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Contents

1 IRRI — The first decade
Robert F. Chandler, Jr.

19 IRRI's role in institutional cooperation in Asia
A. Colin McClung

41 IRRI's current research program
D.S. Athwal

65 International agricultural research institutes: their unique capabilities
Sterling Wortman

77 Rice improvement through international cooperation
D.L. Umali

89 Modern rice research in India and its impact
B.P. Pal

105 The new rice technology and patterns of rural life in the Philippines
Gelia T. Castillo

115 The economic consequences of the green revolution in Asia
Randolph Barker

127 Outlook for world rice production and trade
J. Norman Efferson

143 Maximizing food production through multiple cropping systems centered on rice
Richard Bradfield

IRRI-the first decade

Robert F. Chandler Jr.

That the 10th anniversary of the International Rice Research Institute happens to coincide with my own 65th year is rather fortunate for me, for had I been but 1 year older and thus already retired from the institute, I should have missed the memorable honor of addressing this distinguished gathering. On the other hand, had I been younger and so perhaps expected to continue as director for a further period, the account of IRRI's founding and first decade of operations that I have been asked to give today might have been less objective than I hope to make it. After all, the perspective of a wader after he has forded the stream, as it were, is somewhat calmer and more detached than when he is still breasting the flood (and that probably is as neat, if unintentional, a rationale for advancing years as I can hope to come up with). Such speculations, however, must not be allowed to interfere with my serious purpose of reviewing, in necessarily abbreviated form, the first 10 years of existence of the International Rice Research Institute.

No description of a new organization is complete without reference to its conception. Where did the idea for it originate? What actions were taken, and by whom, to make the thought a reality? Such questions are never easy to answer. Events, even when chronologically unimpeachable, are subject to many interpretations. Nevertheless, as witness to or participant in virtually every phase of the institute's development so far, I feel able to offer a maximum of fact and a minimum of conjecture.

It is amusing to recall, incidentally, that at least 10 persons have claimed individual authorship of the idea for an international rice research center and have expressed gratification to see their proposal finally bear fruit. Representing four nationalities from two hemispheres, the would-be originators, to my knowledge, were all equally mistaken about their role in

IRRI's formation. Perhaps, however, the institute should consider such claims a compliment, for as has been said, "Victory has many parents, but defeat is usually an orphan."

Although naturally it is possible that a number of individuals or organizations foresaw the value of a world center for rice research, the record clearly shows that the specific concept of an international rice research institute was first developed during the Asian visits — in the early 1950's — of Dr. Warren Weaver and Dr. J. George Harrar, then respectively director and deputy director of the Division of Natural Sciences and Agriculture of The Rockefeller Foundation. Their subsequent report, in 1954, to the foundation's board of trustees outlined the need for a research center devoted exclusively to the study of rice, a major world food crop. They pointed out, however, that their exploration of possible financial support for such an institute from the governments of the rice-growing countries of Asia had been disappointing. None of the top officials approached seemed to be against the idea, yet each took the stand that his country could provide funds only if the institute were located there. This reaction eliminated any hope of creating a rice center financed by multi-national contributions.

Considering the amount of money needed to build and staff an international research organization large enough to have a major impact on rice production in Asia, the world's principal consumer of that grain, the officers and trustees of The Rockefeller Foundation decided that it would be unwise for the foundation to attempt such a project single-handedly. Instead they chose the more realistic and timely policy of providing funds to strengthen already promising rice research programs in Asia. Dr. Weaver and Dr. Harrar, who had become acquainted with many rice scientists and their institutions while in Asia in 1952 and 1953, felt that before they committed funds to implement the new plan a more thorough study should be made to identify the places and the projects where the foundation's support could most profitably be used. To that end they were fortunately able to obtain — for a period of 18 months, beginning in January 1955 — the services of Dr. Richard Bradfield, the eminent agronomist from Cornell University.

Dr. Bradfield (whom I had the privilege of accompanying during the first 8 months) visited the principal colleges of agriculture and agricultural experiment stations in most of the Asian countries that then permitted Americans to travel about unrestrictedly. That was the start of The Rockefeller Foundation's action program in agriculture in Asia.

As a result of our recommendations, many grants were made for scientific equipment, for books and fellowships, and for several specific

research projects. As one of the ablest and most promising institutions in Asia, our good neighbor here in Los Baños, the College of Agriculture of the University of the Philippines, naturally received major attention.

At the close of the survey in mid-1956, Dr. Bradfield submitted a report on agricultural research and education in Asia to the foundation which included recommendations for activities that The Rockefeller Foundation might most usefully support. Dr. Bradfield then returned to Cornell University, while I, working out of the New York office, continued to handle The Rockefeller Foundation's agricultural interests in Asia.

Although from 1955 onward the foundation made many agricultural grants in Asia, I do not recall that the subject of an international rice research center was significant in our discussions until August 18, 1958. On that day, Dr. Harrar (then director for the agricultural sciences of The Rockefeller Foundation) and I were invited to join a group of Ford Foundation officers at a luncheon meeting, at their dining room, to discuss possible cooperation between the Ford Foundation and The Rockefeller Foundation in a project to strengthen the College of Agriculture at Lyallpur, West Pakistan. Those present from the Ford Foundation were Dr. Forrest F. Hill, vice president; Dr. George F. Gant, program director for South and Southeast Asia; Mr. Alfred C. Wolf, program director for Latin America; and Mr. Walter Rudlin, program associate. I distinctly recall that toward the end of the luncheon Dr. Hill turned to Dr. Harrar and, in effect, said, "You know George, someone should undertake to work with rice the way you Rockefeller Foundation people have with corn and wheat." George Harrar replied that we (The Rockefeller Foundation) had been concerned with that problem for some time. Frosty Hill's final remark was something like "We have some money. You have experience in agricultural research in the developing countries. We both are interested in doing what we can to help solve the world's food problem. Why don't we get together and see what we can do? "

That exchange, in my opinion, was the beginning of the idea of cooperation between the Ford Foundation and The Rockefeller Foundation which in turn eventually resulted in their joint establishment of the International Rice Research Institute in the Philippines. In the 2 months immediately following the luncheon meeting, several conferences were held. The discussions, although principally between Harrar and Hill, at times involved other officers as well. These included President Henry Heald and Dr. Gant from the Ford Foundation, and President Dean Rusk and Dr. Albert H. Moseman, deputy director for the Agricultural Sciences from The Rockefeller Foundation.

The next I personally heard of the idea, after the Ford Foundation luncheon conference, was a few months later, during a visit to Japan that my wife and I were making as part of an extended tour of Asian agricultural institutions. Dr. Harrar wrote that the idea of an international rice research institute had been thoroughly discussed among officers of the Ford Foundation and The Rockefeller Foundation and that serious mutual interest in a joint project existed. He stated that the first choice for the location of the proposed institute was the Philippines. And he asked that when we went there the following month that I determine the interest of appropriate officials in having such a center established in their country and, more specifically, at Los Baños, adjacent to the College of Agriculture of the University of the Philippines.

Our visit to the Philippines took place from November 18 to December 6, 1958. During that time I conferred with, among others, the secretary of agriculture and natural resources, the Hon. Juan de G. Rodriguez; the president of the University of the Philippines, Dr. V.G. Sinco; the dean of the College of Agriculture of the University of the Philippines, Dr. L.B. Uichanco; and the head of the rice and corn research program at the College, Dr. D.L. Umali. There was nothing but enthusiasm on the part of Philippine officials for the establishment of an international rice research center in their country. Dean Uichanco announced that the College of Agriculture could spare 40 hectares of land and that an additional 40 hectares could be purchased from neighboring landowners. I reported these optimistic findings to Dr. Harrar before continuing on our travels.

In January 1959, Dr. Richard Bradfield, while on a 2-month trip through Asia for The Rockefeller Foundation, stopped in the Philippines and further explored the matter of the institute. He reported that interest in the project remained high and that he and Dean Uichanco felt that the institute buildings should be located on a knoll called Higamot Hill, which adjoined the experimental rice fields of the college.

In June 1959, after several months of additional correspondence between the Philippines and the foundations, Dr. Harrar, Dr. Hill, and I spent 5 days in the Philippines conferring with key government and university officials. We met with President Carlos P. Garcia, Secretary Rodriguez, and Undersecretary (of the department of Agriculture and Natural Resources) Amado M. Dalisay. We talked with President V.G. Sinco of the University of the Philippines, and in addition, at the College of Agriculture in Los Baños, with Dean Uichanco, Assistant Dean F.O. Santos, and Dr. Umali. During the course of our discussions we presented the outline of a suggested form of organization for the institute, and explored how, under Philippine law,

it could function as a non-profit, philanthropic organization with specific reference to such concerns as tax exemption and the immigration status of its staff. We also discussed the composition of the Board of Trustees and the acquisition of land for buildings and experimental fields. At this time it was agreed that if at some future date it should be mutually decided to terminate the institute as an autonomous enterprise, all its buildings, equipment, and other assets would become the property of the College of Agriculture of the University of the Philippines.

Between June and September 1959, agreement between the two foundations was reached that the Ford Foundation would provide the funds for the physical plant and The Rockefeller Foundation would furnish the money for operating costs. I was asked to move to the Philippines in September to get the project started. The Ford Foundation advanced $250,000 for such initial costs as land purchase and architectural fees. The Rockefeller Foundation provided $165,000 for 1960 operational expenses. My wife and I arrived in Manila on September 27, 1959.

By the time we arrived, the College of Agriculture, largely through the efforts of Dr. D.L. Umali, had made arrangements to purchase 40 hectares of land for the needed experimental fields. The college likewise provided land for buildings, both professional and residential, and 20 hectares for additional experimental fields. Later, another 20 hectares were bought for experimental work. All land was purchased in the name of the University of the Philippines. This land, plus that already owned by the University, was leased to IRRI for 25 years, at 1 peso a year, with an option for renewal for another 25 years at the same token fee.

On December 1, 1959, Mr. José D. Drilon, Jr. joined the staff as administrative assistant. Mr. Drilon was later to become the first executive officer of the institute. His ability to handle people diplomatically and to take quick and decisive action, and his flair for good organization, contributed greatly to the speedy construction and staffing of the institute. Furthermore, his vigorous and skillful approach to the Philippine Congress and to various top governmental officials was indispensable in obtaining the various actions needed for the efficient operation of the institute.

During our early months in the Philippines, primary attention was devoted to selecting architects for the design of the physical plant and the staff housing. Although many were interviewed, not more than eight were seriously considered, and finally, in December 1959, the firm of A.J. Luz and Associates was asked to prepare cost estimates and to draw perspectives and floor plans for the research center buildings. At the same time, the

firm of C.D. Arguelles and Associates was engaged for similar operations for 15 residences and a guest house. These preliminary plans and estimates were sent to officers of the Ford Foundation and The Rockefeller Foundation on January 27, 1960. In March 1960, the Board of Trustees of the Ford Foundation approved a grant of $6,900,000 for constructing and equipping the buildings. This grant, added to the $250,000 already allocated, brought to $7,150,000 the contribution of the Ford Foundation toward the construction of the original and principal buildings. Such quick action in response to the proposals of those of us in the field was a highly important factor in the success of the building program.

On February 11, 1960, Dr. Sterling Wortman arrived to assist in developing the institute. He remained for 4 years, serving first as assistant director and later as associate director. His creative thinking, propensity for vigorous action, and warm personality were invaluable assets in designing the physical plant, in selecting capable staff members, and in developing the early research and training programs.

The International Rice Research Institute was formally organized on April 13 and 14, 1960, when its board of trustees met for the first time. It had been decided earlier that there would be six ex-officio members, three of them from the host country, the Philippines. These would be the secretary of agriculture and natural resources, the president of the University of the Philippines, and the chairman of the National Science Development Board. The other three members would be a representative from the Ford Foundation, one from The Rockefeller Foundation, and the director of IRRI. In addition there initially would be four members from among the major rice-growing countries.

The charter members of the board of trustees who met to organize the institute formally in April 1960 were J. George Harrar, vice president, The Rockefeller Foundation; M.C. Chakrabandhu, director-general of the Rice Department, Thailand; K.R. Damle, secretary of agriculture, India; Paulino J. Garcia, M.D., chairman of the National Science Development Board, Philippines; Forrest F. Hill, vice president, Ford Foundation; Hitoshi Kihara, director, National Institute of Genetics, Japan; Paul C. Ma, dean, college of agriculture, National Taiwan University, Republic of China; Juan de G. Rodriguez, secretary of agriculture and natural resources, Philippines; and Vicente G. Sinco, president, University of the Philippines. This group assembled at the institute's initial office in the Trinity Building, San Luis (now Kalaw) Street, in Manila. Significant actions taken at that meeting included the election of J.G. Harrar as the first chairman; the selection of the director and assistant director of the

institute; the formal approval of the by-laws; the acceptance of the two architectural firms mentioned earlier and of their preliminary sketches; the approval of the sites for both research center buildings and residences; and the acceptance of the services of Mr. Robert Letort of The Rockefeller Foundation as the institute's first treasurer.

From April through June 1960 the institute's small staff worked closely with the architects in developing plans for the buildings. During the first week of June, architect Luz and I took the plans to New York and presented them to officials of the two foundations and to Mr. Ralph K. Walker, who had been retained as an architectural consultant. The plans were accepted with only minor revisions, and immediately both architectural firms started preparing final working drawings and specifications so that the construction contracts could be let. Site preparation and road building work began in late June 1960. The service building was started in October and finished in March 1961. Contracts for the remainder of the buildings were let in January 1961, and construction was finished a year later (except for the earlier completion of some of the residences).

Mr. Loyd Johnson, agricultural engineer, arrived in September 1960. By the time the construction was finished in January 1962, the 80-hectare experimental farm was complete with roads and irrigation system. On February 7, 1962 when the institute was formally dedicated, the majority of its staff members had been hired, all buildings had been finished, and the research program was under way.

The brief dedication ceremonies were honored by the participation of President and Mrs. Diosdado Macapagal, Mr. and Mrs. John D. Rockefeller 3rd, and, of course, all members of the board of trustees, and many members of the diplomatic corps in Manila.

In just 2 years and 4 months from the date of our arrival in the Philippines at the end of September 1959, the institute had been planned, built, and staffed. This timing never could have been achieved without the inspiring confidence and total support of the principal donors, the Ford Foundation and The Rockefeller Foundation, nor without the fullest cooperation of many officials of the government of the Republic of the Philippines and of our neighbor, the College of Agriculture of the University of the Philippines.

Before citing the high points of the institute's achievements, I would like to mention certain general policies implemented by the

institute which I believe had a most significant impact on the success of the program. Realizing the possibility of some duplication on that subject between my remarks and those of Dr. Sterling Wortman in his paper, I shall limit my comments on a topic that invites enlargement.

Certainly, one of the most important factors that enabled the institute to move fast in its early life was the freedom accorded it by the major donors and by the board of trustees. Institute officers were allowed to use their best judgment in selecting staff members, in allocating funds to the various activities, and in determining program emphasis. At the same time, the Ford Foundation and The Rockefeller Foundation were from the onset always willing to give us the benefit of their experience and ready with the necessary financial support. The recognition of our debt to the two foundations, and to later donors, is implicit throughout this paper.

