prepared by Dr. Robert F. Chandler, Jr., Director of IRRI, and fellow staff members: "The International Rice Research Institute Considers Its Role in the 1970's." This analysis was prepared as the discussion piece and sent to the conferees before the conference.

Names and affiliations of conferees, all of whom have direct interests in agricultural development, are appended.

PART 1 / Conference reports

The role of rice in national economies

Rice is and will remain the major food crop in South and Southeast Asia (Table 1). In the immediate future the growth of supply may run somewhat ahead of increases in effective demand —despite population growth and some improvement in economic conditions. This does not mean that the nutritional needs of the poor will be met, even though exportable surpluses may exist. And since many Asian nations that formerly had a deficit of rice will probably enjoy a period of near self-sufficiency, some reduction in intra-regional trading in rice can be expected (Table 2). A further decline in the price of rice in commercial trade is likely. In the absence of national price support schemes, lower farm and retail prices for paddy and milled rice will follow.

The intermediate future—the next 5 to 10 years—is less certain. The rate of growth in production established in the late 1960's will be maintained only if public funds are effectively invested in national research and agricultural extension services and in improved irrigation, drainage, and transportation. Private investment in agricultural chemicals, marketing, and credit will also be important. Inadequate public or private investment could keep the new productive potential unrealized and precipitate renewed food crises. In other words, such crises would result less from technological weaknesses in production than from neglected opportunities, now presented for the first time, for modernizing agriculture.

TABLE 1. Statistics on Asian rice growing countries.

Country	Population: Total 1967 (thousand)	Population: Annual growth 1963-67 (percent)	Rice crop area (thousand ha)	Annual average paddy production: Total 1966-68 (thousand mt)	Annual average paddy production: per hectare 1966-68 (mt)	Rice production per capita (kg)	Rice exports (imports) 1966-68 (thousand mt)
South and Southeast Asian rice trading community							
Burma	25,811	2.1	4,516	7,613	1.7	192	657
Ceylon	11,741	2.6	520	1,165	2.2	64	(401)
India	511,115	2.4	35,598	53,648	1.5	68	(562)
Indonesia	110,100	2.4	7,668	14,680	1.9	87	(426)
Malaysia	10,071	3.1	490	1,158	2.4	75	(352)
Pakistan	107,258	2.1	10,480	18,338	1.2	111	53
Philippines	34,656	3.5	3,081	4,720	1.5	89	(82)
Thailand	32,680	3.1	6,878	11,023	1.6	219	1,337
Singapore	1,956	2.5	..	..	..	..	(198)
Other Asian non-communist block							
Cambodia	6,415	2.2	2,182	2,785	1.3	282	213
China (Taiwan)	13,142	3.0	789	3,185	4.0	158	140
Japan	99,920	1.0	3,254	18,029	5.5	117	(516)
Korea (South)	29,784	2.6	1,231	4,962	4.0	108	(122)
Laos	2,770	2.5	916	..	..	..	..
Nepal	10,500	1.9	1,030	..	..	..	..
Vietnam (South)	16,973	2.6	2,295	4,474	1.9	173	(625)
Hong Kong	3,834	1.8	9	..	..	..	(357)
Other Asian communist block							
China (mainland)	720,000	1.4	..	..	..	..	..
Korea (North)	12,700	2.5	700	..	..	..	..
Vietnam (North)	20,100	3.1	2,500	..	..	..	..

Source: FAO

TABLE 2. South and Southeast Asia rice trading community – imports and exports, 1962-64, 1966-68. Projected import demand and export potential 1971.

	1962-64 [a]		1966-68 [a]		1971 potential [b]	
	Export (thousand mt)	Import (thousand mt)	Export (thousand mt)	Import (thousand mt)	Export (thousand mt)	Import (thousand mt)
Burma	1,595	..	657	..	637	..
Ceylon	..	491	..	401	..	326
India	..	52	..	562	..	423
Indonesia	..	1,065	..	426	..	424
Malaysia	..	465	..	352	..	286
Pakistan	127	..	53	..	983	..
Philippines	..	185	..	82	..	21
Thailand	1,527	..	1,337	..	1,308	..
Singapore	..	163	..	198	..	219
Total	3,249	2,895	2,047	2,021	2,928	1,739

[a] Source – FAO

[b] Estimated by R. Barker, IRRI

In the long term—say during the life of the next generation—production based on presently available advanced technologies of rice production will be inadequate to feed Asia's people unless population growth rates drop substantially. Research workers are still confronted with the need to lift yield levels beyond those now possible, especially on land not well adapted to rice production.

Both the immediate and the longer run objectives of research should aim at more than simply meeting the region's food requirements. Continuous efforts should be made to lower the real cost of food to both urban and rural consumers and improve the quality of the food available. National development policies should encourage the use of the new rice production technologies as a foundation for sustained improvement in economic activity and the welfare of mankind. Proper national production and distribution policies must also be formulated and implemented.

Compared with Asia, rice is less important in the other regions of the world.

In the United States production is highly mechanized. Yields per hectare are high but due to the competition for resources used for rice production, so are production costs. When world prices were high in the mid-1960's, the U. S. emerged as the major exporter of rice. With lower prices U. S. exports are expected to decline, but the extent of this decline will depend upon the effectiveness of production control programs and the willingness of the government to subsidize exports.

In Latin America, some rice production is highly mechanized. Most rice is grown under upland conditions. Yields are low and production costs high. In most countries of the region, production is likely to continue to expand to meet the growth of local consumption as long as domestic markets are protected from world competition.

In Africa, rice is grown under relatively primitive conditions and the technical basis for expanded production is thin. Research institutions are now being organized but they will need to draw heavily on IRRI and other Asian experience. It will be some time before husbandry skills and technical potentials reach the level now being achieved in South and Southeast Asia.

The goals of The International Rice Research Institute

Until the mid-1960's rice yields in most nations of the Asian tropics and subtropics were generally low and rising slowly. Increases in total output had for the most part been obtained through cropping ever greater areas of land. Attempts to increase crop yields through use of fertilizers or plant protectants had met with little success. National efforts to intensify production were, with a few exceptions, receiving only modest financial support from governments. Too few scientists were engaged in coordinated efforts to increase rice yields through varietal improvement, development of fertilizer use technology, and control of diseases, insect pests, weeds, and rodents, or through generation of other information and materials required for higher and more profitable yields. Many observers had little hope that yields could be raised quickly. In the face of projected population increases, a general feeling of profound concern was commonplace.

This was the situation when the International Rice Research Institute was established in 1960.

The conference reported here was held, however, in an atmosphere of hope and against a background of solid achievement by rice scientists. Over the previous 5 years scientists had shown that tropical rice yields could be raised severalfold. In a span of only a few years some rice-growing countries had converted chronic rice deficits into self-sufficiency. The price of rice in world trade had fallen substantially, reflecting increased supplies of this and other important cereals. In part, this improved outlook can be ascribed to favorable seasons; but at least a portion of it was the result of the spectacular successes of scientists working on production problems. Regardless, it was desirable to take stock of a situation that even the more optimistic had scarcely foreseen, to reassess research goals, and to examine the economic and social consequences of the new production technology.

Before looking at these areas, however, it must be stressed that most rice research in Asia, including that of the Institute, still is focused on improving production in favorable soil and climatic situations where water is not a serious limiting factor.

TABLE 3. Estimate of percent rice crop area by specified land type in South and Southeast Asia.[a]

Land type	Effective crop area %	Production %
Irrigated		
Single cropped	10	15
Double cropped	10	25
Total	20	40
Rainfed		
Deep water	10	8
Other	50	42
Total	60	50
Upland, total	20	10
Grand total	100	100

[a] Judgment of R. E. Huke and R. Barker.

TABLE 4. Estimates of area of new rice varieties in nine countries of south and southeast Asia.[a]

Country	Total rice area 1966	Planted to new varieties 1967/68	1968/69
	(thousand hectares)		
Burma	4,516	3	190
Ceylon	520	..	7
India	35,598	1,468	2,020
Indonesia	7,668	..	170
Laos	916	1	2
Malaysia (West)	344	9	9
Nepal	1,030	..	42
Pakistan, East	9,062	67	154
Pakistan, West	1,418	4	308
Philippines	3,081	447	1,049
Vietnam, South	2,295	..	44
Total	66,448	1,999 [b]	3,995 [b]

[a] Principal source: D. G. Dalrymple, International development, FAS, USDA. The hectarage of high-yielding varieties may increase by 50 to 100% above the 1968/69 levels during the 1969/70 crop season.

[b] Includes principally varieties introduced since 1965 – Taichung (N)1, IR8, IR5, and a small hectarage of other new varieties. Excludes H-4 and H-8 in Ceylon, ADT-37 in India, Mahsuri in Malaysia, and BPI-76 in the Philippines.

It is in such situations that improved technology has the greatest leverage in increasing output.

The concern in much of tropical Asia is for more adequate food supplies. Initial concentration has been on technology applicable under conditions of reasonably adequate water supplies (Table 3). But improved production methods suitable for favored situations are not necessarily as successful on the land area that is less favorably endowed. Therefore, in interpreting the discussion that follows, the areas to which existing new varieties and improved production practices are applicable need to be kept in mind.

During the first 2 years of IRRI's existence, after considerable debate by the staff, three major goals emerged—goals against which the Institute's progress could be measured. These goals (implied if not stated) were:

(1) *To help increase national average yields of rice, especially in the nations of the tropical Asian rice bowl.*

Such increases, the staff felt, could occur only if more productive and profitable methods of production were developed, substantial numbers of technical personnel could be trained, necessary inputs became available, national governments provided the necessary support and established appropriate policies, and farmers were willing to change.

The Institute was expected to contribute to an increase of national average yields by solving technical problems limiting yields, particularly those requiring interdisciplinary attack, modern instrumentation, and advanced techniques, and especially those that could not as successfully be handled by other institutions; by demonstrating what yield levels could be obtained by simultaneously applying relevant results from the various disciplines; and by promoting the use of high-yielding varieties and improved production techniques where applicable.

(2) *To help develop strong national technical and related capabilities in interested rice-growing nations.*

It was recognized that intensification of rice production in any nation was the responsibility of that nation, its farmers, and its institutions. Only they could plan, set policies, coordinate efforts,

provide adequate funds, reach the farmers, grow the crop, and organize its marketing. Strengthened national institutions were seen as a prerequisite to accelerated progress.

Realizing the fundamental importance of national institutions, the Institute was expected to assist countries by training technicians and scientists, by advising on organization and other matters when requested to do so, and by contributing technical information and improved biological materials.

(3) *To stimulate international cooperation on important regional or worldwide problems.*

It was clear that problems of production often crossed national boundaries and that progress in any single nation would be accelerated by cooperation and by pooling of limited scientific and financial resources. Cooperation was particularly necessary on means of control of diseases and insect pests, identification of superior germplasm, and techniques for managing similar soil types.