The early decision to develop a problem-oriented research program was a wise one. It influenced the choice of staff members and, of course, established the nature of the research and training program. As I look back on it now, I believe we developed an appropriate balance between the theoretical and the practical. Each research project of the institute originated because of a problem that existed for the Asian rice farmer, yet we did not hesitate to explore concurrently, through more fundamental studies, the causal factors involved.

Obviously the institute would have had little impact on rice production had it not decided to make a team approach to the solution of rice-growing problems. Our original description of the institute was "a complete plant science research institute devoted exclusively to rice." For example, we knew that the plant breeder without the entomologist and plant pathologist would be incomplete. Likewise, the agronomist needed the agricultural economist to determine the economic viability of his findings; and so on for the other interlocking disciplines.

Another well-chosen policy was to have an international senior staff. The scientists selected in 1961 and 1962 came from seven countries. Our belief that no nation or race has a monopoly on intelligence or competence has long since been substantiated.

To make maximum use of carefully selected scientific talent from many countries, it was deemed essential to provide them with an environment where they could fully use their training, imagination, and ingenuity. On arrival each scientist was asked what books he would wish to have in the library, to what journals he would like us to subscribe, and what scientific equipment he needed in his laboratory. To my knowledge, we complied with essentially

all such requests, and in so doing I feel certain that we contributed immeasurably to the success of the research program.

We are often asked how we maintain an integrated program directed toward specific goals without giving the individual scientist a feeling that his powers of imagination and creativity are being stifled. We consider that a challenging and stimulating atmosphere is maintained at the institute through a continual dialogue among scientists and administrators alike emphasizing the exciting potential that exists for increasing the yield and quality of rice in the tropics. Discussions at the two weekly seminars, in the laboratories, in the corridors, and in the experimental fields center on this theme. Furthermore, at an early stage the results of the research programs demonstrated that although major advances were possible, the problems engendered by a complex biological system are ever-changing and their solutions challenge all the ingenuity that the scientist can muster.

Another important factor influencing the impact of the institute was the decision to have a truly international organization, not only with respect to the origin of its staff, but to its program concepts and scope. From the beginning the administrators and the senior scientists have travelled to every important rice-growing country in Asia, and — to a considerable extent — in the world. There they have become acquainted with other scientists, have developed cooperative research projects, have selected research scholars to come to the institute, and, above all, have seen at first-hand the conditions and problems of the rice-growing regions. Without their observations the influence of the institute would have been severely restricted.

The *esprit de corps* of an organization is an important ingredient of its success. I believe that the International Rice Research Institute has achieved more than ordinary progress in this direction. I sense elements of pride, dedication, and enthusiasm among our entire staff. We have tried from the beginning to set high standards for every institute activity. Whether it be writing a letter, driving a car, cleaning a building, or conducting scientific research, in an environment where the best is needed and expected of everyone each employee can feel that he is playing a significant role no matter what his assignment.

Before proceeding to my real topic, I must emphasize that although I have continually mentioned the success of the institute, I am referring to the assessment of its overall program. On a smaller scale, errors of omission and of commission have been made and probably will continue to be made, however infrequently; and we have come to recognize our inability to solve

complex biological problems quickly. Nevertheless we are aware of the world-wide publicity that we have received, and the responsibility of living up to our reputation gives us a sense of humility and of constantly renewed drive.

Time prevents my giving due credit to the many successful research and training projects of the institute, a subject, however, which has been covered in considerable detail in the papers of Dr. D.S. Athwal and Dr. A.C. McClung. I shall mention, then, only some of the highlights, regretful that many achievements will have to remain unmentioned.

All of our staff, I am sure, would agree that the single most important accomplishment of the International Rice Research Institute is the development and distribution on a massive scale of a new plant type for the tropics. It is well known that the traditional, tropical rice plant was tall, with long, drooping leaves. It did not respond to heavy application of fertilizer. Its good qualities were largely those of being able to produce moderate grain yields under adverse conditions and, in varying degrees, to resist insect and disease attacks.

The basis for IRRI's advances in changing the architecture of the tropical rice plant originated in Taiwan, where, as early as 1949, plant breeders at the Taichung District Agricultural Improvement Station had crossed a semi-dwarf indica variety, Dee-geo-woo-gen, with another indica variety, called Tsai-Yuan-Chung, which was tall, but drought resistant. A selection from this cross was named Taichung Native 1 in 1956. This was the first semi-dwarf indica variety developed for the tropics through plant breeding.

Without question the fast progress that the institute made in developing a series of short statured, fertilizer-responsive varieties would not have been possible without the availability of the dwarfing gene from Dee-geo-woo-gen, which was simply inherited and could readily be introduced into the varied and extensive germ plasm of the tall tropical varieties of South and Southeast Asia.

Although the creation of Taichung Native 1 in Taiwan was a signal advance, it required an organization such as the International Rice Research Institute to implement a massive crossing program resulting in an extensive series of semi-dwarf genetic lines that could be distributed to rice breeding units throughout tropical and sub-tropical Asia and to many other parts of the world as well.

IRRI rice breeders made 37 crosses in 1962, 11 of which involved either Dee-geo-woo-gen or I-geo-tse (another semi-dwarf variety from Taiwan, very similar to Dee-geo-woo-gen). Our scientists soon discovered that the dwarfness in these Taiwanese varieties was controlled by a single recessive gene. Thus, in accordance with Mendelian laws of heredity, in the second generation of a cross between a tall and short variety one-fourth of the plants were short and three-fourths were tall. IRRI scientists discarded the tall ones and made careful selections from thousands of the short ones.

Not only did the rice breeders and geneticists accomplish that ambitious program, and identify the genetic factors involved as well, but their colleagues in other disciplines were able to gain new insight into the physiological reasons for the great increase in yield potential and to develop appropriate cultural practices and pest-control methods for the modern rice plant.

I need not repeat here the details of IRRI's early efforts in developing short, stiff-strawed, early maturing, fertilizer-responsive varieties, for it has been chronicled many times. It is enough to say that by 1965, only 3 years from the time of the first cross, the institute had developed a series of genetic lines of varying background that were distributed to the principal cooperating rice breeders of South and Southeast Asia.

As these lines were tested and as the team of IRRI scientists studied them in more detail, it became clear that a new breed of rice was now available to the tropical rice farmer that had double the yield potential of the traditional rice plant which had been grown for centuries.

The successful members of this collection had a number of morphological features in common. They were about 100 centimeters tall (60 to 80 centimeters shorter than their tall parents) their leaves were short and upright, they had a heavy tillering capacity, the grain-to-straw ratio was about 1.0 (as compared with 0.6 to 0.7 in the tall parents), and they were at most only mildly sensitive to length of day and thus could be planted at any time of the year in the tropics.

The first variety named by IRRI was IR8, in November 1966. This was followed by IR5 in 1967, by IR20 and IR22 in 1969, and by IR24 in 1971.

The new breed of rice was highly efficient in converting solar energy and plant nutrients into grain. Its short, stiff straw prevented it from lodging (falling over); its short, upright leaves allowed the penetration of sunlight; and its heavy tillering capacity aided in producing more panicles

per unit area of land, thus allowing a stand of rice to compensate for missing hills, or in direct-seeded rice, for any thinly seeded areas.

Although many further advances in the science of rice production will be made, probably no other discovery will have such an impact on yield potential as has the redesigning of the rice plant from a tall, droopy leaved, lodging-susceptible one, to a short, upright-leaved one.

The availability of this new plant type in varying forms to tropical rice farmers around the world and the fact that rice breeders in many countries have changed their breeding objectives to develop for their own countries suitable versions of the modern rice plant, are direct results of the institute's far-flung and intensive program and constitute IRRI's most important achievement.

In addition to the significant accomplishment of redesigning the rice plant for the tropics and of distributing the new genetic materials in a massive way, there have been many other contributions by our professional staff. It is impossible to place a relative value on each of them. Nor, in a paper of this sort, is it practicable to include all the achievements. Therefore, I have chosen to make succinct statements about certain of the more important components of the science of the rice plant and its culture which were not known, or at least not well understood, in 1962, but which have been clarified by our scientists during the past decade.

1. There is a strong positive correlation between grain yield and the amount of solar energy received by the rice plant during the last 45 days before harvest. On our experimental fields, from 2 to 3 more tons per hectare of grain are always obtained in the sunny, dry season, than in the cloudy, monsoon season. Such information is highly useful in predicting the economic returns from irrigation systems.

2. Rice varieties vary by 100 percent in the photosynthetic rate of individual exposed leaves. This opens a new vista for further increasing the potential of rice through plant breeding.

3. Zinc deficiency occurs more commonly than previously suspected. Our scientists have shown that a simple and inexpensive cure is to dip the seedlings in a zinc oxide solution before transplanting.

4. Today, through the efforts of our plant physiologists, we have a good understanding of the reasons why the modern rice varieties yield so much more than the traditional ones. Their thorough studies of leaf area index, of mutual shading, of photosynthetic efficiency, of tillering capacity, of crop growth rate, and of other factors affecting plant performance, have given us new insights into yield potentialities.

5. It is now possible to obtain grain yields of over 10 t/ha under ideal conditions in the tropics, and of over 5 t/ha under the less favorable

conditions of the cloudy, monsoon season. A decade ago these figures would have been one-half of what they are today.

6. Weeds can be controlled in flooded rice paddies with one application of herbicides in granular form at a cost of less than half that of hand weeding. Certain of the compounds can be used on either direct-seeded or transplanted rice. Ten years ago, granular herbicides were not used on rice, and any chemicals available for spraying direct-seeded rice were either too expensive or required such precision in mixing and applying that they were impractical for the Asian small farmer.

7. Field trials have firmly established that modern rice varieties will produce from 12 to 30 kilograms of rice for every kilogram of nitrogen applied. In the Philippines a farmer can purchase a kilogram of nitrogen with 3.3 kilograms of rice. Before the advent of the new varieties in the tropics, fertilizer was indeed a precarious investment for the farmer.

8. During the past decade the soil chemistry department has produced, through careful scientific work, the most complete set of information on the chemical kinetics and thermodynamics of submerged soils that exists in the world. The results are too many and detailed to set forth here, but it is a remarkable achievement. The work has attracted the attention of soil scientists around the world and the results have given us an understanding of paddy soils that would not have been possible otherwise.

9. Of importance in the use of insecticides on rice are the studies of pesticide residues in the soil. A number of important insecticides, such as lindane, diazinon, and DDT, degraded much faster (left smaller amounts of residue) in flooded soils than in upland soils. That means that certain insecticides can be used safely on flooded rice without danger of polluting the soil with harmful chemicals.

10. From studies conducted by the plant pathology department, we now know that there are a few rice varieties that are resistant to most physiologic races of the rice blast disease, which is considered to be the most destructive and ubiquitous of all rice diseases. Without the screening of IRRI's vast world collection of rice varieties (now numbering over 14,000) and the conducting of over 200 trials of hundreds of rice varieties in 25 countries, it would not have been possible to identify these unique specimens which are now serving as valuable parents in our rice breeding program.

11. Today, in contrast to 10 years ago, we know much about the nature, the vectors, and the control of the tungro and grassy stunt virus diseases of rice. Our pathologists, for instance, have proved that the serious disease known as *penyakit merah* in Malaysia and the *mentek* disease in Indonesia are the same as the tungro disease. Before our studies, the cause and specific

nature of these diseases were unknown. That a great deal remains to be done in tungro control is evident from the recent epidemic of that disease in the Philippines. Incidentally this outbreak would have been even more widespread had it not been for the presence of such resistant rice varieties as IR20, developed by the institute, and C4-63 of the college of agriculture.

12. The work of the institute on the bacterial blight disease has been outstanding. Cooperatively, the departments of plant pathology and varietal improvement have screened thousands of varieties and have identified some that are resistant. These have been, and are still being, used as parents to introduce the resistance factor into the modern varieties.

13. The chemistry department has accumulated the most complete information that exists in the world today on the chemistry of the rice grain. As in the case of the soil chemistry department, the data are too numerous to quote, but we take pride in knowing that the institute is considered a world leader in this field.

14. The agricultural engineers have developed machines to ease the labor and increase the efficiency of the small farmer. Threshers, weeders, seed cleaners, seeders, a low-lift water pump, and a small power tiller are among their inventions that can be manufactured locally in many developing countries.

15. The agricultural economists have provided solid information on the effect of high-yielding varieties on farm costs and incomes, especially in the Philippines. Of particular interest is their conclusion that the use of the new technology has slightly intensified the labor requirements rather than reduced them.

16. We now know that there are rice varieties that are highly resistant to leafhoppers and planthoppers, and at least moderately resistant to rice stem borers. This knowledge came about from the exhaustive screening of over 8,000 rice varieties by the entomologists. The plant breeders and entomologists are cooperatively working toward the development of high yielding varieties containing resistance to most of the major insect pests of rice. Had it not been for the institute's massive attack on this problem, no such goal would have been in sight today.

17. The varietal improvement department has made over 2,100 crosses since 1962, and is now at a point where some remarkable varieties are about to be produced — varieties that possess a broad spectrum of resistance to all major insects and diseases, excellent grain appearance, varying growth durations from 100 to 140 days, wide adaptability, and of course high yielding capacity. This work again is too complex to describe here, but there is no rice breeding program in the world that is so comprehensive. Surely the next few years promise to be rewarding ones.

Meanwhile, the institute can be justly proud of the fact that the five varieties already named at IRRI, plus those varieties developed in other countries from crosses between their local varieties and genetic lines sent to them by the institute, are being grown on more than 10 million hectares of land and have increased average yields on farmers' fields by about 1 t/ha. IR20 has proved to be widely adapted because of its resistance to insect and disease attack and its tolerance to adverse soil conditions.

In addition to this item-by-item account of the institute's research achievements, a few other major activities deserve mention. The training program can be called a definite success. About 650 people have received training at the institute for periods ranging from 2 weeks to 2 years, most of them staying for at least 1 year. This amounted to 575 man-years of training by the end of 1971, of which 445 man-years were devoted to to training in the various research departments, and the rest were in more practical areas, such as rice production and multiple cropping. The work in multiple cropping deserves high praise for showing the potential of the humid tropics for year-round production of a series of crops including rice. The spread of such cropping systems would add important proteins, minerals, and vitamins to the cereal-based diets of the population in many developing countries. The international programs in India, Pakistan, Bangladesh; Ceylon, Indonesia, and South Vietnam, described in detail in Dr. McClung's paper, are doing much to strengthen national programs in those countries. The institute has an excellent library which we believe contains the world's most complete collection of technical information on rice. It publishes and makes available to rice scientists everywhere an annual bibliography of the rice literature. We consider that our publications are both appropriate and of high quality. The IRRI annual report contains a complete analysis of all research conducted at the institute and provides a source of information to many an isolated rice scientist in Asia who does not have access to a good library.

A sense of great inadequacy must necessarily accompany any effort to give proper credit in a brief paper to a decade of devoted effort by our professional staff. Much must be left unsaid. I feel that there has been an important impact of the institute which is not reflected by the work of any one man or any one department or in any one scientific advance. It is the pervasiveness of the new technology developed at IRRI. It has brought

hope and optimism to the rice-growing peoples of the world, a world previously convinced that not much could be done to improve their lot. Rice research workers and extension people in many countries have completely revised their attitudes toward the future; new goals of yield and production have been revealed to them. Many now see that the tropics offers the planet's greatest untapped resource for feeding mankind. Furthermore this resource will have to be used to its limit before man has succeeded in controlling his numbers and averting disaster for his species.

At any scientific meeting that involves rice there is an IRRI scientist to present a paper of high quality. This applies everywhere, not only throughout Asia, but in Europe, the Americas, and Australia as well. IRRI has no Albert Einsteins, but it has assembled a group of top-rank scientists outstanding in their particular fields. It has been our general policy to hire fairly young scientists, who in their eagerness to establish their reputations in their own professional fields have established and furthered the reputation of the institute. This is not to slight the significant contributions of the several more senior scientists who have not only maintained their earlier eminence but have even surpassed it, to the renown of the institute.

We believe that although we have not been bashful in portraying our achievements to the public our announcements have always been information releases, never publicity handouts. On the whole, the local and world press has dealt kindly with us and has helped establish IRRI's prestige. I am sure that the press realizes that nothing in the institute's effort is for show. On the contrary IRRI's program has been and remains an objective, problem-oriented one.

It seems to me that a significant, albeit involuntary, achievement of the institute has been to demonstrate that a group of scientists of eight nationalities can work and live together harmoniously and pursue successfully a common goal of high purpose.

Personally, I deem it a great privilege to have been associated with such a team for the past decade. I consider that science in its pursuit of knowledge and truth is a high calling. For a scientist to apply his intelligence and creativity toward the solution of practical problems — as has been done here, in improving the yield and quality of rice for the benefit of the rice-growing and rice-consuming peoples of the world — is one of the finest ways he can serve mankind. Indeed, science in the service of the people offers a never-ending challenge and inspiration.

Thus, as we complete the first 10 years of the life of the International Rice Research Institute and reflect on the achievements of that period, we

must realize that much remains to be done, that future support for the institute rests on its continued accomplishments, and that, very importantly, its performance should be concentrated in the area of solving the problems faced by the small rice farmer, the man who constitutes the bulk of Asia's rural population and on whose improvement — economically, educationally, and socially — rests the future of much of humanity and the peace of the world.

IRRI's role in institutional cooperation in Asia

A.Colin McClung

The International Rice Research Institute has been widely acclaimed for its contribution to knowledge of the rice plant and for the influence that its research has had upon rice production in tropical Asia. Observers of tropical rice production in the past decade have been almost invariably generous in their evaluation of IRRI's role. This institute, an agency charged with determining and effecting change, came into being just as an enormously increased public interest in obtaining such change was developing. The opportunity was there and IRRI rose to the occasion.

What has not been fully recognized and, in fact, has often been almost ignored, is the role of international cooperation in making the IRRI program possible and in carrying IRRI's results to experiment stations, planning offices, extension agents, and ultimately to farmers' fields around the world. My objective in this paper is to call attention to these facts, to express IRRI's appreciation for the help it has received, and to submit that one of the most important jobs for IRRI in the next decade is to foster further international cooperation. As important as the direct research results of IRRI are, they are rapidly being overtaken by the results being achieved by national agencies working on their own problems, but doing so with full awareness of results being obtained elsewhere.

At the time IRRI was founded, certain international activities were already under way with rice in Asia. FAO had sponsored short courses for rice specialists at the Central Rice Research Institute in Cuttack, India. The

International Rice Commission (IRC) existed and IRRI scientists were welcomed to its discussion tables along with representatives of rice-producing nations. They were invited to present their research results in the IRC Newsletter. Dr. N. Parthasarathy, a former director of India's Central Rice Research Institute, was the FAO regional rice specialist in those days, and he provided a strong helping hand in establishing IRRI as an international agency. From the beginning, IRRI scientists were accepted and had full opportunity to make their contributions.

Early IRC conferences led to the development of a japonica-indica hybridization program to combine some of the yield-contributing features of the japonica varieties with the preferred grain type, disease and insect tolerance, vigor, and other desirable characters of indica varieties. The program, which started about 1950 was a true international effort. Scientists from several countries cooperated in indentifying parental lines. The crosses were made and the first generation plots were grown at the Central Rice Research Institute in India. Seed from these crosses went to cooperating countries so that locally adapted varieties could be slected. Two varieties from this program were named in Malaysia, and one in India.

An early international endeavor of the International Rice Research Institute was the start of a collection of seeds of Asian rice varieties. Asian rice scientists and governmental officials responded willingly to IRRI's requests for samples of seeds of their native and improved varieties. Some of these requests were made by R. F. Chandler and Sterling Wortman in their initial visits to explain the IRRI program to national rice research officers. Others were made by T.T. Chang and P.R. Jennings directly or by correspondence (they wrote 160 letters of request in 1961 and 1962 and received samples from about half these contacts). Dr. Chang, who has looked after the world collection, tells me that when he arrived at IRRI in November 1961, some of these early accessions had already arrived. In January 1962 he and Dr. Jennings planted 266 varieties in IRRI's experimental fields. Among these were Dee-geo-woo-gen, Peta, I-geo-tse, Tankai Rotan, Siam 29, Kaohsiung 68, and BPI-76, all of which became important parental lines in the IRRI breeding program (the first two became the parents of IR8).

By the end of 1962, the IRRI collection contained 6,900 accessions, the bulk of which came from the U.S. Department of Agriculture, Japan, and the University of the Philippines College of Agriculture. During 1963, 2,500 additions were received, bringing the total to more than 9,000, basically through the collection activities of persons in other centers.

Since that time, the collection has slowly grown to about 14,000 entries. Now a major effort is under way to add as much as possible of the remaining rice germ plasm before it is lost. Perhaps another 20,000 cultivars can be added. IRRI is currently soliciting the cooperation of national groups throughout the world to collect and preserve this valuable material.

From 1963 to 1971, IRRI sent out about 30,000 seed packages from the world collection in response to 850 requests from more than 100 countries and territories. For the breeding lines and named IRRI varieties, 65,845 packages were sent from 1965 to 1971 in response to 1,570 requests. The number of requests for world collection material or breeding lines has been declining somewhat recently because of two developments. First, in several countries a national agency tends to consolidate requests. Second, more national agencies are serving the smaller stations within the country or in neighboring countries. The sister institutes of IRRI in Africa and South America also serve as sources of seed for national programs. On the other hand, sometimes a national program which is not well situated to send out samples of its own materials may ask IRRI to respond to a request which it has received.

A second area of international activity has been the major symposia held by IRRI. During the first 2 years, four major symposia were held to deal separately with genetics, plant nutrition, the rice blast disease, and rice insects. These were followed by symposia on virus diseases and on rice breeding. The symposia brought together, frequently for the first time, leaders in important phases of rice research. They served the vital function of helping IRRI focus its own research program on critical problems. Results obtained elsewhere were taken into account and duplication of effort was avoided to a large degree. This substantial contribution to the world's rice literature and to IRRI's program was the result of hard work by the scientists who prepared the reviews. Without the willing cooperation of so many scientists, IRRI would never have been able to marshal the world's information on the crop so adequately or so rapidly.

The national agencies of the region took a highly cooperative attitude in permitting their scientists to participate in these symposia. Several of the countries were not accustomed to allowing their scientists to attend international conferences except when they made the nominations. Almost invariably they modified their procedures to permit the organizing committee for the symposium to invite key specialists.

The vast amount of basic research on rice by Japanese scientists, years before IRRI was established, was another important factor. An analysis of the world's literature shows that even now about 45 percent of all scientific

articles on rice are written in Japan. Without this backlog of information and Japan's willingness to share it, IRRI's progress would doubtless have been slower.

Another point of frequent contact with the world's rice scientists has been the IRRI library and documentation center. The IRRI library aims to have available all scientific articles published about the crop each year. Most of them are in the original, but if this is not possible then photocopies are obtained. This literature is available to rice scientists who request it. To facilitate their doing so, and to inform the scientific community, IRRI publishes an annual bibliography of rice. Anyone wishing copies of selected articles may obtain them by contacting the library. They are supplied at cost or, in some cases, gratis.

Many libraries around the world assist IRRI in maintaining this service, but I would particularly like to mention the National Institute of Agricultural Sciences (Nishigahara) of Japan. To keep abreast of the Japanese literature, the IRRI library employs a small staff with headquarters at Nishigahara. The director of Nishigahara has provided these facilities to IRRI for the last 10 years at no charge and has otherwise facilitated this work. This service has recently been expanded to include cataloging of articles on corn and sorghum.

Many of the IRRI training activities could be reported upon either as a part of the research program or as part of the international cooperative effort. On a day-to-day basis, research training is fully integrated into IRRI's continuing research effort. In the longer view, however, the purpose of training is to help national programs upgrade the technical proficiency of staff or to introduce multidisciplinary team efforts into the operations of rice research workers. Without deprecating the contribution of the research trainee to IRRI's core research, we have always looked upon the training program from the point of view of what the trainee is to do when he returns home.

The term "trainee" is used loosely at IRRI. The group in question included not only recent B.S. graduates but also young men and women with M.S. and Ph.D. degrees. The latter are actually temporary members of IRRI's research staff who work largely independently but as members of a team.

Visitors to IRRI frequently ask two questions related to training. First, "How many trainees can IRRI handle?" and second, "What is the size of the population that is expected to be influenced? That is, how many

farmers must be contacted if the training is to have a measurable impact?" The first question is easy. IRRI can handle about 80 man-years of training per year. The second is harder, but nearly any answer runs into hundreds of millions. The question, often unasked, obviously is, "How much good can this handful do?" I submit that the answer is *a great deal* if the trainees are selected carefully, trained appropriately, and kept in contact after returning home. Candidates are selected with a view to filling a specific post in a national program. Each individual has the assurance of a position when he returns and he may set about better qualifying himself for it.

The degree of follow-up is an important factor in providing a small group with leverage. The majority of returned IRRI participants can count on close contact with the IRRI staff either directly or through a cooperative program in his home country. Often he receives periodic visits from IRRI staff and he may return for conferences from time to time.

At present the top rice breeder in Korea is a returned IRRI fellow. He spent 2 years in the Philippines about 7 years ago. The leading figure in rice breeding in Ceylon is also a returned IRRI participant; so is the leader of rice breeding in Indonesia. In India it is not possible to identify a particular individual as the leader of breeding work, but several key members of the All-India Coordinated Rice Improvement Project were participants at IRRI early in their careers. The same could be said for Pakistan and Bangladesh, for in both countries the principal figures in rice breeding have been closely involved in the IRRI programs. It might also be appropriate to mention a young Japanese scientist who spent 2 years at IRRI as a research fellow in plant physiology and then returned to Hokkaido University for his doctorate in genetics. He then came back to IRRI for 6 months' participation in practical rice breeding. He is now employed by North Carolina State University as a member of its team in Peru where he is the principal adviser on rice breeding to the Ministry of Agriculture.

These men and many others were carefully selected and their interests and talents were fostered. Their influence far surpasses their numbers. As time passes their numbers and contributions will increase — and at a rate faster than the rate at which total man-years of training will increase, for the first graduates have reached a stage in their careers where their influence is felt.

In production training there are also ways in which great leverage can be obtained from a handful of people. The aim has been to "train the trainer" and to train him in all phases of modern rice production, not merely in theory. Also, innovations have been developed for dealing with larger numbers of farmers and extension workers. For example, phased plantings of

rice permit a group of farmers or extension workers to see rice in all stages of development at any given time. A training group may start on Monday morning by planting rice according to improved methods and they may finish the course on Friday of the same week with harvesting and drying operations. Each stage in crop development is covered, not merely with words but in actual practice. This is a technique that cannot often be used in the temperate zone, but is a natural for rice in the tropics.

The rice production kits developed in the Philippines were another means of giving massive leverage to the production-oriented extension worker. These kits contained a bag of 2 to 5 kilograms of a new rice variety and small bags of fertilizer and insecticide — just enough to meet the crop's requirement at each stage of development. These kits, together with instructions on how to use them, assured farmers of having the right input in the right quantity and at the right time. The kits offered the farmer his first opportunity to try out a new technology and they proved to be a powerful tool for change. Their effectiveness has been proven in Ceylon and South Vietnam as well as in the Philippines.

A few specifics about IRRI training programs might be helpful at this point, although this is not the place to examine the program in detail. In research, IRRI cooperates with the University of the Philippines College of Agriculture to arrange M.S. programs for young B.S. graduates. The required course work is taken at the college and the thesis research is done at IRRI. Senior staff at IRRI are affiliate members of the college's graduate faculty and they participate in planning the course work as well as the research programs. This training requires about 2 years. Recently, similar arrangements have been made for selected Ph.D. candidates at the Indian Agricultural Research Institute (IARI). Selected participants may do course work at IARI, do research at IRRI, and receive the degree from IARI. On a case by case basis, similar arrangements have been made with universities in the United States, Australia, Germany, and the United Arab Republic.

Non-degree programs in research are also arranged for persons who have a B.S. or M.S. degree (The former are called "scholars," and the latter "fellows"). These programs are tailored to the individual's needs. He reads in his field and plans, conducts, and reports upon a research program which he develops under the direction of a senior IRRI staff member. In many ways the program is similar to a graduate program in the Japanese or European pattern. Usually these courses of study require 1 year and they are rarely shorter than 6 months, about the time necessary to plan experiments and grow a rice crop.

The post-doctoral program is more highly specialized and, as mentioned earlier, it might be more accurately described as a temporary staff activity.

Maximum independence is offered the post-doctoral fellow as he develops his research within the overall program. It is an activity that has grown in recent years and is expected to become increasingly important in the years ahead.

Rice production training at IRRI started in 1964. A rice specialist from the California Extension Service, W.G. Golden, was spending a sabbatical year at IRRI to observe and study Asian extension activities. Although IRRI had little to extend at the time, he was asked by Sterling Wortman, then IRRI's associate director, to consider a training program that would produce production-oriented specialists suitable for Asia. A group of five Philippine extension officers were selected for training. The result was a new sort of specialist who, almost overnight, was in great demand. The concept included actual testing of new ideas and materials in farmer's fields, not rote learning or instruction. Communication principles were emphasized and some of the techniques alluded to earlier were developed. Since 1964 this program has been expanded and modified. At present about 35 participants are accepted for a 6-month course each year. A similar program was started in 1969 for multiple cropping built around rice as the main crop (Mr. Golden stayed on after his sabbatical year and provided leadership for the rice production training program; he is now serving as IRRI's liaison officer in Ceylon and working with some of his former students in developing their national program).

Through 1971, IRRI had arranged programs for 657 participants from 40 countries. They have taken a total of 575 man-years of in-residence training or independent study. Every field of study at IRRI has been involved. About two-thirds of the participants were in research and about one-third in production, although, because of longer average programs in research, the relationship in man-years has been about three-fourths in research and one-fourth in production.

IRRI has always given high priority to training. The director has been closely involved in all phases and the associate or assistant director has had coordination of the training program as his major responsibility. Numerous seminars are held at the departmental level and a regular seminar, oriented toward the training program, has been a major feature of each week's activity at IRRI for the past 10 years.