The Institute was, therefore, expected to facilitate cooperative experimental work and the exchange of germplasm and research results. It would organize international field tests, cooperative research, conferences, publications, information services, and visits of IRRI staff to national programs, and it would encourage national scientists and administrators to visit the Institute.

Improved technology and yields

By the 1966/67 crop year, new dwarf rice varieties developed at IRRI and elsewhere, particularly Taiwan, were beginning to make an impact in several areas of Southeast Asia. In the Philippines, India, Pakistan, and several other countries, a significant area of the new varieties was planted. In the following year (1968/69) about 4 million hectares, roughly 5 percent of the rice area in South and Southeast Asia, were planted to the new varieties (Table 4). The adoption of these varieties, favorable weather, greater use of chemicals, and improved cultural practices, raised rice production so much that an upward drift in rice prices which had occurred in the mid-1960's was reversed (Figure 1).

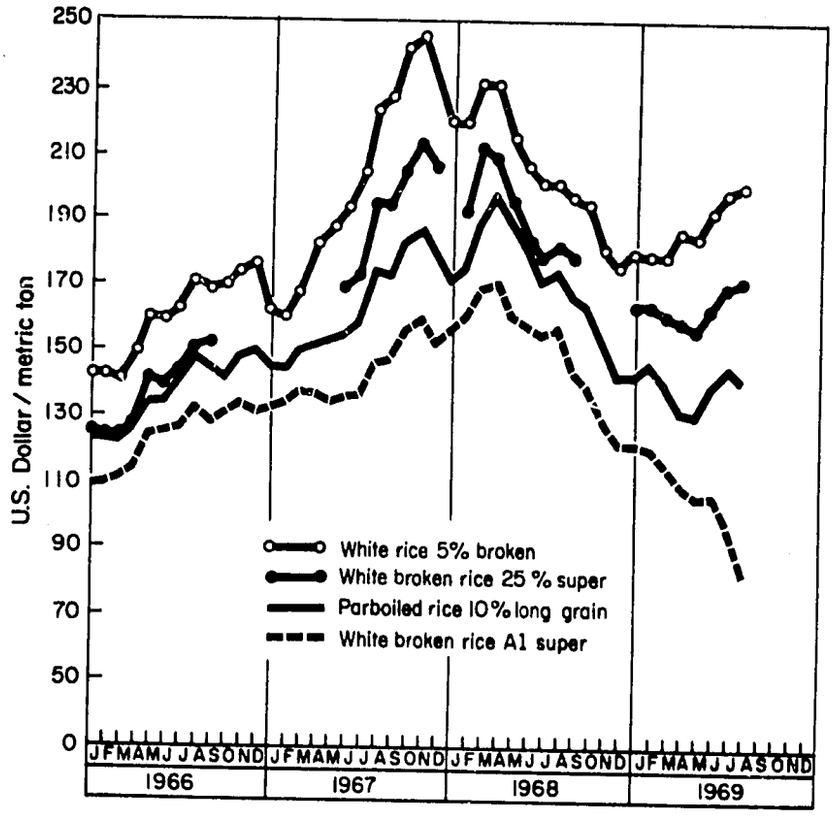

FIG. 1. The Thai export price of rice – F.O.B. Bangkok.

Although the new varieties and the cultural practices developed with them have so far been used in a limited proportion of the total area devoted to rice, their impact has been dramatic. Combined with advances in the technology of wheat production, they have engendered optimism regarding the possibilities of food production in Asia. Many rural people sense a spirit of change and opportunity. Incomes of farmers who have adopted the new varieties and practices have often risen sharply.

For many regions of Asia no substantial improvement in production has been effected. New varieties and technology need to be tailored to local conditions. Also, the economic and social ramifications of the new technology are not well understood and may occasionally be undesirable. Some landowners, for example, have turned to direct production from their own land so that farmer lessees have lost tenure of the land. Adjustment difficulties may be expected as production problems are solved. Although adequate food supplies are by no means secure, it is now possible to look beyond the goal of meeting the immediate food problem. It is possible to consider the full potential of new technologies for accelerating the general development of national economies and improving the welfare of rice producers and consumers.

National capability in rice research and training

The Production Yearbook (1967) of the Food and Agriculture Organization of the United Nations shows that 41 countries produce rice on more than 100,000 hectares. Using this arbitrary yardstick, at least 41 countries require a national rice research capability. Twenty-three of these countries and most of the world's rice production are in Asia. By 1969 only a beginning had been made toward raising the capability of the national services.

MONSOON ASIA. The governments of most rice-growing countries in monsoon Asia now believe that national rice research can play an important part in achieving increased rice production. This view did not prevail in 1960. The new respect for rice research has resulted, in some countries, in larger national research budgets, larger and better trained research staffs, more interdisci-

plinary research, a flow of scientists from national stations to IRRI and other training centers, the launching of national rice improvement projects and, in several countries, the creation of new rice stations.

Greater interest in rice research was stimulated in part by visits to IRRI in the 1960's of large numbers of agricultural policymakers and administrators from Asian countries: Ministers, directors of agriculture, directors of research and managers of rice research stations. This flow of visitors continues and is important to the spread of the technology of dwarf rice.

So far the new support for national research is only partly reflected in better research. Increased capability is becoming evident in six Asian nations where resident research advisors affiliated with IRRI have been assigned. In these six countries, the national research services are capable of conducting applied research trials sufficiently reliable to verify the performance of new rice lines and practices under local conditions. Some of these nations have progressed further than others and have demonstrated an ability to conduct original research with local staff on local problems at acceptable international levels of quality.

These statements on national capability could not have been made 5 years ago. But despite the gains, national organizations have only begun to improve. Far greater progress is required in the 1970's. Discussion at the conference called attention to the low level of national research administration that prevails in many Asian countries, limiting the benefits from increased investment in rice research.

Even in Asia many major rice-growing countries have so far had little exposure to the new rice technology.

Approximately 300 research scholars and fellows, most of them from 10 Asian nations, have received 1 or 2 years training at Los Baños before returning to research or related responsibilities in their homelands.

Discussion at the conference indicated that three countries (India, Pakistan, and Thailand) which had each sent 40 to 50 students to Los Baños during the 1960's considered their need for training of scientists in the new technology to be only half met by 1969. Other Asian countries have availed themselves of

training at IRRI only in recent years, and the number of their participants is rising.

The Rice Production Training Course at IRRI stresses the practical aspects of rice growing. It has been attended by about 150 extension officers from 20 countries, the majority from monsoon Asia. On returning home, some of these officers have organized national extension training programs that have reached several thousand additional participants. But of the many extension workers who assist rice growers in monsoon Asia, only a small fraction has so far been exposed to a training course in dwarf rice production. And many rice-growing countries have not yet trained their trainers.

Tables 5 and 6 summarize the IRRI training program from 1962 to 1969.

The flow of applications for IRRI's courses suggests no reduction in training requests for the 1970's. The Institute staff appears to be alert to the shifting needs for training and is adapting course-work to the rising qualifications of participants.

LATIN AMERICA. Rice-growing countries in Latin America produce and consume 10 million tons of rice a year. The creation of a sister research institute, Centro Internacional de Agricultura Tropical (CIAT), at Cali, Colombia, and the transfer to CIAT of an IRRI staff member to advise on rice research in Latin America, made it possible to augment research and action programs in that region. The Inter-American Rice Program, with headquarters at CIAT, was created in 1967. Because Latin Americans prefer long grain and a dry cooking quality, new dwarf varieties have had limited impact on rice production in the region so far. Initial breeding efforts at CIAT have produced a wide range of lines that combine desirable quality with the dwarf plant type and improved resistance to local diseases and pests. These lines and additional information on cultural practices can help Latin America achieve technical advances.

The rice research capability of government research services in Latin America remains weak, but some government scientists are now training at CIAT, and one is at IRRI.

The principal rice areas in Latin America are remarkably similar in rice disease and insect problems and consumer pref-

TABLE 5. Number of participants and man-years of training provided in different areas at IRRI.

Area	Number of participants	Man-years of training								
		1962	1963	1964	1965	1966	1967	1968	1969	Total
Agronomy	48	3.8	9.5	9.1	9.8	8.4	8.3	9.9	7.5	66.3
Varietal improvement	60	2.9	7.2	7.4	8.0	8.3	6.8	4.2	10.1	54.9
Plant physiology	26	..	4.0	7.4	7.7	3.7	3.0	3.2	5.4	34.4
Entomology	25	1.3	3.2	4.9	5.0	3.2	3.7	6.0	6.5	33.8
Plant pathology	28	2.2	3.5	6.0	4.7	4.2	3.7	3.6	2.8	30.7
Soil chemistry	15	1.7	4.8	6.1	4.1	1.2	1.3	1.1	1.6	21.9
Ag. economics	15	..	..	1.6	3.3	2.3	2.5	5.4	5.2	20.3
Ag. engineering	11	1.7	4.3	3.2	2.3	0.4	1.9	1.0	0.5	15.3
Soil microbiology	9	..	..	1.8	4.0	3.0	1.9	2.8	1.3	14.8
Chemistry	11	0.6	2.9	4.4	1.5	0.5	1.3	1.9	0.8	13.9
Statistics	10		0.1	1.8	2.0	1.5	2.7	0.8	1.8	10.7
Communication & extension	5			0.5	1.0	1.5	1.3	1.9	2.5	8.7
Rice field experimentation	20		..		..	..	..	2.5	..	2.5
Research training	283	14.2	39.5	54.2	53.4	38.2	38.4	44.3	46.0	328.2
Production training	146	..	..	2.7	5.3	14.7	17.7	17.9	17.5	75.8
Multiple cropping	14	..	..		..	..	..	..	4.6	4.6
Total	443	14.2	39.5	56.9	58.7	52.9	56.1	62.2	68.1	408.6

TABLE 6. Participation by country of research scholars and rice production trainees at IRRI.