From the beginning, an aggressive information services program contributed significantly to all aspects of IRRI's operations — research training and international cooperation. Research results of IRRI quickly

found their way into established journals or the institute's own technical reports. A comprehensive technical annual report, widely circulated, made the total scope of IRRI's research results readily available each year. A bi-monthly, semi-popular newsletter helped to focus attention on and generate interest in the major problems of concern to IRRI and the progress being made on them. Proceedings of the major symposia entered world distribution channels as professionally produced books. A rice production manual, developed cooperatively by IRRI and Philippine agencies, has been through three editions, revised substantially each time. Other materials, such as motion picture films, sets of slides, and various diagnostic field and laboratory manuals, have helped returned trainees get into action at home more quickly and effectively.

The term "outreach" was introduced to the IRRI vernacular by F.F. Hill to describe the multiplicity of activities through which the International Rice Research Institute could be of service to rice research and development activities around the world. The impression may at times have been gained that this amounted to introducing IRRI—developed varieties and related technology to other countries and fostering their adoption. As valuable as these materials and ideas have been, I shall attempt to show they were only a part of the process.

The major symposia also influenced national programs. Scientists concerned with specific problems were able to confer with world leaders in the subject and to modify their own research accordingly. This was one of the first expressions of outreach. The symposia led to many kinds of cooperation. Sometimes cooperative efforts were recommended by the assembled group. More often, small but well-focused cooperative projects were undertaken between IRRI scientists and those in other countries. Between 1963 and 1968, 35 such cooperative projects were undertaken in genetics and breeding, soil microbiology, soil chemistry, agronomy, plant physiology, entomology, cereal chemistry, and communication.

These were the first cooperative research projects of IRRI. They were extremely important in broadening the outlook and experience of the IRRI staff. They produced useful scientific data, but more important they led to long standing inter-agency ties. They were made possible by the availability to IRRI, through a grant from the Ford Foundation, of a fund for cooperative research. Modest research undertakings toward specific objectives were possible without extensive negotiations and elaborate

accords between agencies. Usually a project was discussed and prepared by the two cooperating scientists. When their work plan was approved by the directors of the respective agencies, it became operative. This flexibility in funding and operational procedures was extremely valuable in the formative stages of the international program. It is recommended for other international centers. The amount of money needed to foster such projects need not be large to be of great value.

The travel of IRRI staff members to Asian rice-producing countries was an important phase in internationalizing the IRRI program. Staff members were encouraged to familiarize themselves with the rice-growing problems of the region and to become acquainted with their colleagues in the various countries. The symposia and other conferences made it possible to schedule these visits with considerable precision, and the IRRI staff became aware quickly of the nature of rice-growing in key areas. Because of this background and broad orientation, it has proven possible for an IRRI staff member to make a worthwhile advisory visit in the region with a minimum of time spent at the site. Because of the small number of scientists in any particular field at IRRI and the need to maintain an active research program at the home base, it is rarely possible for an IRRI scientist to spend more than a week or 10 days at a time as a consultant. But when he is familiar with the area in question and when he is dealing with colleagues he already knows, this is usually enough.

At the point in time when several of the activities I have mentioned were under way or had been carried through, the stage was set for IRRI to participate more fully with the national groups in the development of their own programs. That is, with several symposia completed, the world collection assembled, a number of cooperative projects in progress, with IR8 and related technology in the offing, and so on, it was about time for IRRI to assist specific countries in accelerating their rice research and development activities. The date was about 1965, which coincided with seasons of inadequate rice production in several key countries and with a world-wide rice shortage. It was a time of impending disaster.

Starting in 1965, IRRI became involved in more comprehensive rice research and development programs in several major producing countries. Where a long-term involvement was planned, a formal agreement or understanding was established to provide a frame of reference for the project. At least three parties were involved in each such agreement, the national agency,

IRRI, and an agency willing to finance IRRI's participation in the program and to assist in various phases of the financing and implementation of the project.

The basic philosophy of these agreements was guite clear on an important point: they were in no sense intended to lead to the establishment of branch stations of the International Rice Research Institute. Rather, they were designed to foster improvements in the host countries' research and development programs. The degree and pace of IRRI's involvement would be set by the decisions of local authorities and the work would be directed solely towards problems of concern to local rice scientists and rice farmers.

While the emphasis was upon improving research capability, it was always assumed that the technical resources of the projects would be applied to the efforts of the host country to increase rice production. Likewise, while the long-term goal was to enhance the research capability of the national agencies, it was understood that full attention would be paid to the evaluation of the current output of IRRI's own research program as it pertained to the cooperating country's drive to increase rice production.

The memorandum of agreement covering several years of prospective cooperation is an excellent basis for international collaboration, but IRRI experience has shown that it is not essential. Once an operational procedure has been developed it is amazing how much can be accomplished at the scientist-to-scientist level, with little more than general concurrence being required between administrative units.

As the "country programs" are just that, and not an extension of IRRI, the procedure has been to leave the reporting on them up to the national group. Except for reports required by the funding agency, IRRI writes rather little about them. In this report, however, I would like to give a brief summary, country by country, of the work in progress.

Bangladesh. The International Rice Research Institute has been closely involved in rice research and development activities centered in Dacca since 1965. At least one IRRI senior staff member has been stationed in Dacca over these years and sometimes as many as three have been in residence. Numerous short-term advisory trips have been arranged. The goal has been to assist in the modernization of rice research and training, to test as rapidly as possible the new rice technology and to assist in training and development activities leading to increased rice production. IRRI's participation in this project has been supported by the Ford Foundation. More recently, USAID has contributed significantly towards the physical plant and training.

Rice-growing conditions in Bangladesh are difficult, particularly during the main monsoon season. In this part of the year, up to 60 percent of the rice-growing area is flooded with 75 to 600 centimeters of water. Disease and insect problems are acute during this season. The soils are generally less fertile than those of many other regions and some saline areas occur.

At the request of local authorities, IRRI examined the situation and recommended a long-term plan to build a rice research center staffed with scientists from the key production disciplines and from economics, training and communication, and so on. The rice-growing problems in Bangladesh are such that a complete center is needed. Adaptive research alone will not suffice. When the unit is adequately meeting national research needs, it will represent something of a regional center of study of several important phases of rice research.

The rate of progress towards these objectives has been good. It was necessary for the government to change regulations to permit the development of a semi-autonomous research center, but at each critical juncture the local authorities have done so. Staff is not available in several key disciplines and training abroad is a long-term major need. It seems that the Bangladesh rice research unit could make effective use of IRRI advisers and training facilities over the next 5 to 7 years on much the same basis that has prevailed over the past 7 years. Provided a major effort is made in local training, it should be possible to phase down beyond that point. It would also be expected that the annual research output of the center would be on a sharply rising curve over the same period, for much of the groundwork has been laid.

Pakistan. IRRI rice varieties have probably had their greatest impact in Pakistan. The prevailing conditions for crop production were good and the new varieties had demonstrated their worth. Within a 2-year period following the introduction of IR8, average yields in the southern zone of Pakistan were up by 60 percent.

Since late 1965, IRRI, with funds from the Ford Foundation, has had an agreement with Pakistan to assist in developing rice research and production programs. Over most of that time a resident scientist has been headquartered in Lahore to assist in local developments and to provide liaison with IRRI. A number of advisory trips have been arranged with IRRI staff and occasionally with rice scientists from other centers. Training has had an important place in IRRI's participation. Degree and non-degree programs have been arranged in the Philippines, and a few doctoral candidates have been sponsored abroad. A special workshop in field experimentation techniques with rice was held at Los Baños to upgrade the

skills of the junior professional staff at two of the main Pakistan rice stations.

Equipment and supplies for rice research have been obtained from abroad when needed, and local funds have been used to construct new key facilities. Within the last few years IRRI has been able to assist Pakistan breeders by growing their lines in the Philippines during the winter season. Thus the Pakistan group is able to produce an additional generation each year.

Rice-growing conditions in Pakistan allow a relatively large amount of technology to be introduced from other places. Sometimes an experimental variety which fails at IRRI because of disease may perform quite adequately in Pakistan. On the other hand, a number of limiting factors must be studied on the spot. Soils problems are among these. Some insect problems also require close local attention. A careful study of the population dynamics of stem borers in Pakistan may disclose methods of control that would be much more economical than those introduced from the outside. Grain quality studies associated with basmati rice is another area of importance. Basmati quality depends much on local climate, and imported technology will not suffice.

India. In 1967, IRRI entered into an agreement with the U.S. Agency for International Development and the Indian Council of Agricultural Research to participate in the development of rice research. The agreement focused on the All-India Coordinated Rice Improvement Project (AICRIP) which had been founded by the council in 1965. Contractual arrangements call for IRRI to provide the services of resident scientists in several fields, to arrange training programs for Indian staff, to establish study tours, to provide short-term consultants, and generally to assist in the development of the coordinated program.

The "coordinated" concept as developed in India aims to use existing facilities, personnel, and agencies with a minimum of organizational change to avoid proliferation of new centers or stations. Existing resources may be modified or supplemented, where necessary to get the job done, but every effort is made not to interfere with or limit the role of a particular center in handling local problems and obligations. The approach has its greatest value where an agricultural research framework already exists and a number of agencies are already at work on a particular commodity. It allows agencies that have objectives much broader than a particular crop to contribute to solving immediate problems without sacrificing their long-term goals. Often, such agencies can be strengthened by participation in a national coordinated program.

The greatest value of the coordinated approach is that new ideas or materials can be tested and developed promptly and over a wide range of

conditions. Limited manpower can use the leverage of a broad testing program. In India, several hundred persons at more than 50 research stations constitute a nationwide team working toward common objectives. The country is divided into zones and regions which helps give a local focus to broad problems.

The quality of research can be upgraded strongly by workshop and evaluation procedures that scrutinize results clearly and impartially. Ideas or materials of limited value quickly fall by the wayside. AICRIP holds both zonal and national workshops in which selected staff members participate. The national workshops, held twice a year, play a major part in the planning of the overall research effort. To generate new ideas or materials, the coordinated program needs a small but highly competent research staff associated with its headquarters. This team conducts exploratory research on specific problems and encourages specialized centers within the network to focus on particular problems encountered in the region. At the same time, the headquarters avoid any tendency to become a center which controls or directs research efforts.

The progress of India in coordinated rice research has been excellent. Rapid advances have been made in testing and creating new rice varieties for use throughout India. The objective of developing high-yielding, nitrogen-responsive varieties has been adopted by all units. It has been accepted not as the result of an intellectual exercise, but as a result of actual field testing. Scores of nation-wide tests were run in which the semi-dwarf indica varieties were compared with the best local varieties and with the japonica "ponlais" introduced from Taiwan. The results, obtained over several seasons, offer one of the best evaluations anywhere in the world of the potential of the new high-yielding rice varieties. Supporting studies in agronomy, entomology, and plant pathology have accompanied varietal evaluation. Under the agreement IRRI is to provide AICRIP with a five-member team of scientists, who are specialists in plant pathology, entomology, plant physiology, agronomy, and agricultural engineering. Short-term consultants are supported in these and other fields from the Philippine-based staff and from other research centers. Funds for equipment and supplies are also channeled to the project, and training and study are arranged. In addition. The Rockefeller Foundation has assigned one of its specialists to serve the project as team leader. He has been named Joint Coordinator of the AICRIP.

Ceylon. A senior rice scientist from IRRI has been stationed in Ceylon since mid-1967. This Ford Foundation-financed project has been provided with funds for training abroad, and for supplies and equipment for training and research activities within the country.

Ceylon has an active rice research program which has contributed some locally adapted, higher yielding varieties of its own such as H 4. This program is in close contact with that of IRRI in most phases, but the principal direct participation of the IRRI resident adviser is in the area of rice production training. Ceylon has made extensive use of IRRI's rice production training program. Twenty-two Ceylonese have participated in the 6-month rice production training course at IRRI, more than any country outside the Philippines. Most of the full-time trainers in Ceylon are graduates of the IRRI program. In addition, 10 Ceylonese have taken similar training in IRRI's multiple cropping training program. Thirteen others have undertaken study programs (mostly in the United States) in research areas.

Two national in-service training centers have been developed by the Ceylonese authorities. These centers offer tightly organized 2-week courses in modern rice production for agricultural instructors (extension officers) and for village-level extension workers. During the past year, 400 participants in the former category and 1,400 in the latter have completed these courses. Other participants have brought the total number of trainees to over 2,000 in the past year. Plans call for similar numbers of participants in the coming year. The objective is to have a continuing program where each extension officer returns for training each year.

These programs are all essentially ones of "training the trainer." They are directed towards improved training at the district level and at the village level. In the past year, about 40,000 farmers participated in village-level training classes and about 3,000 have taken them at the in-service centers. These classes were supplemented by extension contacts at the farm level. In the current season, for example, 100,000 rice production kits were placed with farmers (Ceylon has about 700,000 farmers). These kits contained about a kilo of seed of a new rice variety together with enough fertilizer to meet the needs of the crop. This technique of demonstrating new technology has proven a powerful extension tool in the Philippines and it should be extremely useful in Ceylon.

Ceylon has recently released several new varieties, and management practices for the different zones are being developed. While research has not been neglected, the special story there has been the emphasis upon and success of the training activities.

Indonesia. A senior rice adviser has been stationed in Indonesia since 1970 with funding by the Ford Founation. He serves as joint coordinator of the Indonesian National Rice Research Program. In addition, IRRI manages a grant to Indonesia from the Netherlands Ministry of Foreign Assistance. A third project to strengthen Indonesian rice research in which IRRI

is a participant has just started with funds from the U.S. Agency for International Development.

In 1969 the Indonesian government invited an international team of scientists to study its agricultural research structure and advise on its modernization. The team recommended the establishment of an Indonesian agricultural research organization which would serve as a coordinating body to focus existing research facilities on problems of national importance. Nation-wide, coordinated research efforts organized along commodity lines were envisioned. The government accepted the basic features of this plan.

As a first step towards implementation of the comprehensive plan, a National Rice Research Program was started in 1970. Several existing agricultural institutes will contribute to this effort, as will the agricultural faculties and the extension service. It will serve a coordinating function similar to that of AICRIP in India, and is not to be an independent, separately staffed institute. The National Rice Research Program will make few changes, if any, in the existing organizational and administrative pattern. It will seek ways to strengthen existing institutions with particular attention to regional research centers.

It should be noted that the head of the AICRIP, S. V. S. Shastry, was able to make an extended consultation trip to Indonesia to describe the Indian experience and to help outline its adaptation to Indonesia. This visit, arranged by IRRI under its Ford Foundation grant, represents the sort of cross-transfer of developmental experience which is becoming increasingly useful.

At the same time that these plans were being drawn up, the Indonesian government arranged with several developmental assistance agencies to contribute to rice research. Bilateral agreements were signed with the Netherlands to assist in entomology research and with Japan to assist in pathology research. Discussions were also carried out with the Ford Foundation to seek ways of involving IRRI in the Indonesian rice research effort. It was decided that IRRI would provide an experienced scientist to serve as joint coordinator of the National Rice Research Program. To the extent possible, IRRI expertise would be brought to bear on Indonesian rice problems through provision of consultants and training opportunities.

In Indonesia, IRRI will have something of a coordination role in seeking additional foreign assistance, where required, to strengthen specific aspects of the national program. In this direction, favorable action was taken by the Government of the Netherlands, through a grant to IRRI, to channel a sizeable fund for the improvement of regional Indonesian rice research

stations. The U. S. Agency for International Development is giving major assistance to the national program through a contract with IRRI. This contract calls for increased IRRI participation by stationing staff members in rice breeding, rice agronomy, multiple cropping (breeding and agronomy), and statistical evaluation of research results in Indonesia.

Training of young Indonesian scientists is an important component in these agreements. Training requirements are considerable and a long-term effort is contemplated. The willingness of so many agencies to participate in one or more phases of the program is, of course, highly favorable, although it will require a great deal of inter-agency cooperation to realize its full potential.

Thailand. As an exporting nation, Thailand has had a somewhat different point of view about the changing rice technology which has swept across Asia in recent years. The Thais are interested in obtaining the benefits of higher yield potential and more economical use of inputs, but they must do so within the context of the demands of their markets abroad as well as at home. To achieve these goals Thailand has accelerated its research program significantly over recent years. Through an agreement with The Rockefeller Foundation, Thailand has acquired the services of an experienced breeder to advise them and to participate in the breeding program. He also acts as a continuing liaison with IRRI to assure that full use is made of research results.

Thai breeders have made many crosses and selections and have named three varieties that have the new plant type. They have also made progress towards breeding a "deep water dwarf," a seemingly contradictory term which refers to a plant that remains short under normal levels of water but elongates significantly under deep flooding. Other phases of the Thai research program are directed toward special soil situations which occur there.

Many Thai scholars have participated in training programs at IRRI and representatives regularly attend IRRI conferences and symposia. Also, many IRRI senior staff members act as short-term consultants to the Thai group on specific problems.

Korea. The involvement of IRRI in Korean rice research started more than 7 years ago when a member of the Korean research group came to the Philippines to participate in the IRRI breeding program. He was attracted by the semi-dwarf plant type being developed at IRRI. As his special research project, he decided to see if he could develop similar lines that would thrive under the climatic conditions of Korea and would have the type of grain preferred there. He made crosses between the IRRI lines and

traditional Japanese varieties, and when he went home he took seed with him to test under Korean conditions.

A plan was developed to evaluate materials in the Korea-IRRI program in Korea during the summer and in the IRRI experimental fields during the winter. Each winter a young member of the Korean rice breeding group would travel to the Philippines to supervise the plots and to improve his proficiency by studying with the IRRI rice breeders. IRRI scientists have followed up the program by visiting the plots at least onece during the Korean summer.

This program has been carried along to the point that one variety from it has been named. It was grown in seed multiplication and observation plots throughout Korea last year and is expected to have a significant impact. These materials may have application in other places such as the United Arab Republic and temperate South America. As a plant type generally adapted to temperate conditions, they may also be of interest to Japanese breeders.

At the same time the breeders were involved in this collaborative work, Korean scientists in other fields came to IRRI for training. Usually three or four are in residence in the Philippines at any given time.

The cost of this program has been minimal, amounting to little more than the cost of training and associated travel, but the potential pay-off is large. Even though IRRI is basically a tropical rice research center rather than a temperate-zone center, the facilities and staff have been of important service to Korea.

South Vietnam. For several years IRRI has received trainees from South Vietnam. Some of them have been in research, but many more were in production training courses. The returned production trainees have organized a continuing series of training courses of their own for Vietnamese extension workers and farmers. As a result of their efforts, IR8 and IR20 were introduced to Vietnam and widely adopted. Sometimes IR8 is referred to by Vietnamese farmers as "Honda" rice because of the number of motorcycles it helped buy.

More recently IRRI was asked to examine Vietnamese conditions to determine if there was a place for closer collaboration between IRRI and the Vietnamese group in rice research. The result of this study was a contract with the U.S. Agency for International Development under which IRRI will station two senior scientists in Saigon to facilitate work in varietal improvement and agronomy. Over the near term, this work will rely heavily on the IRRI program. The IRRI breeding program will be extensively screened to identify lines suited to Vietnamese conditions. Among the wealth

of material in the IRRI program there are bound to be some lines of particular value to South Vietnam, especially for the excellent rice-growing areas of the Mekong Delta.

Philippines. The Government of the Philippines has cooperated with IRRI in many ways additional to the paramount one of allowing the Philippines to be IRRI's headquarters. No overall agreement to cover these many kinds of cooperation has ever been deemed necessary. Instead, IRRI and the agency in question work out a program and go ahead with it.

For a number of years cooperative work between IRRI and the University of the Philippines College of Agriculture, the Bureau of Plant Industry, the Agricultural Productivity Commission (the extension service), and other agencies was funded by a special Ford Foundation grant. More recently, funds from the Philippine National Science Development Board have been channeled in support of cooperative work with the Bureau of Plant Industry. Funds from commercial grants have also assisted in the execution of cooperative work. While the work being undertaken covers a broad range, it relates mostly to the evaluation and adaptation of IRRI research results throughout the Philippines and to comparison of results at IRRI with those coming from other centers.

Recently The Rockefeller Foundation financed a special project which calls for IRRI production specialists to work closely with the Philippine extension service in upland and rainfed areas. This is a pilot project which includes elements of applied research as well as extension and training. Twenty Philippine extension workers and a number of IRRI staff are working as a team to find better ways of bringing modern technology to less advantaged farming areas.

Burma. For several years officials of the Union of Burma Ministry of Agriculture have called on IRRI from time to time for advice on their rice research program, particularly breeding. Burmese trainees have been particularly interested in breeding, but trainees in several other fields have also participated in the IRRI program. Burma has recently expressed a willingness to participate in the current world-wide program to preserve rice germ plasm.

Malaysia. IRRI has been in contact with Malaysia's rice scientists from the start. Scientists from Malaysia have participated in all symposia and conferences, and Malaysians have been in the training program. Cooperative work was carried out on *penyakit merah,* a disease which proved to be caused by a virus similar to tungro in the Philippines. Malaysia was one of the first countries to adopt IR8 as an official variety for release to farmers. Their scientists have regularly screened IRRI releases, choosing those which they found to be best suited to Malaysian conditions.

Taiwan. Rice scientists from Taiwan have been unfailingly cooperative in planning and developing IRRI's program. The major importance of breeding stocks from Taiwan has been mentioned many times in describing the IRRI varieties. Cooperative studies with Taiwan scientists have dealt with genetics and cytogenetics, plant pathology, plant physiology, soil chemistry, soil microbiology, and agronomy. Many scholars and fellows from Taiwan have participated in IRRI training programs and senior rice scientists from there have participated in all of IRRI's conferences and symposia.

The development of these cooperative projects in Asian countries has been an exciting experience. The countries in the region have been keenly interested in forming cooperative relationships leading to the improvement of rice production. This interest has been evident at the scientist level and in top governmental circles. Occasionally the Minister of Agriculture has taken a personal interest in determining the course of the work and in seeing the project develop. The response, highly gratifying to IRRI and its sponsors, suggests a strong underlying desire for change and possibly a more effective way to assist national programs.

The interest of Asian countries in cooperating with one another and with international agencies has been repeatedly demonstrated by their responses to projects of FAO and other agencies, many of which pre-date IRRI. The first problem in facilitating such interchanges has been to find a mechanism that will produce concrete results and not just expressions of interest and goodwill. The second problem is to find self-sustaining channels of interchange which will require a minimum of third-party participation. The IRRI experience seems to point to a procedure for the first of these objectives.

I suggest that the principal reasons for the ready acceptance of these projects are that IRRI has operated from a base of expertise that is continually being renewed by its research program, and that IRRI has focused on the needs of each national group and has not tried to introduce a fixed pattern to all countries. These are not new ideas, but IRRI has been able to function with a high degree of flexibility and hence has been able to respond to changing situations.

The idea of an expert with a fixed degree of expertise is out. The level of training and research in Asia is such that the adviser who is not also a participant soon will be out of date. IRRI has tried to protect the time of its scientists so that their research continues at a high level despite acting as consultants and performing other duties. It has also drawn on

consultants from other centers to broaden the base beyond that possible with its own limited staff. If it is to be of value, the competence of the international advisory group must be of top quality.

Likewise, the project must focus on the needs and interests of the national program if it is to thrive. The results of national programs may have broad application, and, taken as a group, they may constitute something of an international network, but they exist to fill a national need. The IRRI approach has been to focus on this point and to bend every effort towards the national objectives of the project in question.

The basic objective of the national group in an international cooperative program should be to use to the maximum the ideas and materials arising elsewhere, but at the same time to build local competence so that local problems can be attacked directly and introduced ideas modified as required. The international group can help in this process. Any tendency to reduce effort in the national program simply because an international one might fill local needs is discouraged. Conditions vary from place to place. Rice is such an important crop that essentially every country in Asia requires a degree of local input in the basic disciplines related to it. The IRRI program of cooperative activities has aimed at helping the local groups to achieve an appropriate degree of such input.

Essentially all of the regional cooperation mentioned here has been of a rather special type; it has involved an international agency. Multilateral or even bilateral cooperation in rice research without the involvement of such an agency has been the exception rather than the rule. For the time being, an organization such as IRRI seems essential if broad-scale interchanges are to be expected among rice researchers of Asian countries. Sometimes it is easier for the national agency to turn its materials over to an international center for increase and dissemination than it is to send them directly to other countries. As a longer term goal, IRRI encourages more interchanges among the national groups.

Toward this end as well as to meet current needs, IRRI sponsors an annual international rice research conference attended by rice researchers from throughout Asia. These conferences have traditionally been held in April to permit participants to evaluate current results well ahead of the main monsoon crop of most of Asia.

These conferences are essentially working meetings which deal with current research problems. Usually two or three major subjects are covered. For example a particular meeting, 4 or 5 days in length, may deal with breeding, pathology, and entomology. The conference the next year may

cover soils, agronomy, and physiology. The conference is built around the work of the participants in these fields and serves as an excellent place to exchange information and plan cooperative work. Data not yet ready for publication are exchanged and attention is given to work in progress in the IRRI fields, greenhouses, and laboratories.

It appears that one outcome of this series of conferences may be a truly international variety testing program. The objective would be for participating groups to exchange several of their more promising lines for inclusion in standard tests throughout the region. There may have been a tendency to avoid this until local lines were available which would clearly compete with those from other countries. Many programs are now turning out lines of highly desirable type, ones that they should seek to enter in outside comparisons. Such trials could serve as the core of a continuing exchange among countries of the region.

IRRI's international programs have benefited enormously from the imaginative input of donor agencies. The early entry of IRRI into cooperation in East Pakistan was largely brought about by Haldore Hanson, then the Ford Foundation representative in Pakistan. Mr. Hanson was in close touch with local problems and he was able to envision some of the things that IRRI could contribute. He may have seen some of these things more clearly than IRRI itself. In any event, his enthusiastic interest, together with that of the local Secretariat of Agriculture, led to the formation of a long-standing partnership.

The interest of staff members of the U.S. Agency for International Development in India in encouraging the All-India Coordinated Rice Improvement Project was instrumental in introducing IRRI into the rice research efforts of that country. This program has moved rapidly from a stage where the core of its testing program was IRRI breeding lines to the present, where these are largely included for comparative purposes. These are but two examples out of many in which the program has been strongly influenced by others.

The international status of IRRI has also had attractive features for prospective donor agencies interested in assisting in rice development. That is obvious in some of the country programs described. A particular agency may be able to contribute to a certain phase of the program of a given country but unable to contribute to another phase. Or it may be able to come in for a while, but unable to commit itself over a long enough period of time to meet the needs of the project. An agreement with IRRI may surmount some of these difficulties for the donor agency, and it may

lead to a more valuable package for the host country. The best example to date is the Indonesian project where IRRI has agreements with three donor groups to assist an agency which already has two bilateral assistance agreements.

A few years ago it was not uncommon for a prospective donor agency to want to go it alone. If one agency was already involved, others would tend to look elsewhere. It seems that this attitude has been almost completely reversed. In some projects in which IRRI is currently involved, interested donors have studied the matter jointly and decided among themselves, with the host government, and with IRRI, which phases each would support. Actually a joint effort may be more attractive than a separate one. Several examples could be cited. I am speaking here of the outreach type of activity, but the same attitude is evident in funding the international centers themselves.

I would like to return to a comment made in the introduction to this paper: as valuable as the research output of IRRI has been, it is rapidly being overtaken by that of the national agencies with which it cooperates. IRRI welcomes this situation and takes pride in the fact that it has been able to assist these agencies. In the coming decade IRRI's research can be expected to venture into new areas with which the national agencies find it difficult to cope. At the same time IRRI will continue to foster developments within the national agencies to the extent to which it is requested to do so.

IRRI's current research program

D.S. Athwal

The research program of The International Rice Research Institute is directed towards increasing the production of rice and improving its quality. This has necessarily involved a careful analysis of the problems that affect rice production and a concentration of research efforts on finding solutions to such problems. Research is carried out in 11 disciplines related to rice culture — genetics and plant breeding, agronomy, plant pathology, entomology, plant physiology, chemistry, soil chemistry, soil microbiology, statistics, agricultural economics, and agricultural engineering. The major research topics in each area are listed in Table 1. Although the institute has separate departments, each responsible for research in a particular discipline, most of the research work involves a team approach based on interdisciplinary cooperation.

Often, a distinction is made between basic research and production-oriented research of an applied nature. If basic research on rice is defined as the research merely carried out to seek new knowledge without regard to its application for improving rice yield and quality, it will not fit well into the institute's research program. On the other hand, the institute will not hesitate to undertake basic research if it is designed to collect information needed to answer questions that are limiting progress of rice production research. As major problems affecting rice production are gradually overcome, new and more complex problems are being uncovered. To solve these problems not only is the need for interdisciplinary cooperation becoming stronger but basic research is also often indispensable.

It is not possible to present in detail the institute's entire research program here, but I shall review some important research problems that are currently receiving the major attention of the institute's scientists: Disease and insect control, improvement of rice quality, weed control, soil fertility,

Table 1. Major research topics in different departments of IRRI.

Plant physiology
Physiological basis of high yield potential.
Varietal differences in photosynthetic efficiency.
Rice nutrition and physiological disorders.
Photoperiod and temperature response.

Plant pathology
Variability in pathogenic organisms with special reference to blast, bacterial leaf blight, and tungro virus.
Identification of sources of varietal resistance to rice diseases.
Development of superior sources of combined resistance to several diseases.
Epidemiology of rice diseases.

Entomology
Chemical control of rice insects with special reference to stem borers, planthoppers, leafhoppers, and whorl maggot.
Identification of sources of resistance to rice insects.
Development of superior sources of combined resistance to several insects.
Biological control of insect pests.
Studies on insect ecology.

Varietal improvement
Development of improved varieties that combine resistance to diseases and insects with good grain quality.
Breeding for resistance to environmental stresses with particular reference to low temperature and drought.
Breeding for high protein content.
Genetics of various plant characters of agronomic importance.
Maintenance, evaluation, and augmentation of rice germ plasm.

Chemistry
Physico-chemical basis of nutritional and processing quality of rice.
Protein and starch metabolism.
Biochemical bases of resistance to insects and diseases.