Country	Number of participants	Man-years of training								
		1962	1963	1964	1965	1966	1967	1968	1969	Total
Philippines	143	7.8	18.3	24.0	22.3	24.5	18.4	16.1	18.2	149.6
Thailand	42	5.7	11.6	7.8	5.1	2.3	2.5	2.2	5.6	42.8
India	48	..	0.4	2.4	4.2	4.5	6.2	11.0	9.2	37.9
Taiwan	21	..	2.9	7.8	9.8	6.0	3.3	2.6	3.0	35.4
Pakistan	50	..	..	0.5	2.0	4.2	7.9	8.3	7.4	30.3
Japan	24	0.7	4.2	6.6	3.7	1.2	3.3	1.9	2.1	23.7
Korea	21	..	..	1.2	4.2	3.1	1.8	3.8	4.4	18.5
Indonesia	14	..	0.2	1.0	2.1	1.7	3.3	4.2	0.8	13.3
Ceylon	14	..	..	0.8	1.0	0.8	2.5	2.3	3.3	10.7
Vietnam	11	..	1.2	2.1	2.0	0.9	..	2.0	2.0	10.2
Others*	55	..	0.5	3.0	2.4	3.6	6.8	7.6	12.1	36.0
Total	443	14.2	39.3	57.2	58.8	52.8	56.0	62.0	68.1	408.4

* Afghanistan, Australia, Burma, Cambodia, England, Fiji, Germany, Ghana, Guinea, Iran, Iraq, Kenya, Laos, Malagasy Republic, Malaysia, Mexico, Nepal, Netherlands, Nigeria, Panama, Sudan, Switzerland, Tanzania, UAR, U.S.A.

erence for grain size and quality. This should facilitate rapid adoption of improved technology. However, substantial numbers of technicians must be trained in production techniques and this should be done in Latin America itself.

TROPICAL AFRICA. Since 1966 Chinese rice production teams from Taiwan have been demonstrating improved Asian rice production methods in more than 20 tropical African countries using dwarf rice varieties, including some from IRRI. These demonstrations have consistently produced yields equal to those of dwarf rices in Asia: 5,000 to 6,000 kg/ha in the wet season and 6,000 to 8,000 kg/ha in the dry season.

Despite the demonstrations, almost no dwarf rice is grown commercially in tropical Africa, partly because consumers prefer long-grain, dry-cooking rice. The dwarf varieties demonstrated by the Chinese tend to be short-grained and sticky. Also, most rice in tropical Africa is grown under conditions different from those of Asia. Researchers must do more work on problem soils in tropical Africa and on developing appropriate cultural methods for upland rice (which makes up 50 percent of tropical African rice), deep water rice (10 percent of tropical African rice), and tidal swamp rice (5 percent of tropical African rice). The remaining third of the tropical African rice crop is grown with some form of water control, such as river diversion or inland swamp, and might profit immediately from dwarf varieties and the new production practices.

The great majority of rice-growing countries in tropical Africa have no research capability of their own. Three French-speaking countries (Senegal, Ivory Coast, and Malagasy) have resident rice research teams from the Paris-based research organization, Institut Reserches Agronomique Tropicales et des Cultures Viuvieres (IRAT). English-speaking territories in tropical Africa have varying degrees of research capability. Nigeria is the strongest. Some facilities exist in Ghana, Sierra Leone, Kenya, Tanzania, and Zambia.

The new sister research institute to IRRI, the International Institute of Tropical Agriculture (IITA) at Ibadan, Nigeria, is under construction (1969), has its first staff on site, and the first

experimental crops in the ground. An IRRI staff member is joining IITA in 1970 to participate in its research program.

Recently the West African Rice Development Association (WARDA) was formed when 11 tropical African governments decided to work together on rice improvement programs. They recognized that rice improvement is important to all of them but that none individually could provide the staff and resources needed for the task. Donors, including developed nations and international bodies, are eligible for associate membership. The role of WARDA in research, and what assistance IRRI and IITA can give to this new association, are still to be worked out.

Increased rice production in tropical Africa will not be achieved without considerably more local research, in addition to transferring the techniques developed in Asia. This is because rice production methods in tropical Africa are very different from those of Asia and basic reforms are needed in several aspects of agricultural production. Some fundamental weaknesses in tropical African farming:

Shifting agriculture
Lack of draft animals
Lack of irrigation
Tribal or communal holding of land
High price of agricultural chemicals
Intercropping
Lack of storage and processing facilities

A major improvement in rice production in tropical Africa will require research on all of these problems, in addition to the types of research conducted at IRRI.

Training of African research workers at IRRI has begun and probably should continue at the rate of five a year or more, if the Institute can absorb them. Training of rice production trainers should probably be organized in Africa rather than in Asia because of the substantial differences between production methods and because French is the official language in 18 countries in tropical Africa.

International cooperation

The efforts of the Institute to foster and help implement cooperative work among nations have met with considerable success

Most Asian nations with a major interest in rice production have established contacts with the Institute and have derived benefits from its program. Scientists and public officials with responsibility in the field of agricultural development are regular visitors. Also, the genetic materials developed at the Institute have been shared at all stages with rice research workers throughout the world.

The senior staff of the Institute, drawn from seven nations, is in itself an example of internationalism. In addition, research scientists from 25 nations have worked for periods of up to 2 years at the Institute in association with senior staff members before returning to work in their own countries. Crop production specialists from 20 countries have studied applied aspects of rice production, and several now conduct similar practical training in their home countries.

International seminars and workshops conducted by the Institute have allowed participants to pool their experience, to summarize present knowledge about rice production and to identify important unresolved problems. Major symposia have dealt with:

Genetics and cytogenetics
Rice blast disease
Mineral nutrition of the rice plant
Major insect pests of rice
Virus diseases of the rice plant

The monographs reporting these symposia are landmarks and reference points for recording progress in their respective fields.

The Institute has compiled and published a bibliography of the world's scientific literature on rice for the decade 1951-60 and keeps it up to date with annual supplements. The size of this effort is indicated by the 1967 annual supplement which required over 350 pages of text and included over 2,700 items. The cumulative index for 1961-65 is organized by subject, author, and geographic location.

The Institute library answers requests from all over the world for references to the rice literature. If a reference is not otherwise available, the Institute furnishes a photocopy on

request. Over 2,000 such photocopies have been supplied to scientists in 36 countries.

The Institute sends a newsletter, the IRRI Reporter, to about 4,000 interested people. The Reporter covers current research and items of concern to rice workers. The annual report of the Institute is mailed to about 2,000 people and libraries.

A series of uniform international tests and experiments has been conducted by the Institute. For example, to identify the variability of the causal organism of rice blast in different locations and to test the reaction of different varieties and genetic lines to races of the organisms, an international rice blast nursery is grown in about 25 countries. The information gained is assembled and coordinated by the Institute staff.

In Pakistan (both Eastern and Western provinces), Ceylon, and India, the Institute has administered contracts under which it has employed and supervised teams of expatriate scientists located in these countries who assist in developing national programs of research on rice production and improvement. Annual program review conferences at IRRI have included participation by scientists from such projects. The Institute is thus a world center to which scientists may turn for assistance, advice, and genetic materials.

Rice research needs

In terms of concrete accomplishments, rice researchers have in recent years scored major successes. The Institute's research program has, for example, exceeded even the more optimistic expectations of its founders, and often has led to greatly altered research objectives for the coming years.

The knowledge already gained will doubtless be consolidated and extended. New paths of investigation will be explored as they become apparent. An obvious need exists for further research into many aspects of rice production, for example: Increasing the quality and quantity of the protein content of the rice grain, new methods of combatting diseases and insect pests, more knowledge about fertilizer application methods, a greater insight into the microbiology of rice soils, better farm and processing machinery. Some research should be undertaken at IRRI; much needs to be done elsewhere.

These points and many others are discussed in Part 2 of this report. While such points were taken up at the conference, the group did not assign priorities or recommend specific actions. Some of these research areas (mostly problem-oriented rather than discipline-oriented) came under consideration several times, however, and the idea of refocusing the Institute's program toward more basic work on certain of them was discussed. Among the reasons advanced were that most of these research areas have received some attention at the Institute or are included in planned future activities. Also, other research institutions are not likely to solve these problems in the next decade. IRRI may be in a better position to provide the scientific manpower and facilities that these problems demand.

Some of the scientists present took the view the Institute should concentrate on these problems, and perhaps others of a similar basic nature, and shift its research attention away from the usual continuing ones such as breeding for conventional disease resistance and wide adaptability, agronomic practices, chemical control of insects and weeds, etc. These, they contended, should be left to other centers in developing countries. Instead, Institute scientists should strive for major advances by forming multidisciplinary groups dedicated to breaking down the more formidable barriers to further progress in increasing yield potentials. Others present, however, pointed out that many national centers place great value on the direct output of the Institute's research program now being followed and that they will continue to rely on it for information and for improved varieties at least over the next decade. In their view, the current program should not be precipitously altered.

The research areas which received particular attention in the general discussions at the conference included:

BREAKING THE BARRIERS LIMITING RICE-YIELDING ABILITY. Following the spectacular advance that resulted from replacing traditional tall varieties with the new dwarf ones, a new yield plateau apparently was reached. The yields good farmers get from the new dwarf varieties have stabilized at about 6 to 8 ton/ha, while top yields reported are 10 to 12 ton/ha. Physiologists and breeders agree that further spectacular increases will

not be achieved by more improvements in plant type. Other avenues should be examined in more depth; varietal differences in photosynthesis and respiration appear to be promising possibilities for study.

DEVELOPING STABLE RESISTANCE TO PATHOGENS. The familiar picture of breeding for resistance to crop diseases is that of the breeder striving valiantly to keep ahead, or at least abreast, of new races of pathogens. All too frequently, no sooner has resistance been bred into a variety than a new race of the pathogen renders the variety susceptible. This is true particularly of certain fungus diseases such as rice blast.

New developments in plant pathology, however, may allow scientists to breed varieties that would remain resistant to a specific disease for a long period of time. They would remain resistant despite the development of new races of the pathogen. This sort of resistance is known as horizontal or polygenic resistance. One example at present is that of resistance of potatoes to late blight.

The Institute is presently cooperating with other rice research centers in searching the world collection for this type of resistance to the rice blast disease. If it is found, the next step would be to incorporate it into high-yielding varieties. Similar studies might be made for other important diseases.

YIELDS ON PROBLEM SOILS. Immense acreages of rice are grown on infertile soils. Such soils may be deficient in certain nutrients, be too acid or too alkaline, contain toxic amounts of certain substances, or have undesirable physical features. New varieties such as IR8 and IR5 have been developed at IRRI on a relatively fertile soil and the major successes achieved with them have been on the better rice soils of the tropics. The realization of their full potential on problem soils awaits the identification and use of improved management techniques.

This topic may be approached in several ways. Development of suitable cultural practices through water control, soil amendments, and soil management deserve increased attention. Much of the basic chemistry of flooded soils is already known; this information should be taken out of the laboratory and greenhouse and applied in the field. Varietal differences in tolerance

to certain soil conditions are known to exist. These opportunities should be exploited.

UPLAND, RAINFED, AND DEEP WATER RICE. Substantial amounts of rice grow under upland conditions in Asia, Africa, and South America. That is to say, the crop is grown without bunding and depends on rainfall for its water as do most other crops. Scientists generally agree that upland yields will always average less than those of irrigated rice. Nevertheless, upland yields are at present much lower than they could be. Very little work has been done on the reasons for these low yields, and at present no systematic program is grappling with the problem. The land area involved is so great that doubling average yields from a ton to 2 tons would have a great impact.

Another substantial proportion of the Asian rice is grown on rainfed puddled soils. Confining bunds impound the natural rainfall but farmers do not use supplementary irrigation. In some areas, yields of such crops fluctuate widely from year to year, depending upon the distribution of monsoon rains. These are quite different conditions from those at IRRI where most research has been done on irrigated fields. A prerequisite for puddling, however, is water. Under rainfed conditions puddling cannot be attempted until substantial amounts of rain have fallen at the start of the monsoon season. If too little rain falls, farmers delay planting, sometimes for months. A further criticism of the puddling system, and one that applies even if irrigation water is available, is that it is time-consuming and expensive. Research must be directed toward systems of rice cultivation that do not depend upon puddling; and greater emphasis should be given to rainfed rice, as distinct from irrigated rice, which occupies only a small proportion of the total rice area.

Many research findings on irrigated rice are applicable to the rainfed system, but modified techniques of weed control, fertilization, and soil management need to be developed. New methods of rainfed rice cultivation on non-puddled soils, probably depending upon direct seeding, will allow other farmers to grow crops in rotation with rice, thus diversifying food production. Mechanization would also be easier. Doubling production on the land now rainfed would produce more food than doubling the

yield of fully irrigated rice since the area of the former is so much greater.

Perhaps 10 percent of the rice area in Asia is subject to deep flooding (Table 3). Water covers the land to depths ranging from 50 cm to 2 m or more. To produce rice under such conditions farmers must have varieties with culms able to elongate as flood waters rise so that the top leaves remain above the water surface. Profitable use of fertilizers and disease and insect controls are difficult. It now appears possible to develop varieties which will remain dwarf in the absence of deep water, but which will respond to increased water depth to the extent necessary. This could afford great protection to farmers in areas subject to flooding. Attention should also be directed toward developing new breeding materials and technology for fertilization and insect control under deep water conditions. One Institute role should be to facilitate cooperation among scientists from nations faced with the problem and to assist by incorporating desirable traits into the germplasm likely to be useful in such areas.

IRRIGATION, DRAINAGE, AND WATER MANAGEMENT SYSTEMS. Many problems associated with achieving higher yields can be dealt with by adapting the rice plant to the environment under which it must be grown—to upland or deep flooding conditions, for example. Alternatively, progress can be made by modifying the environment to create more suitable conditions. The farmer's greatest single problem in attaining full yield potential of the new varieties is his uncertainty about the water supply and his lack of precise ways to control and apply water. As a result he is unable to forecast his prospective yield within reasonable limits and hence his prospective returns on investments are highly variable.

A recent survey by the Asian Development Bank made two important observations: The area presently double-cropped amounts to about 5 percent of the land in rice, and the potential for double cropping, with existing irrigation, is less than 10 percent of the total rice area in South and Southeast Asia. Thus, even if rice yields are doubled in the fully irrigated areas, the increase would add no more than 20 percent to the region's total rice production. This estimate probably exceeds that which may

reasonably be achieved without further investment, since many existing irrigation systems are not fully effective.

Research should be directed toward the engineering, agronomic, and economic aspects of the design, development, and management of viable water management systems. This would include, of course, an assessment of water use efficiency by plants under different systems of management. It is unlikely that the objectives can be achieved by researchers working independently in their specialties. A team approach is essential.

DRYING, STORING, MILLING, AND GRADING RICE. The development of an improved rice variety that meets the preference of consumers opens a new area of problems. Much can go wrong between the harvest of paddy and the delivery of milled rice to the consumer. The quality the scientist bred into the variety may not appear in the rice on the consumer's plate because something went wrong during drying, storage, milling, parboiling, or grading. The problem may stem from the inadequate technical knowledge of processors or from inadequate economic incentive to deliver the highest possible quality.

Because of the success in developing improved varieties, emphasis in the next few years must be put on marketing problems, including research on improved drying, storing, and grading, and on market policy programs, market development in the broad sense, and training programs for producers, processors, and marketing specialists.

UNDERSTANDING THE RICE ECONOMY. Better knowledge of how the rice economy behaves is essential for rational decisions on the allocation of various resources. It is important to research directors when allocating funds and scientists' time; to rice producers when allocating land, labor, and money; and to national governments when dividing their revenues between competing commodities and between agriculture and other industries.

The allocation of research resources implies a judgment about the economic environment because the environment determines the value of the research results. Formal analysis of the effects on economic development of changes in the prices of technical inputs and labor, of consumer demand, and of trade prospects should be available so that research priorities may be established.

Furthermore, governments need to be aware of the effects of technical change and economic incentives on producer and consumer behavior. And they must know how consumer behavior is likely to be affected by income growth, price changes, and urbanization. A knowledge of changes in market relationships among nations should be available to governments if they are to select an appropriate plan of agricultural development, and to devise price and income, trade, and land reform policies.

Concluding observations—a role for IRRI in the 1970's

As reflected in Part 2 of this report, extensive problems must still be resolved. The Institute's remarkable accomplishments, however, are in no small measure due to its pursuit of clearly defined objectives. Priorities were set. Activities were launched only if they were clearly designed to increase rice yields in hungry nations.

In less than a decade, IRRI has essentially redesigned the architecture of the tropical rice plant and evolved, tested, and helped to place in use a new set of yield-increasing practices. As a result, a technical foundation now exists for new, high levels of tropical rice production, particularly where the climate is favorable and water is under the control of the producer. The advanced technology, therefore, ideally fits the relatively small portion of monsoon Asia where paddy is most productive. Production on rainfed fields is less affected by this technology. And production on upland soils has so far been little influenced by recent technical advances.

In view of the rapid progress in rice technology and the development of increased national capabilities in rice research during the 1960's this conference asked:

Should IRRI's initial objectives be modified? If so, what program shifts logically follow?

IRRI's program is by design dynamic. Institute staff and Board members participated fully and responsively in the dialogue of the conference. Self-analysis of programs and priorities is thus a continuing process at the Institute. The tone of the conference deliberation, however, suggests that:

1. Research directed toward raising average yields should be given increased depth.
2. Economic research and training capability should be expanded somewhat.
3. Promising agricultural engineering research and development efforts should be encouraged.
4. The training of technicians and scientists should be continued but gradually shifted toward developing a higher level of competence while retaining field experience in actual rice production.
5. Innovative ideas and programs for international cooperative attacks on regional and world-wide problems should be developed.
6. The present and potential importance of ecologically different rice-producing areas should be studied more closely.

The first goal, increased depth in research on average yields, stems from the realization that in one or two decades, population pressure on food supplies in rice-consuming Asian nations may be severe. The better rice-producing areas that have adequate irrigation water will be fully utilized. Land now viewed as marginal for rice production will have to contribute to greater output. Existing institutions concerned with such lands will contribute importantly to the solution of problems of local adaptation and improved practices and by training personnel. They will, however, look to IRRI, for the more basic discoveries which may break prevailing technology and economic yield barriers.

The second goal, expansion in economic research and training, recognizes that a more adequate understanding of the economic and social environment in which rice is produced is essential to the development and wider adoption of improved technology: Factor and product prices, earnings, uncertainty, the marketing chain, consumer demand (domestic and export), retail prices, and producer and consumer behavior.

While the Institute should not enter directly into the policy debates from which agricultural economic policies are forged, it should help develop the research tools and the economic information which planners and policy makers use in making such decisions.

The third goal of encouraging agricultural engineering developments means particularly that emphasis should be placed on ways to lower costs and increase the earnings of operators and workers on small farms. One way might be a temporary expansion of work on techniques for drying and processing rice at the small farm and village level.

The fourth goal is continued training of technicians and scientists with a shift to greater depth. At the production level, the training of trainers will be emphasized with IRRI providing consultative help to national training programs. More programs leading to an academic degree should be available to persons who work in national centers of research and education. IRRI is also expected to build increasingly strong links with both African and Latin America institutions in collaboration with IITA and CIAT. The initial Institute goal of helping to accelerate the growth in competence and performance of national institutions is as valid today as it was 10 years ago.

The fifth goal, innovations in international cooperative programs, is required if the foregoing goals are to be achieved. IRRI's headquarters site is an inadequate field laboratory for investigating some high-priority problems. Because the competence of national institutions is rising and because of the need to study problems in their own ecological and economic setting, centers of collaborative research and testing are likely to expand considerably.

The sixth goal, greater knowledge of ecologically different rice areas, results from the lack of precise information about how much land is in rice under sub-optimal conditions. Involved are impediments to production and harvest such as moisture, drainage, sunlight, temperature, topography, insects, diseases, and economic relationships. There is need, therefore, to define combinations of varieties and production practices that best fit specific ecological and economic situations; to increase world understanding of the present and potential importance of various types of production situations; and to take these more fully into account in designing research and training programs for IRRI and national and international agencies.

PART 2 / The International Rice Research Institute considers its role in the 1970's

Introduction

The International Rice Research Institute (IRRI) started its active research and training program in 1962, 7 years ago. Much has been said and written about the work done in that period. As a co-founder and a major supporter of the Institute, the Ford Foundation has asked that we now analyze the principal unsolved rice problems of the tropics and predict the role the Institute will play in their solution.

Our response is contained in this statement, which, prepared in final form by the Director of the Institute, largely represents the suggestions of the staff of scientists, each of whom was asked to identify the areas in his discipline that would need attention during the years immediately ahead.

It is hoped that the statement, although necessarily limited in coverage, will serve as a basis for the discussions to take place at the Institute from September 30 to October 3, 1969, when various consultants will be invited to join with the Institute staff to consider future goals. Afterward, an attempt will be made to prepare a more complete and relevant statement defining the more important rice research that should take place during the coming decade and the contribution envisaged for the International Rice Research Institute in that effort.

This statement reflects future objectives as seen by the Institute scientists themselves. Each field of study is discussed briefly under the heading of the corresponding department at the International Rice Research Institute.

Varietal improvement

The two named varieties, IR8 and IR5, that emerged from the rice breeding program at the Institute were developed under pressure to create tropical rice varieties that had high yield potentials and responded to intensive management practices, particularly fertilizer application. Though imperfect in grain and eating qualities, IR8 and IR5 have proved beyond doubt that high yields can be obtained under tropical conditions and that the application of appropriate amounts and kinds of fertilizer to tropical rice is a highly profitable operation. This historic breakthrough and the potentialities it revealed, however, far from representing a final, satisfying attainment, instead pointed to the vast task that still lies ahead in varietal improvement.

The tropical rice-growing world needs a series of 20 or more top-yielding varieties which vary in growth duration from 100 to 145 days and yet which are relatively insensitive to day length. These varieties must all have clear, hard, flinty grain with a consequent high recovery of head rice on milling.

The cooking quality must vary to satisfy the taste preferences of the various rice-eating peoples.