Agronomy
Soil fertility and crop environment.
Chemical control of weeds in transplanted, direct-seeded, and upland rice.
Water stress effects and water management.

Soil chemistry
Chemistry of flooded soils.
Study of rice problem soils.
Nutrient availability in flooded and upland soils.
Varietal resistance to adverse soil conditions.

Soil microbiology
Microbial fixation of the atmospheric nitrogen.
Pesticide residue problems.
Microbial transformation of minerals in rice soils.

(Cont. on next page)

Table 1. Continued.

Statistics
Evaluation and improvement of field plot techniques and sampling procedures.
Evaluation of methods for collecting rice statistics in farmers' fields.

Agricultural economics
Economics of using different levels of production inputs.
Survey of adoption of modern production practices by rice farmers.
Socio-economic effects of new rice technology.

Agricultural engineering
Development of land preparation equipment.
Development of harvesting and threshing equipment.
Development of machines for weeding and seeding.
Development of small-scale rice processing and drying equipment.
Economics of mechanized rice production and of machinery manufacture.

upland rice production technology, and rice mechanization. Research on multiple cropping systems will not be discussed because it is the subject of a separate paper by Dr. Bradfield.

About 10 years ago when the institute started its research program, the extent of damage caused by many rice diseases and insects in the tropics was not fully recognized. The viruses were practically unknown though they were prevalent. Bacterial diseases had been reported but they passed unnoticed by most people. Often, the damage caused by stem borers was not correctly diagnosed.

Warm temperatures and high humidity, which are typical of the rice environment, are optimum for the development of a variety of organisms that are harmful to the rice plant. About 20 diseases and insects cause serious damage to the rice plant in the tropics. Most of them are present in the Philippines. The institute scientists have concentrated their attention on blast, bacterial leaf blight, and tungro virus among the diseases and on stem borers, planthoppers, and leafhoppers among the insects. These are the most widespread and damaging pests. Another major insect pest is the gall midge, which is not found in the Philippines. Also, the institute has carried out considerable work on bacterial streak, sheath blight, grassy stunt virus, and whorl maggot.

The institute named its first variety, IR8, in 1966. The new plant type exemplified by this variety doubled the yield potential of the rice plant. The new management practices, such as optimum use of fertilizer

that are essential for high yields, also create environmental conditions that favor the development of diseases and harmful insects. Next to fertilizer use, the control of diseases and insects is probably the most important problem in fully realizing the potential offered by the new plant type. Institute scientists in several disciplines have been engaged in research on this problem.

For diseases, the primary method of control has been the development of resistant varieties though some work has been carried out to evaluate chemicals for disease control. The success of chemical control of rice diseases in Japan prompted many workers in the tropics to follow this approach, but the Institute has all along recognized that the use of chemicals is not very effective and economical in the tropics. On the other hand, chemical control of insects is highly successful and has received major attention. Breeding for resistance to insects is a relatively recent approach but it has become highly significant because excellent sources of resistance are now available and because insecticides are expensive and present pollution problems. The limited studies carried out on biological control of rice insects have not produced any striking successes.

Chemical control of insect pests. An important development in the use of insecticides was the standardization of insecticidal application to the paddy water rather than on the foliage. Granular insecticides are most convenient for paddy water application. Such applications are far more effective than conventional foliar sprays or dusts which do not penetrate dense foliage well and are easily washed off by rains. Repeated application of foliar sprays and dusts are essential for effective control. On the other hand, insecticides applied to the paddy water function systemically in the plant. Also, they move by capillary action between the leaf sheaths and stem and kill a wide variety of insects by fumigation effect.

Among the compounds first tested, institute entomologists found that lindane was the most effective for controlling stem borers and maggots, the least hazardous to man, and comparatively less expensive. In a series of trials, two applications of lindane to paddy water provided more effective insect control than eight to twelve foliar sprays of such potent compounds as endrin and parathion. Lindane has since been used extensively either alone or in combination with various carbamate pesticides which augment its effectiveness against planthoppers and leafhoppers. In subsequent tests, diazinon was found to be highly effective against the common species of stem borers, leafhoppers, planthoppers, and whorl maggot. Its low mammalian toxicity made it highly acceptable.

Recent studies have shown that soaking the roots of rice seedlings in 0.04 to 0.1 percent insecticide solution before transplanting controls common insect pests for 2 to 3 weeks after transplanting. The method is simple, relatively cheap, and effective. Thus it promises to become popular in areas where seedling pests are important. Several insecticides are effective but carbofuran has given the best results. Carbofuran, which is available in granular formation, also controls all major insects when applied in paddy water, but its cost is relatively high.

The residue effects of lindane and diazinon in paddy water, soil, rice straw, and grains have been investigated by institute scientists. Both compounds degrade almost completely in about 1 month after application. Recommended rates are not toxic to common fish and do not impart off-flavor to the rice grain.

The rice paddy has a unique anaerobic environment. Some of the organo-chlorine pesticides, like lindane, which are highly persistent under upland conditions, may not cause any residue problem in paddy fields in the tropics. They are rapidly degraded by soil microorganisms to relatively harmless products. Institute microbiologists have demonstrated that the biodegradation pathways of these insecticides in flooded soils differ substantially from those in upland soils. The first biochemical step in the degradation was found to be the reductive dechlorination of the molecules which can only take place under anaerobic conditions. Diazinon, an organophosphorus insecticide, was also found to degrade rapidly in paddy soils. In fact, diazinon which was used as a standard insecticide in the institute experiment fields for years has ceased to be effective mainly because its continuous use has led to the gradual build-up of bacteria which degrade diazinon.

Chemical control of diseases. The chemical control of rice diseases has not been very successful in the tropics. Chemicals sprayed on the rice plants are washed off by frequent showers during the monsoon season whem most rice is grown. The year-round cultivation of rice in the tropics leads to rapid and frequent build-up of pathogenic organisms which necessitates many applications of fungicides that may not be economical. Such chemicals as Blasticidin S and Kasumin, which have been extensively used for controlling blast in Japan, have been evaluated but the results are not encouraging. Recently, institute plant pathologists found that newer chemicals such as Benlate, Topsin, and NF48 have good systemic action against blast. But they are too costly for tropical rice farmers.

Development of varieties resistant to diseases and insects. Farm surveys by institute economists have shown that farmers have increased the

use of insecticides over the past few years. But amount applied is low and the normal farm practice is to use a chemical only after damage occurs or is clearly visible. Farm losses are highly variable from location to location, from season to season, and from variety to variety. These investigations suggest that at present, it is difficult to rely on chemicals as a major control measure for insects and diseases on Asian rice farms. On the other hand, farmers are quick to identify and adopt resistant varieties.

The development of resistant varieties is an ideal method of controlling diseases and insects. It is economical and causes no environmental pollution. A team of institute scientists gathered basic information on the behavior of pest organisms and host-pest reactions that has enabled the development of an organized program to breed varieties possessing resistance to major diseases and insects.

The institute plant pathologists have identified more than 200 races of the causal organism of blast, *Pyricularia oryzae,* in the Philippines. Conidia from a single lesion, from a monoconidial culture, or even from a culture originating from a hyphal tip of a germinating spore consist of many races. While great variability enables the fungus to produce races to attack any rice variety, the situation is not as hopeless as it appears. The races are not persistent or constant and they represent a transitory phenomenon. That limits the build-up of specific races because they change into other races in every generation. Thus a variety with a broad spectrum of resistance may withstand variation in the pathogen and maintain its resistance for a long time.

A significant step in studying varietal resistance to blast was the organization of international blast nurseries in 1963. From the leading rice varieties of tropical countries, 258 were selected and tested at more than 50 locations in 26 rice-growing countries. Two years later the institute plant pathologists screened 8,320 varieties of the world collection and selected a second group of 320 varieties for tests in international blast nurseries. Up to now, 250 repeated tests have been made. This comprehensive screening has led to the identification of about 20 varieties that possess a broad spectrum of resistance to blast. Among these, Tetep, Carreon, and Mamoriaka are the most prominent. They represent a type of stable resistance because virulent races isolated from these varieties in the greenhouse fail to re-establish and multiply on them because of their wide spectrum of resistance.

Although bacterial leaf blight has long been known in the tropics, it was recognized to be a serious disease when new fertilizer-responsive varieties were extensively grown under good management conditions.

Institute scientists found that the so-called "kresek" disease in Indonesia which causes complete death of young seedlings was in fact a severe form of bacterial leaf blight. Isolates of *Xanthomonas oryzae* differ in their relative virulence though races with a truly differential reaction of host varieties have not yet been identified. Institute plant pathologists screened 8,700 varieties using virulent strains and selected 125 varieties as most resistant. These varieties have been tested in several other countries. Most of the sources of resistance now known in the tropics came from this group of varieties. The institute has further tested these varieties against many virulent strains and several varieties, especially BJ1 and Nagkayat, possess a broad spectrum of resistance. TKM 6 is another variety that shows good resistance in the field.

During 1963 and 1964, the institute plant pathologists reported three new virus diseases — tungro, grassy stunt, and orange leaf. Further experiments showed that the *penyakit merah* in Malaysia and *mentek* in Indonesia, which had been previously considered to be physiological diseases, were actually tungro virus. Tungro was also found to be common in Thailand, Bangladesh, India, and other countries. The disease is now one of the most important problems of rice production in tropical Asia. Institute scientists identified insect vectors that transmit tungro and grassy stunt and developed mass screening techniques for identifying varieties resistant to these viruses. Thousands of varieties have been screened. There are many varieties resistant to tungro, such as Pankhari 203, Habiganj DW-8, Red Rice, and HR21. No cultivated rice variety has a high degree of resistance to grassy stunt, but one strain of the wild species, *Oryza nivara,* has been found to be highly resistant. The resistance is simply inherited and has been transferred to cultivated rice.

The stem borers are the most widespread and serious insect pests of rice. The striped borer, *Chilo suppressalis,* the yellow borer, *Tryporyza incertulas,* the white borer, *Tryporyza innotata,* and the pink borer, *Sesamia inferens,* are of major significance in Asia. Testing of about 10,000 varieties against the striped stem borer showed distinct differences in susceptibility among varieties. On resistant varieties, the insects lay fewer eggs and the larvae that hatch from the eggs suffer high mortality, have slower rate of growth, are smaller in size, and develop into more male than female moths. These phenomena exert a cumulative restraint on the build-up of borer population on resistant varieties. About 20 varieties have been identified through intensive field and greenhouse tests as resistant to striped borer. Generally, varieties resistant to one species also show resistance to other species of the stem borer.

TKM 6, a variety from India, is the most promising source of resistance to stem borers.

Several species of planthoppers and leafhoppers are serious pests of rice. They cause damage to the rice plant by feeding on it and by transmitting virus diseases. The brown planthopper, *Nilaparvata lugens*, and the green leafhopper, *Nephotettix virescens*, are the most widespread in the tropics. The brown planthopper transmits grassy stunt virus and the green leafhopper transmits tungro virus. The resistance to each insect is independent of the resistance to the virus it carries. By screening the IRRI varietal collection, entomologists have identified many varieties that are resistant to these insects. For example, Mudgo, CO 22, and H 105 are highly resistant to the brown planthopper and Pankhari, Su Yai 20, and DV 139 are highly resistant to the green leafhopper. ASD 7 and Ptb 18 are resistant to both insects. The development and survival of the insects on resistant varieties is so poor that they can do little damage to such varieties. The resistance appears to be biochemical in nature and is simply inherited. Institute geneticists have identified two genes for resistance to the brown planthopper and three genes for resistance to the green leafhopper. Although the existence of different biotypes of these insects has not been recorded in the field, studies in the greenhouse have shown that the insects have the capacity to change and attack a variety that was previously resistant.

Most varieties that show resistance to diseases and insects are primitive varieties. They are tall, have droopy leaves and weak stems, are lodging susceptible, and have poor yield potential. To transfer the desirable traits of these donor varieties, crosses were made with varieties and selections that have improved plant type. Perhaps the most significant result of resistance breeding so far is the development of IR20 which possesses a moderate or a high level of field resistance to stem borers, green leafhoppers, tungro virus, bacterial leaf blight, bacterial leaf streak, and blast. Another variety, IR22, combines a high degree of resistance to bacterial leaf blight with high yield potential.

Institute plant breeders now have in their assembly line many selections that combine desirable plant and grain characteristics with disease and insect resistance. Specifically, they have transferred the blast resistance of Dawn, Zenith, Tetep, and Carreon, the bacterial leaf blight resistance of Zenith, Tadukan, and Wase Aikoku, the bacterial leaf streak resistance of DZ 192 and CP-SLO, the tungro resistance of HR 21, Peta, and Gam Pai, the grassy-stunt resistance of *Oryza nivara*, the brown-planthopper resistance of Mudgo and ASD 7, the green-leafhopper resistance of

Peta, Pankhari 203, and ASD 7, and the stem-borer resistance of TKM 6 and EK 1263, to varieties that have improved plant type. Some of the high-yielding selections from these crosses are listed in Table 2 along with their reaction to important diseases and insects. Among them, IR833-6-21, IR1364-37-3, and IR1541-102-6 are being considered as possible new varieties and deserve special mention. The IR1541 selection possesses resistance to bacterial leaf blight, tungro, bacterial leaf streak, brown planthoppers, green leafhoppers, and stem borers. In addition to disease and insect resistance, the new selections, of course, possess desirable combinations of other traits such as daylength sensitivity, grain size and appearance, cooking quality, and growth duration.

Rice grain quality has three major aspects — the physical appearance of the grain, cooking quality, and nutritive value. Long, slender, clear, translucent grains generally are preferred by consumers in tropical Asia and fetch higher prices in the market. The cooking quality of rice depends primarily on the amylose content of the grain. Varieties with high amylose content, about 28 to 30 percent, cook dry and fluffy and those with intermediate amylose, 22 to 25 percent, exhibit softer texture when cooked. While low and intermediate amylose rices are preferred in the Philippines and Indonesia, high amylose rices are consumed in the Indian subcontinent. In addition to amylose content, there are, of course, other grain characteristics such as gelatinization temperature and aroma and taste of cooked rice for which people have varying preferences.

Table 2. Some promising selections and their reaction to major diseases and insects. [a]

Selection	Parents	BL	BLB	BLS	TG	GS	BPH	GLH
IR833-6-21	IR262-43 x Gam Pai	R	S	S	R	S	S	R
IR841-85-1	IR262-43 x Khao Dawk Mali	R	S	S	MR	S	S	R
IR1330-5-3	(Leuang Tawng x IR8) x EK1263	S	S	MR	R	S	R	R
IR1364-37-3	HR21 x IR262-43	R	S	MR	R	S	S	R
IR1487-194-5	IR127-80 x IR442-2-50	R	R	MR	MR	S	S	R
IR1529-677-2	IR305-3-17 x IR24	R	R	R	MR	S	S	R
IR1541-102-6	IR24 x TKM-6	S	R	R	R	S	R	R
IR1561-228-3	IR74B$_2$-6 X IR579-48-1	MR	R	MR	S	S	R	S

[a] BL = Blast; BLB = Bacterial leaf blight; BLS = Bacterial leaf streak; TG = Tungro; GS = Grassy stunt; BPH = Brown planthopper; GLH = Green leafhopper; SB = Stem borer; R = Resistant; MR = Moderately resistant; S = Susceptible.