Although rice can never become a high-protein food, it appears possible to increase the protein content through plant breeding by 2 percent. For example, the protein content of the polished grain of the IR8 variety is about 8 percent. Perhaps equally high-yielding varieties can be developed that will average 10 percent protein when adequately fertilized. Such an increase would make a great difference in populations where more than half of the protein intake often comes from rice. This increase would be enough to improve significantly the health and development of growing children.

Great strides are needed in developing resistance to the major diseases of the rice plant. There is hope that a broad spectrum of resistance to the many races of the rice blast disease can be

developed in the high-yielding varieties by crossing them with certain varieties (now identified in the world collection) that have resistance to almost all of the known races of the disease and yet are unsuitable as varieties themselves. The development of varieties with horizontal resistance, likewise, should be attempted as a long-term breeding project.

It now seems certain that rice varieties can be bred that have a high degree of field resistance to bacterial blight and bacterial streak, two serious diseases of rice in the Asian tropics.

The two worst virus diseases of tropical rice are tungro and grassy stunt. The success of a breeding program to develop varieties with immunity, or at least high resistance, to these two diseases can not be predicted yet. However, resistance to the insect vectors of these diseases can be bred into the high-yielding varieties, thereby greatly decreasing the field incidence of the diseases.

To develop varieties with all these characteristics without losing the plant type and yielding potential of IR8 is neither easy nor quick. Indeed, to do it in 10 years would constitute a miracle. Each time a plant breeder attempts to introduce an additional beneficial character into an already improved variety, he almost has to start over again. Because so many undesirable characters are present in the plant that carries the one beneficial character, at least seven generations may be required to purify the new progeny.

To understand the difficulties involved in developing a variety with "everything," consider IR127-80-1-10, which resulted from a cross between (CP231 x SLO 17) and Sigadis. The former parent had good grain quality and short, stiff straw; Sigadis, an Indonesian variety, had disease resistance, heavy tillering ability, and adaptation to the humid tropics. On the Institute's well-managed experimental fields this variety showed disease resistance, high grain quality, stiff straw, and nitrogen responsiveness, and yielded well. On farmer's fields, however, it simply did not tiller enough to yield well at medium management levels. Thus, IR127-80-1-10 will never be recognized as a variety, although 4 years of hard work went into its development.

The Institute, despite its successes, after 7 years has yet to bring out a variety with grain quality as high as the best rices of the world and that yields well under tropical conditions in any country. Such high-quality varieties are in the making, however, and will be developed, but not without continuous, high-level support for the next 10 to 20 years.

A natural question is whether the International Rice Research Institute will breed rice varieties for the world indefinitely. Such countries as India and Thailand undoubtedly will soon have well-developed breeding programs of their own and will cease to look to the Institute for much help. However, it seems to us now (and this is difficult to predict) that many other countries will continue to depend upon the Institute for much of their basic genetic material for testing in their environments. We expect to be asked to furnish breeding material to be used in Burma, Laos, Cambodia, Vietnam, Malaysia, and Indonesia—and, probably to some extent, in the Philippines—during the next 10 to 20 years at least. Furthermore, the Institute is likely to continue to provide the original stimulation and to produce the germplasm for rice breeding programs in the tropics and subtropics around the world.

Worth mentioning certainly is the role the Institute should play in more fundamental studies, such as the inheritance of quantitative characters and the identification of genes responsible for resistance to the various diseases and insects. Even the possibility of obtaining improved varieties through heterosis should be explored. The inheritance of such qualities as photosynthetic efficiency or the efficiency of enzyme systems in carbohydrate and protein metabolism can well be investigated at the Institute where plant physiologists, biochemists, and geneticists work side by side in a spirit of cooperation and exchange. The possible use of the germplasm from some of the 22 known species of the genus *Oryza* should be thoroughly studied, and the world collection of *Oryza sativa* should be expanded and maintained indefinitely as a source of germplasm for rice breeders everywhere.

No change in the number of Institute plant breeders or geneticists is anticipated during the years ahead, although there

may be shifts in emphasis within the varietal improvemen program.

Plant pathology

A host of unresolved and important problems remain in the field of rice diseases. Let us consider several of the more important ones.

THE RICE BLAST DISEASE, in spite of all the work done on it, continues to take a heavy toll around the world. We have not yet shown the true role of plant breeding in developing strong resistance to this disease. The identification of varieties with resistance to nearly all races and their potential value in breeding programs has just begun. The cause of the extreme genetic variation in the fungus itself needs exploration through basic research. The nature of resistance to the blast disease is not understood. The search for the availability of horizontal resistance should continue and the possibility of creating composite varieties containing many different genes for resistance needs to be explored. Such work should be undertaken jointly between the varietal improvement and plant pathology departments. The epidemiology of the rice blast disease should receive more attention during the years ahead.

VIRUS DISEASES of the rice plant are rapidly spreading throughout Southeast Asia and constitute a major threat to the industry.

The tungro virus disease, or a closely related virus disease with the same insect vectors, has now been identified in the Philippines, Taiwan, Malaysia, Indonesia, Thailand, East Pakistan, and India. Seven years ago, only in the Philippines was the disease considered to be caused by a virus, and even there it had not been thoroughly studied.

Work must be continued to develop varietal resistance to the disease itself and to its vectors, to study the basic nature of the virus, and to follow closely the spread of the disease.

Although the tungro-like viruses have commanded the most attention because of their prevalence, virus diseases such as

grassy stunt also can cause great damage and constitute an ever-present threat wherever rice is continuously grown throughout the year. Whether any varieties have true resistance to the grassy stunt virus is not yet known, but some have resistance to its vector, *Nilaparvata lugens*. This point needs further study. The necessary work on the vector will be discussed later under the heading of entomology.

BACTERIAL LEAF BLIGHT, caused by *Xanthomonas oryzae*, is increasingly recognized as a major disease of rice in the tropics, particularly during the wet monsoon season. Studies still needed include work on the identification of strains of varying pathogenicity, effects of climate and management on the severity of the disease, the means of transmission, and the nature of varietal resistance and further search for resistant varieties as breeding material.

Similar studies should be conducted with bacterial streak, which is a somewhat similar but less serious disease of rice.

SEVERAL OTHER DISEASES are important enough to cause heavy losses under certain conditions. Examples are the helminthosporium disease, sheath blight, cercospora, and stem rot. During the coming years more attention must be paid to these diseases, with detailed research on the causal organisms themselves including their ecology, epidemiology, and varietal resistance.

To predict the growth of good plant pathology research programs in the developing countries is more difficult than to foresee the progress of varietal improvement. The Indian program will likely develop well if the government of India gives it continuing support. Certainly there are Indians, trained abroad or in the process of getting such foreign training, who can handle the plant pathological research. The Indian Agricultural Research Institute and the Central Rice Research Institute now have active and quite effective programs, and the newly initiated programs of the All-India Coordinated Rice Improvement Project is off to a vigorous start.

It seems, however, that most other rice-growing countries of South and Southeast Asia have an abundance of plant breeders but lack enough plant pathologists. The International Rice Research Institute may have to carry on much of the research in most of those countries for some years. Significantly, it was Institute plant pathologists who discovered that Penyakit merah in Malaysia and the Mentek disease in Indonesia were really the tungro virus disease. Likewise, it was the Institute which proved that the Kresek disease in Indonesia was a virulent form of bacterial blight.

The Institute plans to retain three senior plant pathologists, one working with fungus diseases, one with virus diseases, and one with bacterial diseases.

Entomology

Experiments conducted by the Institute over the past 7 years show that the application of insecticides to high-yielding varieties on well-managed fields results in an average yield increase of about 2 metric tons per hectare. Such data indicate the extent of insect damage on untreated fields. Since populations are not likely to decline naturally, substantial efforts to control the pests are a necessity.

So far, the only truly effective method of control has been the use of chemical insecticides. However, rapid advances are being made in developing rice varieties that are resistant to insect attack. Such resistance should appreciably cut the amounts of insecticide needed. Biological control offers some promise but has not yet been a successful man-operated method. More work should be done on sex attractants, chemo-attractants, and sex sterilants to explore their possible usefulness in insect control.

A few of the major unsolved entomological problems, in relation to the Institute's future program:

THE IDEAL INSECTICIDE for use on lowland rice has yet to be identified. Institute entomologists have made a major contribution by showing that such insecticides as lindane and diazinon, broadcast in granular form directly into the irrigation water, give good control of several major insect pests of rice. Lindane, however, has little effect on the pink stem borer, the green leafhopper, or the brown planthopper. On the other hand, diazinon, which gives good control of leafhoppers and planthoppers and is effective against all species of stem borer, is not as long-lasting as lindane for the yellow and striped stem borers. Moreover, in our experience the principal problem with diazinon is that when it is in long, continual use (on Institute fields, for 3½ years) brown planthoppers develop resistance to it. Accordingly, diazinon's effectiveness no doubt will have a time limitation wherever it is in long, repeated use.

The search for good insecticides is a constant one involving Institute testing of new products brought out by agricultural chemical companies. It must investigate the residues remaining in the plant, in the soil, and in the irrigation water to be certain that they are not at dangerous levels for human beings or animals.

Because many developing countries have a great scarcity of foreign exchange, their entomologists have difficulty obtaining new insecticides for testing purposes. So far, the Institute has had to purchase quantities of several promising materials for cooperating experiment stations elsewhere in Southeast Asia. This service will probably continue.

Because insect pests vary from region to region, insecticides must be tested in individual countries. For example, although the Philippines has neither the gall midge nor the hispa, they are serious pests in many other countries of tropical Asia.

BREEDING FOR RESISTANCE to insect pests of rice is in its infancy. Only recently the Institute has shown that varieties of rice can be bred that are essentially immune to the green leafhopper and the brown planthopper. It took 7 years to screen the

world collection of over 8,000 varieties of rice, to make initial crosses, and to show that the factors for resistance to the two insects are rather simply inherited. Three to five years, and perhaps even longer, will be needed to fully incorporate the genes for resistance into otherwise satisfactory varieties.

A high level of resistance to rice stem borers appears impossible to obtain. A variety from India called TKM-6 has the highest resistance we have been able to find, but under severe stem borer attack, tillers sometimes are 30 percent infested. Although the Institute undoubtedly should continue to seek better sources of resistance, we presently believe that insecticidal applications will be the principal method of control for the rice stem borer.

As mentioned earlier, the gall midge is not present in the Philippines. Nevertheless, the Institute has encouraged other countries, mainly India and Thailand, to mount a strong program to study varietal resistance to this insect. Progress in India is promising and prospects are bright that a set of high-yielding varieties resistant to the gall midge can be produced within the next decade.

The possibility of obtaining varietal resistance to a number of other insects has yet to be explored. Attempts to create varieties resistant to damaging insects like the armyworm, whorl maggot, rice bug, and thrips are warranted.

THE POPULATION DYNAMICS of the major insect pests of rice are not well understood. An example is the green leafhopper (*Nephotettix impicticeps*) in the Philippines. In the first years of the Institute's program, the tungro virus disease, which is carried by the green leafhopper, constituted a major problem. Today it is difficult to find the disease on our experimental plots. Our scientists believe that numbers of the green leafhopper, the vector of the disease, have decreased at the Institute because IR8, which is resistant to the leafhopper, has been grown so extensively. As the numbers of insects decreased, so did the incidence of tungro virus disease. This, however, is speculation and should be studied thoroughly. We have some indication that the present

incidence of the tungro virus disease is low all over the Philippines compared with the levels of a few years ago. Perhaps a natural enemy of the leafhopper caused this decrease.

The brown planthopper population seems to be affected by high temperatures. This observation needs to be studied.

Why the gall midge appears and disappears remains a mystery. The insect is so small that, with a few exceptions, it has not been traced throughout its life history.

As investigations of ecological and biotic factors (including parasites, predators, and pathogens) are carried out, it may be possible to forecast major outbreaks of insects and give advance warning to rice farmers.

BIOLOGICAL CONTROL of the major insect pests of rice has not yet been thoroughly explored. Although the limited and sporadic studies carried out so far have not produced any striking success, just enough promise exists to make a sustained effort worthwhile, in cooperation with scientists from other countries. For example, scientists in West Africa report finding a parasite of the rice stem borer that is so effective that it is difficult to raise a parasite-free population.

The Institute's progress in entomology during the past 7 years has been considerable. With a second entomologist being added under the expanded program, it promises to be even more complete in the years ahead.

India, Thailand, and Ceylon may have fairly good programs during the coming decade, but even that is hard to predict. In general, entomologists are in short supply in the rice-growing countries, and the Institute probably should continue to play a major role in entomological research for the next 10 years and more.

Plant physiology

Physiological research at the Institute has shown that the great advances in tropical rice yield, although related to plant morphology actually have come about through the higher physiological efficiency of the rice plant. By remaining upright until

harvest the improved plant has been able to utilize solar energy and soil nutrients more effectively than was possible before.

The Institute's progress in physiological findings over the past 7 years has been so heartening that a continuing study of remaining problems seems essential. Some basic questions, the answers to which may eventually add further efficiency to the productivity of the rice plant:

EFFICIENCY OF PHOTOSYNTHESIS. In 1968 Institute plant physiologists measured the photosynthetic efficiency of detached leaves of 50 rice varieties selected from the world collection and found a variation of nearly 100 percent. This opens a whole new field of endeavor, for after several thousand, rather than merely 50, varieties are analyzed, even more efficient varieties may be discovered. This may be a key avenue of research since the two highest yielding varieties (and hence the first to be named) in the All-India Coordinated Rice Improvement Project had as one of their parents T-141, the top variety among the 50 tested at IRRI for photosynthetic efficiency.

TEMPERATURE, LIGHT, AND CARBON DIOXIDE. Under hot, humid tropical conditions, rice outyields corn. Under cooler conditions at more northerly latitudes or at higher elevation, the reverse is true. Rice exhibits photo-respiration while corn does not. A single fully exposed leaf of corn continues to increase in photosynthetic rate as light is increased up to full sunlight, while the exposed leaf of the rice plant does not respond in photosynthetic rate beyond less than half of full sunlight. Rice at high light intensities shows a remarkable response to increased carbon dioxide in the atmosphere. This whole area of temperature, light, and carbon dioxide in relation to yield needs much more study. The Institute is an ideal place to conduct these basic yet highly useful studies; but good environment control apparatus and air-conditioned greenhouses are needed, and such facilities are costly.

NEW TEMPERATE ZONE RICE. The use of the new plant type as exemplified by IR8 may be a boon to the temperate zone as well as the tropics. There is just enough evidence to make this approach exciting. The Institute, in cooperation with rice research institutions in Japan, Korea, and the U.S.A., could develop new varieties with increased efficiency for the northern climates. It

seems clear that the physiological efficiency of heavy tillering, short-leaved, stiff-strawed varieties now being developed in the tropics surpasses anything yet developed in the temperate zone. If the same plant type, but with cold resistance and all the other factors needed for the more northerly climates, could be developed, new yield ceilings might be created. This is a task that can be undertaken jointly by physiologists and plant breeders. Considerable time—perhaps more than 10 years—would be needed for achieving the objective; but success would be well worth the investment.

NUTRITIONAL DISORDERS. Institute plant physiologists have completed preliminary investigations into nutritional disorders of rice in major rice-growing areas of Asia. They found that nutritional disorders are becoming increasingly important barriers to rice production. This is because after the introduction of improved varieties, the limiting factor in rice growth is shifting to agronomic management such as fertilization, spacing, pest and disease control, and nutritional disorders, and because introduction of new varieties and technology creates new problems in rice growth as exemplified by zinc deficiency in West Pakistan. Studies on nutritional disorders should be continued. Immediate targets in this project should be to identify the role of plant nutrition in limiting rice growth in problem areas and to demonstrate how nutritional disorders in problem areas may be solved. To achieve the above targets, basic studies such as interactions among nutrients and requirement for micronutrients are also needed.

An examination of the potential for plant physiology research in rice-producing countries indicates that, with the possible exception of India, tropical Asia will not be active in this field. To date, all such work in all of Asia has been done either in Japan or at the International Rice Research Institute. It appears that this is a function that IRRI should perform for as long as the Institute exists.

Soil chemistry

The soil chemistry program up to the present has been concentrated on the study of the chemical kinetics and general behavior

of rice soils when flooded. As a result we have a good understanding of the changes that occur when soils are submerged for extended periods. In certain soils, for example, flooding creates soil conditions unfavorable for the optimum growth of the rice plant.

The soil chemistry program for the next decade will largely be focused on the application of this chemical knowledge to the solution of practical problems of rice production. In addition, however, some important fundamental questions are scheduled for further study in the coming decade:

RELEASE AND LOSS OF NUTRIENTS IN FLOODED SOILS. Evidence exists that in some soils more than half the essential nutrients that are released (become available for absorption by plants) are lost in the percolation waters or by diffusion. Fertilizers will continue to be in short supply in most developing countries and methods of exploiting soil sources of nutrients and means of minimizing losses need further investigation.

MALFUNCTIONS IN SOIL METABOLISM. Additional studies of the physiological disorders of rice caused by anaerobic soil conditions must be undertaken. At least five physiological disorders of the rice plant have been attributed to faulty soil metabolism. The toxins causing these diseases and the soil conditions favoring the production of these harmful substances need further study. The areas of problem rice-growing soils need to be demarcated and control measures found through field experimentation. This work will be conducted in cooperation with the plant physiologist and the soil microbiologist

ACID-SULFATE SOILS. The reclamation of acid-sulfate soils must be studied. High soil acidity in these soils depresses rice yields (and in extreme cases prevents the growing of any crop) on several million hectares of land in Vietnam, Thailand, Malaysia, India, and West Africa. Experts vary in their opinions of the practicality of reclaiming these areas. The Institute has found that the application of lime and manganese dioxide to these acid-sulfate soils in pots in the greenhouse causes rice plants to grow normally. The treatment even works on soils that are so acid that they would otherwise produce no rice at all. A series of field

experiments conducted in cooperation with countries having this problem must be undertaken to determine the economic feasibility of the reclamation of the acid-sulfate clay soils.

ACID, SANDY SOILS. The management of acid, sandy rice-growing soils needs further attention. These soils, which have been derived from granitic rock and thus contain a high percentage of quartz sand, occur extensively in Japan, Korea, Thailand, Malaysia, India, Ceylon, and Senegal (to mention only some of the countries). It is difficult to get high yields on these soils, which have a low cation exchange capacity, low pH, low water-holding capacity, and high percolation rates. Because of the wide areas containing such soils, intensive studies of their management should be started.

IDEAL SOILS. The ideal rice soil needs further characterization. To understand better the soil component in obtaining high yields of rice, areas where outstanding yields are obtained consistently should be studied more thoroughly.

UPLAND SOILS. Further studies of nutrient availability in upland rice soils should be conducted. Although rice yields will always be lower under upland than under lowland conditions, large areas of land in Latin America and in West Africa, for example, have economic and topographical conditions which will cause rice to be grown for decades to come. Nutrient availability under flooded conditions has received much attention but soil-plant relationships under upland culture remain to be studied.

Rice-growing countries are unlikely to be able to attack their soil problems adequately during the next decade or more. Again, India has enough talent to do so if it chooses. Thailand has a bright young soil chemist who recently returned from graduate study abroad. But in Southeast Asia too little attention is being paid to soil chemistry and physics in relation to rice production. More people should be trained in these disciplines and, of course, put to work under adequately supported programs. This is more easily said than done, and we believe IRRI will play the major role in this field for at least the next decade.

Although the Institute does not expect to increase the size of its soil chemistry staff, additional funds may be required to

handle the many cooperative field studies on the management of problem soils in Southeast Asia.

Agronomy

The agronomy program will continue to seek practical answers to problems in the general area of cultural practices, which include weed control, planting methods, fertilizer use, and water management.

Experimentation to obtain maximum yields, taking advantage of all that comes out of the other programs, will be continuous through the years. For example, new varieties, improved insect control practices, new knowledge in soil chemistry—all will be subject to constant application by the agronomy department to develop optimum practices for obtaining the highest possible grain yield. At present Institute agronomists are obtaining an annual yield of slightly over 20 metric tons of grain per hectare. The figure may exceed 25 tons as better management methods and more efficient varieties are developed.

Several specific areas of agronomical research to be emphasized during the next decade:

DIRECT SEEDING OF RICE. Practical methods of direct-seeding rice in the humid tropics will be developed. Although the Institute obtains satisfactory yields of rice when direct-seeded, either in rows or when broadcast, the methods employed are too difficult for the average farmer. For example, after the soil is puddled, the field must be drained and the pregerminated seed planted on mud. After the seedlings are well established, the field is flooded. If, however, a heavy rain occurs just after seeding, snails destroy the seedlings unless the snails are eliminated by the application of a chemical snailicide. Weed control is a problem too. No really satisfactory method of chemical weed control for direct-seeded rice culture under tropical conditions has yet been developed.

If it is to be recommended that the average farmer sow his rice directly in the field without transplanting, methods that work without careful water control must be devised. He should be able to drop the seed directly into a layer of water several

centimeters deep. At present, this practice generally results in a poor stand, apparently due, at least in part, to competition of the young seedlings with snails, algae, and weeds, and perhaps also to the low oxygen content of the water under the high temperatures of the tropics. Through research, answers to these problems should be sought.

WEED CONTROL RESEARCH. As mentioned above, chemical weed control with direct-seeded rice has not yet been worked out for average farm conditions. The few chemicals that perform reasonably well are too expensive for the average Asian farmer.