The institute's first-variety, IR8, has medium-long grains with conspicuous white belly and high amylose content. The new varieties, IR20, IR22, and IR24, combine high yield potential with much better grain appearance. All have clear translucent and attractive grains. IR20 and IR22 have high amylose content while IR24 has low amylose content.

Rice is a major source of protein in the diets of Asian people. The rice protein has about 4 percent lysine content. Its quality is, therefore, better than that of most other cereals. The main limitation of rice as a protein source is its low level of protein. A program aimed at improving the protein content of the rice grain has involved cooperative work among chemists, plant breeders, agronomists, and plant physiologists.

Several reports in the literature indicate that application of simazine increases the protein content of cereal grains. Institute plant physiologists have shown that although treatment with simazine may increase protein content, it is often accompanied by an increase in spikelet sterility and consequently by a reduction in grain yield. It is, therefore, important to take into account both grain yield and protein content while considering the effect of any chemical treatment. Institute agronomists have screened several triazines in field experiments and found that simetryne at 0.5 kg/ha, applied at heading or panicle initiation, increased the protein content without any adverse effect on grain yield.

Protein content is greatly influenced by environmental factors and cultural practices. Generally, protein content is higher during the wet season than during the dry season, possibly because grain yields are lower during the wet season and grain yield and protein content tend to be negatively associated. In field experiments conducted by the agronomy department in 1969, the protein content of IR8 increased from less than 7 percent with close spacing to about 9 percent with very wide spacing primarily because grain yields were lower at wider spacings. Topdressing with nitrogen fertilizer tends to increase protein content. In a 1970 dry-season experiment the application of nitrogen in split doses at planting and heading increased the mean protein content of several varieties by 1 percentage point. Late application of nitrogen also improves the milling yield and head-rice recovery because high protein grains are more resistant to milling losses.

Although a negative association has generally been observed between grain yield and protein content, proper fertilizer management will raise the yields of modern rice varieties without reduction in protein content. The agronomy experiments have demonstrated that the modern semidwarf varieties can use higher doses of added nitrogen more efficiently than the lodging-susceptible traditional varieties not only for producing

higher grain yield but also for improving the protein content. Institute scientists conducted a survey to determine protein content of rice grown in farmers' fields and found that inspite of their higher yields, the protein content of IR8 and IR20 compared favorably with the local varieties probably because the improved varieties were properly fertilized.

In 1967, an intensive research program was initiated to improve protein content of rice grain through breeding. Institute chemists screened 7,760 entries of the world collection of rice varieties for protein content. The protein content ranged from 5 to 17 percent. There were 126 accessions which contained about 14 percent or higher protein based on brown rice samples (at 12% moisture), for two different crop seasons. The grain yields of these high protein accessions were generally low. The institute plant breeders selected six varieties which gave consistently high protein content through 4 seasons and crossed them with IR8. These crosses are now in advanced generations. Unfortunately, most hybrid lines with high yield have low protein content. The results are not as encouraging as anticipated. The varieties used as sources of high protein content were not adapted to tropical climate, they matured very early, gave low grain yields, and apparently their extremely high protein content was due in part to an environmental-genotype interaction. Nevertheless, some F_9 lines that have improved plant type yield only slightly less than IR8 but have a one-fourth higher protein content.

In addition to crosses specifically made for developing high protein lines, the varieties and breeding lines in the agronomy and varietal improvement trials have been regularly screened for protein content. This has resulted in the identification of two selections, IR480-5-9 and IR160-27-3, that have one-fifth higher protein content than IR8. Both have improved plant type and about the same yield potential as IR8. BPI-76, a commercial variety in the Philippines, has also shown about 15 percent more protein content than IR8 but its yield potential is lower.

Although the protein content is markedly influenced by environment, institute scientists have gathered sufficient evidence to indicate that it is partly under genetic control. It appears that the protein content of high yielding varieties can be genetically increased by about one-fourth. If high protein varieties are to be accepted by farmers, they must have as high a grain yield as the ones they would replace and should also be equally acceptable to consumers.

Institute chemists and geneticists continue to gather basic information that will accelerate the progess of breeding for high protein content and quality. Amino acid analysis of F_4 grains of the lines with the

lowest and the highest protein contents from different crosses showed that a decrease in lysine and tryptophan values occurred as protein content increased. Further studies, however, indicate that there is no genetic or physiological barrier to the combination of high protein content with high lysine content. Milled F_7 seeds of five lines with similar protein content (11.4 to 11.8%) contained 3.3 to 4.0 percent lysine (as a percentage of protein content) and 0.9 to 1.2 percent tryptophan. Since lines with similar protein content vary in lysine content, the development of high protein varieties with about 4 percent lysine seems possible. In fact, some evidence is now available to show that at levels of protein, exceeding 10 percent, lysine content may not be negatively associated with protein content. Institute chemists have also screened 10,500 varieties from the world collecton for lysine content and have found two varieties with about 4.5 percent lysine content and normal protein content.

Institute chemists have studied the nitrogen metabolism of the rice plant of varieties that have different levels of protein in the grain. The developing grains, as well as the cell sap entering the panicle of high protein lines, had higher levels of free amino acids than the grains or cell sap of low protein lines. High protein lines, e.g. IR480-5-9, also contained higher levels of leaf nitrogen at booting and flowering, most of which is translocated to the grain. Presumably high protein rices assimilate more nitrogen from the soil and translocate a large portion of this nitrogen to the developing grain after flowering. The study of the biochemical basis of varietal differences in the rate and extent of assimilation of soil nitrogen is expected to provide further information about the causes of varietal difference in protein accumulation in the grain.

When the farmer adopts high-yielding varieties, the payoff from good weed control increases sharply. Hand weeding is laborious and time-consuming. Even on farms as small as 2 to 3 hectares, the existing family labor force has difficulty maintaining adequate weed control by hand weeding. This is particularly true in areas where poor water control combined with increased use of fertilizer stimulates weed growth.

A survey of farms conducted by institute economists in Central Luzon and Laguna showed that labor use for weeding rose from 8 percent to 17 percent of the total labor requirement between 1966 and 1970, the period in which high yielding varieties were being adopted. Thus, labor use in weed control has increased despite the increased use of herbicides and mechanical weeders.

The results of this analysis suggest that except in areas where wage rates are very low or farm sizes are extremely small, increased use of mechanical and chemical weed control methods is likely to be output-increasing rather than labor-displacing.

Although push-type rotary weeders present an improvement over hand weeding, they are slow and hard to operate. Institute engineers have designed a motorized rotary weeder that can be operated easily in small paddy fields. The three-row model of the power weeder is four to five times faster than push-type weeders and eight times faster than weeding by hand.

The recent success of the institute experiments in chemical weed control in transplanted rice may bring about a dramatic change in the weed control practices in tropical Asia. The most interesting results were perhaps those obtained with 2, 4-D. When applied 4 days after transplanting this low-cost herbicide gives adequate control of grasses, broadleaved weeds, and sedges. For a long time, 2,4-D has been known to be effective only against broadleaved weeds and annual sedges. The time of application is the key factor in the ability of 2,4-D to control grasses. It will kill grassy weeds in addition to other annual weeds when used before the weeds emerge. Institute agronomists recommend using 800 grams of the active ingredient of 2,4-D to control weeds in 1 hectare of paddy. The cost of treating 1 hectare is only $2.50 with the liquid formulation and $5.50 with the granular formulation as compared with $12 for hand weeding. While either the granular or liquid form of 2,4-D can be used, the granular form is better because it can be broadcast directly into the paddy water and is less toxic to rice. The herbicide MCPA is equally effective in controlling weeds in transplanted rice.

In direct-seeded rice weed control is more critical and more difficult than in transplanted rice. In direct-seeded rice, the weeds start growing at the same time as rice and are, therefore, highly competitive. The weeds cannot be easily distinguished from rice seedlings of the same age. If the rice is broadcast, laborers cannot move through the field without causing some damage to rice plants.

Since hand weeding is impractical in direct-seeded rice, chemical control is the obvious alternative. Propanil and molinate have been found to be highly effective in controlling grassy weeds in direct-seeded rice in Europe and America. But their high cost and the precise water management required limit their use in tropical Asia. Experiments conducted at IRRI during 1970 and 1971 have identified other chemicals that are suitable for direct-seeded rice in the tropics. Application of 1.5 kg/ha (active ingredient) of benthiocarb or of butachlor 6 to 8 days after seeding was

highly successful and gave complete control of barnyardgrass and water lily. The cost per hectare of either chemical is about equal to the cost of hiring labor to hand weed transplanted rice. Experiments have shown that both of these chemicals applied at lower rates can also control weeds in transplanted rice.

Studies were begun in 1970 to identify chemicals for weed control in upland rice. The best weed control was obtained from spray application of a Japanese chemical, NTN5006, at 2 kg/ha (active ingredient) before the emergence of weeds when rice seedlings were at the one- to two-leaf stage. Effective weed control was also obtained with liquid butachlor at 2 kg/ha applied before weed emergence.

Institute microbiologists have studied the degradation of 2,4-D both under aerobic and anaerobic conditions in Maahas clay soils. The herbicide disappeared almost completely within 15 days under both conditions. The use of 2,4-D, therefore, presents no residue problem.

Unless plant nutrients are available in sufficient amounts and unless substances that interfere with nutrient uptake are absent, the new high-yielding varieties cannot deliver their full potential.

Studies of the chemical kinetics of flooded rice soils by institute soil chemists have led to an understanding of the changes that occur when soils are submerged for extended periods. Flooding generally increases the availability of all nutrients other than zinc. Some of the benefits of flooding are associated with a favorable pH. It decreases the pH of alkaline soils and increases the pH of acidic soils. In some soils the principal benefits of flooding — the increase in the availability of nitrogen, phosphorus, iron, and silica — may be counteracted by the concentration of substances that retard nutrient uptake. The research on the physical chemistry of submerged soils has provided means of minimizing the harmful effects of soil submergence. For example, keeping the soil submerged for a few weeks before planting gradually improves the soil environment for the growth of rice. Mid-season drainage of rice fields — a common practice in Japan — may not be desirable under most tropical conditions because it results in a substantial loss of nitrogen without compensating advantages.

Nitrogen, phosphorus, and potash are the major elements needed for plant growth. A crop of rice yielding 5 t/ha removes about 100 kilograms of N, 20 kilograms of P, and 120 kilograms of K from the soil. Most rice

soils contain adequate potassium for crop growth. Moreover, in many soils its supply is continuously replenished by the addition of rice straw and irrigation water which have high potassium content. Nitrogen is the most important nutrient limiting rice production though addition of phosphorus is also necessary in many areas. Long-term fertility experiments conducted by institute agronomists indicate that soils continuously receiving nitrogen may start showing phosphorus deficiency under intensive cropping.

Liquid ammonia is the cheapest source of nitrogen and has been found to be as effective as ammonium sulfate for rice. The major problem in the use of liquid ammonia for rice fertilization in the tropics is the lack of a satisfactory method of application. Experiments at IRRI have also shown that rock phosphates with high citrate solubility are as effective a source of phosphorus as superphosphates in acid and acid sulfate soils. These rock phosphates are potentially low-cost sources of phosphorus for rice.

The use of commercial fertilizers offer a large potential for increasing rice production in the tropics. But fertilizers are costly. The microbiological fixation of elemental nitrogen from the air could be a cheap method of supplying nitrogen requirements of the rice plant. The soil microbiologists have shown that nitrogen-fixing activity in paddy fields is much greater in planted soils than in unplanted soils. Nitrogen fixation activity continues to increase during the growth of the rice crop until harvest. The total amount of fixed nitrogen in paddy soil at the institute was estimated to be 52 kg/ha and 22 kg/ha in planted and unplanted soils, respectively, during a wet season and 63 kg/ha and 28 kg/ha in planted and unplanted soils, respectively, during a dry season. Studies are now in progress to determine the mechanism of nitrogen fixation and to learn if there are varietal differences in the nitrogen-fixing activity around rice roots.

With greater use of commercial fertilizers, certain micronutrient deficiencies are becoming an increasingly important barrier to rice production. Institute plant physiologists have shown that zinc deficiency is an important problem on many calcareous and neutral soils. The soil chemists have found that zinc deficiency can occur on continuously wet soils regardless of pH. In fact, zinc may be considered the third most important nutrient for lowland rice after nitrogen and phosphorus. Zinc deficiency in most soils can be easily overcome by the addition of zinc chloride, zinc sulfate, or zinc oxide to the soil. Dipping rice seedlings in a 1-percent suspension of zinc oxide at transplanting is a cheap way to cure zinc deficiency. Draining and aerating the soil is the best remedy for zinc deficiency on continuously wet soils.

In Asia 67 percent of the area planted to rice is completely dependent on rain for water. Of this, about one-third is grown without bunding on non-puddled soil. This type of culture is called upland rice. On the other two-thirds, rainwater in impounded and the soil is puddled. This type of culture is called rainfed rice.

Except for the uncertainty of rain, the conditions under which rainfed rice is grown are similar to those of the irrigated rice — the soil is puddled before planting and kept saturated with water or flooded during crop growth if enough irrigation water or rainwater is available. In areas with good rainfall distribution essentially the same technology can be used on both irrigated rice and rainfed rice. Last year, institute rice production specialists conducted more than 100 trials on farmers' fields under rainfed conditions. These experiments showed that with good management, yields approaching those of irrigated rice can be obtained under rainfed conditions. But a substantial amount of water is needed for wetland preparation. Planting of rainfed rice must be delayed if enough rain to puddle the soil is not received at the beginning of the planting season. Institute scientists have obtained satisfactory yields of rainfed rice by direct seeding on unpuddled soil in bunded fields. While direct seeding facilitates early planting under rainfed conditions, the effect of nonpuddling on yield needs critical evaluation under various soil and rainfall conditions.

Upland rice yields are generally lower than those of irrigated and rainfed rice. The yields vary greatly and seldom average more than 1 t/ha. Institute agronomists have shown that when rainfall is adequate and its distribution is good, yields as high as 5 t/ha are possible to obtain under upland conditions. On the other hand, in years of poor rainfall, yields may be extremely low. The high yielding varieties, IR5 and IR8, have yielded consistently more than the upland varieties if soil moisture did not drop much below saturation and other soil factors were not limiting.

During the last 2 years, institute scientists have concentrated their attention on some of the basic problems of upland rice. The reduction in the yield of improved varieties under upland conditions is generally more related to the duration of moisture stress than to the stage of plant growth at which the stress occurred. During moisture stress the availability of nitrogen and phosphorus in upland soil is considerably decreased. The low grain yield in soils at field capacity could be due to aluminum and manganese toxicity in acid soils and to iron deficiency in neutral and calcareous soils. Futhermore, the incidence of blast disease is generally higher under upland than under flooded conditions.

Another reason for low yield of upland rice is heavy weed infestation. Usually weeds are more drought resistant than rice and they compete with rice for moisture which is already a limiting factor in upland rice production. The results of agronomy experiments indicate that butachlor and NTN5006 are promising herbicides for controlling weeds in upland rice.