Major emphasis will be placed on this problem during the years immediately ahead. The Institute has good relationships with major companies producing herbicides and is testing their products. Efforts are being made to find a few chemical compounds that, when applied in granular form, have post-emergence toxicity for the grassy weeds and yet do not damage the rice seedlings. Special emphasis will be placed on discovering a combination of herbicides that requires only one application and yet controls grasses, broadleaved weed species, and sedges. Present experience indicates that 5 to 10 years will be required to attain this goal.

Research on the use of granular herbicides for transplanted rice has been unusually successful during the past year. In the next 2 or 3 years we expect several chemicals and appropriate methods for their use to be fully worked out. New and cheaper chemicals, nevertheless, should continue to be developed by industry and, as released, will be tried by the Institute.

Weed control in upland rice culture presents many obstacles, even more than exist when rice is direct-seeded under lowland conditions. Work already started in this area will be continued. Progress will be slow, because selective herbicides that can control grassy weeds under non-flooded conditions without endangering young rice seedlings have yet to be identified.

WATER MANAGEMENT. Although many authorities say that lowland rice does not suffer from moisture deficiency, water supply is still the most important barrier to higher rice yields in Asia. Approximately 80 percent of the lowland rice areas of South and

Southeast Asia is rain-fed and has no supplemental irrigation facilities. When even short periods of drought occur, the fields often run out of water and yields suffer accordingly.

In spite of the general scarcity of water, many rice farmers use about 80 inches of water to grow a single crop. Yet if the water supply is carefully used, preliminary research results indicate that a good crop of rice can be grown with less than 30 inches of water. Such problems as the nature of drought resistance in the rice plant and the relation to rice yield of puddling, soil structure, and loss of nutrients and water, are among the many factors needing intense study.

To further the program the Institute has employed a soil physicist trained in water science, who will devote full time to water management in rice soils.

SYSTEMS OF CROP ROTATION. The Institute has made an excellent start in its multiple cropping program. Crop rotations allow one crop of rice to be grown during the rainy season, followed during the next 8 months by two or three upland crops, such as soybeans, sweet corn, sorghum, and sweet potatoes. But problems exist. Methods of soil management, insect control, and water management, and the selection of suitable varieties for intensive rotation and intercropping, remain to be studied. This is a long-term project that probably will be continued for the life of the Institute. The promise of reward is great, however, for here research can demonstrate the true food production potential of the earth's immense tropical belt, where—when irrigation water is available—man can produce food 12 months a year.

NEW PHOSPHORUS SOURCES. The world's supply of readily accessible phosphorus is limited. Such phosphatic fertilizers as super-phosphate seem likely to become increasingly expensive. The Institute, in cooperation with the Tennessee Valley Authority (TVA), intends to test many kinds of rock phosphate in lowland paddy fields. Because the soil in our experimental farm contains adequate phosphorus, this work will be conducted in outlying areas in the Philippines and in such other countries as Thailand, Ceylon, India, and Indonesia.

Practical work on cultural practices can be carried out in many relatively small experiment stations. Mainly, the requirements are land and labor, plus a few agricultural chemicals. The Institute will continue to be the leader in various regional uniform cultural practices trials. Our role will be to send specific instructions to each cooperator and to supply the chemicals when necessary. In addition to providing comparative data from all over South and Southeast Asia on a specific practice, such as chemical weed control, this type of cooperative work tends to convince other research workers of the high yield levels that can be attained by the use of modern varieties and cultural practices. Always, regardless of the immediate, often narrow objective of an individual experiment, a complete "package" of practices is recommended.

To the best of our knowledge, during the past 5 years nearly all experimental stations with which we have been cooperating have broken their previous yield records and many have doubled their former top yields.

Tropical Asian countries where some reasonably good work on cultural practices is now going on include India, Thailand, Taiwan, Indonesia, and Malaysia.

Soil microbiology

Because lowland rice is continuously flooded, chemical and microbiological processes take place in an anaerobic environment. Thus, much of the knowledge gained from well-drained upland soils is not applicable. It seems essential that the Institute continue to explore the microbiological processes in submerged soils to reach a more complete understanding of how management affects the root environment of the rice plant.

Some of the more important research activities that will be undertaken by our soil microbiology department during the next decade:

MICROBIOLOGY AT THE ROOTS. These studies will be concerned largely with microbiological activities in the rhizosphere, that layer of soil adjacent to the root surface and the root hairs where large populations of soil microorganisms exist. Studies

will be carried out to show how the presence of beneficial soil organisms relates to the absorption of essential mineral elements. Research on nitrification, denitrification, and organic nitrogen metabolism in the rhizosphere will be conducted.

The damage non-pathogenic microorganisms do to plant roots deserves more attention. Certain physiological disorders of the rice plant which cause significant yield reductions appear to be associated with the presence of certain harmful organisms such as *Pseudomonas* and *Fusarium* in the rhizosphere.

Studies will be made of the possibility of inoculating rice seed with useful bacteria such as those that attack harmful soil organisms.

NITROGEN GAINS AND LOSSES. The fate of no single plant nutrient is more important than that of nitrogen. Although nearly 80 percent of the earth's atmosphere is composed of nitrogen, it is the most universally deficient element in the soil. In flooded rice culture the fate of applied nitrogen, as well as of that already present in the soil, is not clearly predictable. The addition of elemental nitrogen from the air through microbiological fixation must still be measured accurately. However, new hope for obtaining this information comes from the recently discovered method of measuring nitrogen fixation by the degree of reduction of acetylene to ethylene. This method is 100 to 1,000 times more sensitive than methods previously used.

The possibility of altering the population of nitrogen-fixing organisms has yet to be fully studied.

TOXINS FROM MICROBIOLOGICAL PROCESSES. The soil microbiologist will work closely with the soil chemist in determining how much toxic substances formed in the soil through microbiological processes interfere with the maximum performance of rice. The actual substances involved must be identified and appropriate remedies found.

BIOLOGICAL CONTROL. The whole field of biological control of soil-borne pathogens needs study. This is a relatively unexplored area that could yield significant results.

CHEMICAL RESIDUES. The problem of insecticide and herbicide residues must be continually studied as new chemical compounds

prove promising for general use. It has been shown that the persistence of lindane and diazinon in flooded soils is much less than in upland soils; so all compounds must be studied under the conditions of lowland culture no matter how much information exists regarding their behavior under well-drained soil conditions.

Only one senior scientist will be maintained in the soil microbiology department. This may prove to be a rewarding endeavor for another 10 years or so, but whether or not its "payoff" will be great enough after that time remains to be seen.

Strong programs are not likely to be developed elsewhere in this field during the next decade with the possible exceptions of India and Taiwan (among the developing countries).

Agricultural engineering

Improved varieties and intense cropping have increased the requirement for machinery for soil preparation, cultivation, harvesting, threshing, and drying. The availability of a reliable source of power at a cost that small farmers, owning 2 to 10 hectares of land, can afford is basic to farm reorganization for increased production. The development of power-operated equipment suitable for such farms in developing countries is a great challenge for engineers because research in advanced countries is mostly concerned with complex equipment for large farms. Manufacturers of agricultural machinery in tropical countries are generally small-scale operators and do not have adequate resources for the design and development of new agricultural machines. In the past, considerable effort has been directed toward mechanizatioon research in some developing countries, but such work has not made an impact on the farmer. The extension of machinery research to the farmers can best be accomplished by incorporating the results of research into the design of new, commercially available agricultural machines. Institute engineers have recognized that to be effective, the research must be directed towards the manufacturers of agricultural equipment.

For the next decade the Institute's engineering research will be concentrated on developing complete designs of simple power-operated equipment for rice mechanization which could be man-

ufactured in the developing countries and on conducting applied research aimed at helping others in the development of advanced power-operated machinery for rice cultivation. Problems tackled:

TRACTOR DESIGNS. Large and medium-sized tractor designs are based on a machine for developing high traction. The mobility of these tractors under lowland conditions has serious problems. New tractor concepts for wetland work based on the principle of direct transfer of energy to the soil will be evaluated.

In addition, small and medium-sized riding tractors might be developed as a substitute for draft animals to handle the tillage, hauling, and transport requirements of farmers. Small-sized tractors now available are not as versatile as draft animals. To replace animals successfully, an effort will be made to develop relatively small-sized, single-unit, transport-cultivation riding machines which would be within the economic means of the tropical farmer.

LAND PREPARATION. The problems of wetland rotary tillage have not been fully understood. Researchers will evaluate new concepts and prepare machinery designs for rotary tillage. Machines are also needed for a single-pass land preparation operation under wetland conditions.

HARVESTING AND THRESHING. Power-operated harvester-binders produced in Japan are too expensive for developing countries. Research is needed to exploit new concepts and ideas for designing and developing low-cost harvesting. Threshers generally are no longer manufactured in the advanced countries because of the popularity of the more efficient combines. Hence, the development of suitable stationary threshers of different sizes to handle freshly harvested paddy is being worked on by the Institute engineers with considerable initial success.

Conventional combines encounter problems in small paddies and under the difficult soil and weather conditions experienced in tropical countries. Thus, research is aimed at the development of lightweight combines for use in these countries. Institute engineers have just designed a small harvester-stripper that harvests the grain but leaves the stems in the field.

DRYING. Small-sized, continuous-flow dryers are needed for village-level drying. Although suitable designs of large dryers are available, little work has been done on small-sized, continuous-flow farm dryers that could be manufactured locally. This area of research will receive the concentrated attention of Institute engineers. Also, studies will be carried out to develop devices for drying paddy rice with local sources of heat such as rice husk, straw, and solar energy.

PROCESSING. Research will be conducted to develop improved processing machinery like cleaners, hullers, and milling equipment which could be manufactured and marketed within the developing countries.

OTHER PROBLEMS. Other problems which will receive attention include development of row seeders for sowing pregerminated seed under lowland conditions, testing and evaluation of available transplanters under tropical conditions, and development of power sprayers for herbicides and insecticides for flooded field conditions.

When necessary, the engineering department will closely collaborate with private industry to make manufacturers aware of new rice machinery designs. In support of machinery research and extension programs, the work will include studies of the economic attitude of the manufacturer, seller, owner, and user towards a new machine.

The problem of developing rice machinery for tropical countries is too large to be tackled by IRRI alone. Other centers in the tropics can contribute to the development of tractor implements and power-driven dry and wetland agricultural equipment. Improved manual and animal-drawn implements are also needed. Other centers can offer complete design and development services, provide technical assistance for local manufacturers, and assist in the introduction of new rice machinery. The Institute can play an important role in demonstrating the potential of engineering research on the lines indicated above and in stimulating other organizations to direct their research programs towards maximum productiveness and the needs of the farmer.

The Institute is aware of the need for properly trained engineering research personnel in most developing countries. A research program tailored to meet the requirements of developing countries would serve as an excellent training ground for such personnel. The exchange of research information between the Institute and other centers and cooperation in engineering research is expected to greatly influence research programs in other countries.

Chemistry

Rice is a principal source of protein of the rice-eating people of Asia. The quality of rice protein is relatively better than most cereal grains but its quantity is low. Chemists have found a wide variation, from 5 to 17 percent, in the protein content of rice grain of varieties maintained in the Institute collection. The lysine content of the rice grain has not shown a marked variation. Although environment greatly influences protein content, preliminary investigations conducted cooperatively with the varietal improvement department have shown that part of the variation is under genetic control and can be combined with a good plant type.

Problems which the chemistry department will study actively during the next decade include:

PROTEIN CONTENT AND QUALITY. The department will continue to assist the rice breeders in screening lines and segregating material for protein content. When high-yielding, high-protein lines are identified, the effect of the higher protein level on the milling, cooking, eating, and nutritive properties of the grain will be determined. The study of the prolamin and glutelin fractions of rice protein will continue.

PROTEIN METABOLISM. A study of protein metabolism started recently to determine the rate-limiting step or steps in protein synthesis will be continued. It will include the effect of environment on the rate-limiting step or steps. Protein metabolism of the plant from shortly before ear initiation to harvest may also be studied, since solar radiation during this period is strongly related to grain yield.

STARCH METABOLISM. The ratio of starch amylose to amylopectin is important in determining the texture of cooked rice. A study of the enzymes involved in starch metabolism in the developing grain, covering both waxy and non-waxy lines, has been started. As they become available, isogenic lines varying only in the amylose content will be used. Starch metabolism in the leaf and culm will be studied too. Answers will be sought to such questions as the influence of temperature on amylose synthesis in the ripening grain.

OTHER PROBLEMS. In cooperation with the entomology and plant pathology departments it is proposed to study resistance to pests and diseases, using as samples isogenic lines showing marked differences to a particular pest or disease.

Agricultural economics

During its early years the Institute focused on developing new ways to grow rice. While it has been fully accepted that new techniques must be economically sound if they are to have any meaning, the stress has been on the physical side. During the 1970's this seems bound to change, with a distinct trend to more involvement of the agricultural economist. Earlier Institute work in economics was predominantly at the farm level. Is a particular practice profitable and how might it be modified to become more profitable? What causes a farmer to accept one new practice and not another? How does change in one practice affect the economics of another? These and similar questions have occupied much of the time of the Institute's small staff in economics.

To answer some of these questions, the economist has delved more directly into agronomy than economists usually do. At the same time he has been called upon regularly to comment on how broad economic conditions, government policies, private investment, and other similar factors affect the acceptance of research innovations and efforts to increase rice production. Thus, he has had to monitor world and national economic forces — macro-economics—at the same time he was engaged personally in evaluating farm level economic forces—micro-economics.

Not infrequently planners and policy makers ask for specific advice on the implications of current research results to the broader aspects of economic development. Again, the economist is frequently best situated to comment. More recently, the Institute has received questions on problems of milling, storage, grading, and marketing of rice. Successes in increasing overall rice output have made these questions critical in some areas.

In projecting the role of the economist in the Institute's program in the 1970's, some basic questions of the Institute's own role must be resolved. To date, the central role has been to conduct research on the rice plant and its environment and to encourage others to do likewise. Closely supporting this research orientation has been the communication of these results to farmers and, again, the encouragement or training of others to communicate research findings to those who ultimately use it. Both in research and in communications the Institute was visualized as an innovator in technique and focus and as a pace setter, not merely as a source of information. If this approach is truly successful, the Institute's own output of research findings will soon be dwarfed by those of the many national institutions with which it works or which it has indirectly influenced. The dramatic upsurge in enthusiasm in other rice research centers, often accompanied by strong changes in orientation, supports the view that this role is being fulfilled.

Assuming this approach is valid and is one which also should apply in the field of economics, to what extent should efforts be made to provide counsel on the questions now arising from the farm up to top levels of government and industry? The answer seems to be that additional personnel should be employed to cover these diverse phases of economics in more depth. But the role of the Institute as a direct source of detailed advice to planners or farmers should be avoided. Instead, economists at the Institute should conduct research in their own specialties and encourage other centers of study to do likewise. The leverage that has proved effective so far should be sought in any expanded activity of the Institute in economics.

Specifically, it seems likely that the Institute should add a full-time macro-economist to its staff within the next 2 or 3 years.

He should cooperatively study key areas and encourage colleagues at other centers to carry on meaningful studies of broad economic factors that influence rice production and that interact with research output and research needs. The analogy to the physical or biological scientist and his relationship to work in his field and to his colleagues is, of course, not perfect for the social scientist because his work immediately places him in the center of other people's problems. Often he must comment upon them, and he feels pressured to become a full-time adviser. Still, the concept of the Institute's economists as researchers rather than as resource persons, consultants, or advisers must be preserved. We hope that our macro-economist will devote some time to counseling key agencies on specific problems but that he will be able to devote his time largely to studying broad economic trends and their influence upon rice and upon the people whose livelihoods and lives depend upon rice.

At a somewhat different level it appears that the Institute should examine economic aspects of milling, storing, and marketing of rice. The answers to social and economic questions about mechanization could affect machinery development and testing. The questions are so diverse that they probably will have to be handled in a variety of ways. Short-term consultants may be able to assist on some. In our experience, however, the long-term association which Institute staff members develop has an important if indefinable effect on their productivity. Thus, longer term associations will be sought with specialists in these varied fields. Perhaps some understanding should be sought with centers particularly qualified in these areas to permit selected members of their staff to serve at the Institute or with projects associated with the Institute for periods of a few months to a year or two and to repeat these contacts over a period. To be able to draw upon the knowledge of the staff of Louisiana State University on milling, for example, seems a more productive approach than staffing directly in this area.

This approach should be reserved for areas critical to the rice industry on which Institute scientists and economists are not conducting research. For example, IRRI is not conducting research on milling, nor is it planning to, simply because mills ade-

quate for most of the job are already on the market. Still, the economist who considers milling needs cloose association with the engineering and industrial centers that deal with rice milling. Several questions of growing importance which deal with the crop after it has been produced tend to fall in that category. For work on milling and marketing perhaps an average of one man-year per year should be budgeted for economists in the short and intermediate term category.

For the next 2 to 5 years it is anticipated that a farm machinery economist will be employed to evaluate farm machines developed by the Institute engineers and introduced by industry. He would work closely with the engineers and would be able to assist machinery manufacturers who wish to produce simple machinery adapted to lowland rice culture in monsoon areas. The post will be in the engineering department, but it should be cited as a contribution of the Institute to agricultural economics at still another level.

To summarize, during the 1970's the Institute should plan to have two full-time, indefinite-term economists on its staff: one to conduct studies at the farm level and one to turn his attention to macro-economics. At the same time, requirements for the equivalent of one man-year per year in milling, handling, and marketing can be foreseen for the early 1970's. During the same period the assignment of a machinery evaluation economist to agricultural engineering is foreseen.

The training program

The training of young research scientists began the first year and will undoubtedly continue for as long as the Institute exists. The need will slowly diminish, but probably at about the same rate as does the need for the Institute itself. The general system has been described in the Institute's annual reports and need not be repeated here, except to state that it provides experience in research for young agricultural college graduates who come to the Institute to work under the tutelage of senior scientists in their fields. Those who qualify may undertake graduate study toward a Master of Science degree at the College of Agriculture of the University of the Philippines. A few post-master and post-doctoral

fellows are admitted each year. The training period is usually 1 year for non-degree research scholars and 2 years for those pursuing graduate study.

The primary objective of the rice production training course, which is designed to train extension workers and other "change agents" working with rice, is to acquaint the students with the nature of the rice plant and its practical but efficient management. A graduate of this 6-month course is prepared to grow a crop of rice himself, to guide farmers in doing so, and even to organize a similar course in his own country.

At present 35 persons from 9 to 12 countries are admitted annually for the 6-month course which starts in early June. It has been highly successful in providing rice-growing countries with a few people who are fully trained in modern rice production techniques.

The future of this activity is difficult to predict fully. It depends in part on how well the recipient countries make use of the graduates, particularly as teachers of others. So far the Philippines, Pakistan, Indonesia, Ceylon, Laos, and Vietnam, in particular, have taken good advantage of the people trained at the Institute. India has just now started its first course handled by IRRI-trained instructors. The rice production specialist who originated this training course at IRRI will be spending the next 2 years in Ceylon, and presumably this training activity will be strengthened considerably in that country. For the next decade or more the Institute will need to keep in close touch with rice production training activities and related applied research projects carried out on farmers' fields in the countries of South and Southeast Asia. Often a newly started course needs an Institute staff member on hand for the first session. In general, we must visit our alumni as frequently as is practical to help see that they get local support and that their past training is effectively utilized.

The role of the Institute

An attempt has been made to analyze the probable activities of each department as seen by the individual scientists and by the administrative officers. This should be regarded as an approxima-

tion, for new lines of attack and even new problems may arise in the future.

About the only areas of research not now being worked on at the Institute and suggested as worthwhile activities by various persons are 1) the whole field of drying, milling, storage, pricing, and marketing of rice; 2) rodent and bird control; 3) problems of governmental policy planning and education and the consequences of improved technology and productivity on rural and urban society; and 4) the use of such by-products of the rice industry as hulls, straw, and broken grains.

The Institute earnestly seeks the advice of the consultants who have been invited to assemble at Los Baños on September 30, 1969, as to the degree to which such activities should be added to the present program.

Justifiably or not, the Institute has taken some pride in achieving what it did in a short time with a small staff. Its senior scientific staff located at Los Baños has never exceeded 18, yet a conservative estimate of the return, in 1968 alone, to the rice farmers of the world is 400 million U.S. dollars from a total investment of about 20 million dollars.

It is our belief that this high return came about by gearing the research program toward the solution of the major production problems of the rice industry, by providing career opportunities to capable men, by allowing them full freedom to exercise their imagination, and by giving them the financial support to carry out their ideas. To discourage the scientists from developing their private cells of activity, we make every effort to maintain an esprit de corps based on the team approach and the "IRRI way." We try day in and day out, to create among all staff—scientists, technicians, clerical personnel, laborers, all—a sense of pride in belonging, a feeling that something significant is taking place and that each individual is playing an important role in achieving the end result.

It is our aim to maintain a center of excellence to which rice scientists throughout the developing countries can turn for ideas, stimulation, and new knowledge.

As the program goes ahead during the next decade, we are confident that new advances more exciting than those of the past

7 years will be made, largely because the varieties and the practices will be freed from defect after defect. We shall do our utmost to see that the investment made in the Institute by grant-giving agencies will be considered as "good" when measured by the prosperity of the rice farmer and the economic progress of the rice-producing countries of the world.

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