The soil chemists screened varieties for tolerance to the adverse chemical effects of aerobic soil conditions by growing them to maturity on acid, neutral, and calcareous soil maintained at field capacity. M1-48, an upland variety, did uniformly well in all three soils and gave the highest grain yield. M1-48 was greener than the other lines and showed no sign of iron deficiency or manganese toxicity. Of the institute selections, IR661-1-170 approached M1-48 in yielding ability under those conditions.

An important aspect of tolerance to moisture stress is the ability of the varieties to recover from severe stress. IR5 and some other semidwarf lines seem to be able to recover from severe moisture stress to a greater extent than many other varieties. On the other hand, IR5 is highly susceptible to the adverse chemical effects of aerobic acid and alkaline soils and does well only in neutral aerobic soils.

A comparison between upland varieties and IR5 showed that upland varieties including M1-48 have relatively more root development under upland conditions. Upland varieties as well as drought-tolerant lowland types tend to have an extensive root system consisting of a large number of long and thick roots, rather long leaf blades capable of rolling when water stress sets in, and a high root-to-shoot ratio in young plants. On the other hand, the markedly low tillering ability of the traditional upland varieties restricts their yield potential even when water and nutrient supplies are adequate. Probably, a good upland variety should combine a high yield potential with drought resistance, ability to recover from drought injury, and tolerance to the adverse chemical effects of aerobic soils. Since most of these features appear to be relatively independent of one another, it should be feasible to combine desirable characteristics of upland varieties like M1-48 with good traits of IR5 and other high yielding varieties.

The institute plant breeders have made crosses among diverse genetic stocks such as Japanese and African upland types and several IRRI strains to develop most desirable combinations of characteristics for upland culture. Evaluation of F_2 and F_3 progenies grown under moisture stress showed that some genetic recombinations had better root and leaf features than the semidwarfs and better plant type and tillering ability than the traditional upland types.

A farm survey was conducted by institute economists in Central Luzon and Laguna in 1966 and again in 1970 to examine the effect of technological change on employment in rice production. The farms surveyed were those adjacent to the main highway where tractor use for land preparation was increasing most rapidly. The studies showed that over the 4-year period increased use of tractors reduced the amount of labor use for land preparation from 27 to 15 percent of the total labor requirements for rice. This decline in labor was more than offset, however, by a rise in labor use for weeding and harvesting and threshing. As a result, total labor use per hectare of rice increased slightly.

Improved varieties and intensive cropping have increased the economic advantage and scope of rice mechanization. The availability of a reliable, low-cost source of power is basic to the reorganization of small farms for increased production. In tropical Asia, medium-sized farm holdings of 2 to 10 hectares constitute a large portion of the total land under paddy cultivation. As a group, farmers in this category have the potential to support an intermediate level of mechanization. The institute's program in agricultural engineering is tailored to the specific needs of the developing regions. It is primarily focused on the design and development of machines for medium-sized farms which are too large to work economically with animals but which cannot justify investments in large agricultural equipment imported from the industrialized countries.

The extension of new machines to rice farmers in cooperation with agricultural equipment manufacturers is an important goal of the institute's program. Manufacturers of agricultural machinery in tropical countries are generally small firms lacking adequate resources for the design and development of new machines. The institute's assistance to small manufacturers generally involves development from the basic machine concept to the final prototype. It often includes provision for technical assistance in planning production programs and evaluating the manufacturers' initial models. The institute has also encouraged manufacturers from the industrialized countries to produce special equipment for tropical agriculture and has assisted them by carrying out applied research on specific problems of mechanization.

The institute has recently released the designs of several machines which are being commercially manufactured in Asian countries.

— Rotary power weeder. The three-row, portable weeder is powered by a lightweight, 1-hp engine. Sheet-metal shields protect the rice plants from damage by the weeding rotors. The rotors uproot and incorporate the weeds in

the mud. The machine can weed 1 hectare in 17 man-hours as compared to 70 man-hours per hectare for the manual, push-type Japanese weeders.

— Table thresher. The thresher is designed as a lightweight, hold-on feeding type machine. It uses a circular, flat, rotating surface for threshing. A flat screen around the periphery of the threshing surface separates paddy from straw, and the grain is winnowed as it falls under the screen. The machine can be used for threshing wet or dry paddy with an output of up to 350 kg/hr.

— Seeders. Single-hopper, six-row and eight-row machines for seeding pre-germinated paddy on puddled soils have been developed. Five to seven man-hours per hectare are required for seeding with these machines as compared with 120 man-hours for transplanting. Farmer's response to the single-hopper paddy seeders has been encouraging in the Philippines. Another six-row seeder with separate hoppers for each row is being developed.

— Power grain cleaner. This is a simple rotary screen-air cleaner that can be used to clean wet or high-moisture paddy. The long exposure of a tumbling mass of grain to the air stream inside the rotary screen provides a vigorous winnowing action. The machine can clean up to 3 tons of paddy per hour.

— Power tiller. The high cost of imported power tillers discourages their use by tropical farmers. A simple, lightweight, single-axle power tiller has been developed which can be manufactured in most developing countries. The tiller uses an imported 4 to 6 hp air-cooled gasoline engine. The rest of the tractor components are easy to fabricate in small shops.

— Low lift bellows pump. There are many low-lift irrigation needs for which low-priced pumps are not available in the tropics. A simple, twin-bellows pumps has been developed at IRRI, which can deliver 200 to 250 liters of water per minute. The pump is light and can be easily carried by one man.

Several machinery development projects are nearing completion. These projects will make a significant contribution to the mechanization of tropical agriculture. A process for rapid drying and parboiling of rice has been developed using heated sand. The design of a machine using this process is almost completed. A low-cost stripper field harvester is expected to be ready soon.

The program will not only be concerned with the development of individual machines for agricultural operation but will also examine the implications of developing and introducing an intermediate mechanization technology consistent with the agro-climatic, socio-economic, and industrial conditions of the developing world.

There are other valuable results of research that I have not discussed. These include studies related to cold damage, physiological disorders, amelioration of problem soils, water management, genetics of agronomic characters, and improvement in the yielding ability of rice. The following is a brief report of some of the more significant findings.

Cold damage. In the tropics, rice is mostly grown in warm weather. But there is a considerable area of rice at high elevations and at northern latitudes where low temperatures are experienced during the growing season and the crop may suffer cold injury.

Experiments conducted by the soil chemists suggest that the poor performance of high yielding varieties under low temperature conditions is partly due to adverse chemical environment of rice roots produced by low soil temperatures. Cold injury is more severe in acid soils than in neutral soils. Internal drainage, mid-season soil drying, liming, or continuous submergence minimize the harmful effects of low temperature on the growth of rice.

Institute plant breeders and plant physiologists have carried out studies to determine the nature of cold injury, identify sources of cold resistance, and transfer genes for cold resistance to the semidwarf tropical varieties. At low temperatures (15 to 21 C), IR8 shows leaf yellowing, produces shorter internodes and poorly exserted panicles, and possesses a higher percentage of sterility and a longer growth duration. Most japonica varieties or selections inheriting predominantly japonica traits show cold tolerance. Some native indica varieties cultivated under low temperature conditions also possess appreciable resistance to cold injury. A greenhouse technique developed to screen material for cold resistance in the seedling stage consists of growing seedlings in wooden flats placed in tanks full of cold water. The seedlings of susceptible varieties become yellow and stunted and are clearly differentiated from resistant varieties which look normal. Seedling reaction to cold water in the greenhouse, however, may not be related to cold damage at later growth stages in the field. There are probably different sets of genes responsible for resistance to cold at different growth stages.

Cooperative tests at several locations in Asia have shown that rice may suffer cold damage at different developmental stages depending on the temperature pattern at a particular location. For example, in Korea, cold damage is serious only at the seedling stage and at maturity which results in leaf discoloration. In Bangladesh, low temperature mainly affects rice at the

tillering stage by causing stunting and leaf discoloration. In Pakistan, Nepal and India, low temperatures may affect rice throughout the growing season and damage is expressed in the form of leaf yellowing, stunting, prolonged growth duration, and sterility.

Institute plant breeders screened progenies of many crosses involving cold-resistant parents at several locations. A line resistant at one location is not necessarily resistant at another location. Selections from the IR610 and IR1308 crosses are resistant at the seedling stage and show normal fertility at maturity in Kashmir, India, but they lack resistance to leaf discoloration at maturity in Korea. IR781 selections have resistance at maturity in Swat Valley, Pakistan, as well as in Korea, but failed to mature in Kashmir. Studies, however, indicate that resistance to different kinds of cold damage can be combined in a single variety of improved plant type. Selections from more recent crosses are expected to have a higher level and wider spectrum of cold resistance.

Maximizing production. The yields good farmers obtain from the new semidwarf varieties have stabilized at about 6 to 8 t/ha though under the best conditions higher yields can be obtained. The realization of the potential yield of new varieties in many areas is limited by environmental factors besides sub-optimal management practices. Studies by institute agronomists have demonstrated that solar radiation is an important influence on rice yields. In the wet season when most rice is grown, the yields are generally 25 percent lower than the yields obtained during the dry season when solar radiation is relatively greater. There is a strong relationship between the amount of solar radiation received during the last 45 days of the growth period and crop yield.

The grain yields obtainable with new semidwarf varieties in the dry season in the tropics are almost comparable to those of good varieties in temperate countries. Thus, on per crop basis, the tropical environment in the dry season appears to be as productive as the temperature environment. In addition, in the tropics three or four crops a year are possible, provided irrigation is available. Plant physiologists and agronomists have produced 24 to 26 t/ha in a year by continuous rice cropping. Analysis of these experiments suggests that 27 to 28 t/ha is a realistic estimate for top annual rice production under Los Baños conditions.

Improvement in rice-yielding ability. The semidwarf plant type has the potential of producing a maximum yield of about 12 t/ha. Physiological studies on IR8 have established that grain yield increases with increasing leaf area index and reaches the plateau yield at leaf area index of about 6. The

plateau yield is stable over a wide range of leaf area index values unless the crop lodges. It is unlikely that further spectacular increases in grain yield will be achieved by more improvements in plant type.

Institute plant physiologists have made basic studies to explore other ways to increase the yield potential of the rice plant. Experiments on carbon dioxide enrichment have shown that increased carbon dioxide assimilation by the rice plant before heading increases the number of spikelets while increased assimilation after heading increases the percentage of filled grains. The results indicate that more spikelets per unit land area could increase the grain yield of the semidwarf plant type by 25 to 30 percent in both the wet and dry season. Preliminary investigations have also shown large differences in photosynthetic efficiency among varieties. From information now available, it appears that a combination of higher photosynthetic efficiency and larger spikelet number per panicle will further increase the yield potential of the semidwarf plant type.

The general policy of the International Rice Research Institute is to continually evaluate its research program to benefit from past experience and to modify its future directions to take care of any new problems that arise in the rice industry. The institute will especially strive through multi-disciplinary groups to break down some of the barriers to further progress. We anticipate advances in the next decade will be as exciting as those that have occurred in the past. I will attempt to give you a glimpse of some of the things that are likely to happen or the problems that will receive special attention.

The development of an integrated method of disease and insect control will receive a high priority. Soon we should have a better understanding of various environmental factors that influence population trends of insects and incidence and distribution of diseases. Although the search for cheap chemicals and other methods of pest control will continue, major attention will be devoted to varietal resistance. Most pest organisms are highly variable. To build up insurance against losses through changes in disease and insect organisms, future varieties must contain different genes for resistance or some kind of stable resistance. Genetically diverse sources of resistance to brown planthoppers and green leafhoppers have been identified. Some success has been achieved in identifying varieties such as Tetep that have broad resistance to blast races. TKM 6, EK 1263, and Ptb 18 are sources of resistance to several pest organisms. New sources of long lasting and multiple resistance will be discovered. Investigation of the biochemical bases

of resistance to some of the insects and diseases will be undertaken. The basic information obtained from such studies will greatly help the resistance breeding program.

Different semidwarf selections possessing resistance to several diseases and insects have been crossed and complex crosses have been made to obtain high yielding varieties with resistance to all major diseases and insects. For example the newer corsses, IR2034, IR2039, and IR2061 combine resistance to tungro and grassy stunt as well as to brown planthoppers. and green leafhoppers. Resistance to the two viruses and their vectors, to blast, and to bacterial leaf blight is present in IR2048 and IR2054.

In addition to high yield and disease and insect resistance, future varieties will possess good grain quality including higher protein content, and tolerance to cold temperature and drought. The institute is also working on rice varieties that mature in about 100 days and yet yield as well as later-maturing varieties. We hope to develop a better screening technique for protein content and current research indicates the possibility of identifying high protein lines in the vegetative stage. A clearer understanding of the biochemical basis of varietal differences in protein content and of the physiological bases of cold and drought resistance will accelerate the progress of the breeding program.

We foresee the possibility of further increasing the yield potential of the semidwarf plant type by increasing its photosynthetic efficiency and its panicle size. Work is already under way to confirm genetic differences in photosynthetic efficiency. The institute will soon have a phytotron which will facilitate basic studies on temperature, light, and carbon dioxide in relation to yield potential.

The problem of release and loss of nutrients in submerged as well as upland rice soils will be more thoroughly investigated. Only about half the fertilizer nitrogen is recovered by the rice crop in a submerged soil and even less than half in an upland soil. Nitrogen is lost in the percolation water and by diffusion, or is rendered unavailable by immobilization. Means of minimizing losses will be investigated. The possibility of enhancing the microbial fixation of atmospheric nitrogen will be futher explored.

A crucial factor in the success of the new rice technology is the water environment. We expect not only to improve the capacity of the rice plant to endure drought but also to amplify our knowledge of the soil-plant-water relationship. More attention will be given to improving the production technology for rainfed and upland rice. New methods of rainfed rice cultivation on non-puddled soils will allow farmers to conveniently grow other crops in rotation with rice, thus diversifying

food production. In fact, the institute has plans to substantially expand its research program for developing multiple cropping systems for the humid tropics.

Yield increases in farmers' fields as a result of adoption of new varieties have not been as high as would be expected from the well-established fact that the yield potential of rice has been doubled. As IRRI's program continues, there will be more emphasis on analysis and investigation of the problems faced by farmers in adopting the new technology. For example, the economics of different herbicides and insecticides is an essential factor in determining recommendations to farmers. Soil problems and physiological disorders may seriously limit yields even when improved varieties and practices are used on farmers' fields. The institute will continue to demonstrate on a community or area basis what can be done to increase rice yields and to improve the living conditions of farmers.

In the end I should point out that much of the work for increasing rice production in any nation will have to be carried out by research centers of that nation. Strong national institutions are essential prerequisites to accelerated progress. The International Rice Research Institute recognizes the fundamental importance of well-supported national programs. The institute stimulates cooperative work to further the goal of increased rice production. More attention will be given in the future to strengthen IRRI's research links with national programs.

International agricultural research institutes: their unique capabilities

Sterling Wortman

During the past 10 years, based in large part on the unique efforts of The International Rice Research Institute to increase rice yields in Asia and to strengthen Asian institutions, a growing interest has developed in international research and training institutes as an innovative means of accelerating agricultural and general economic development of nations.

The early success of IRRI and the nations with which it has cooperated led to the establishment in its present form of the International Maize and Wheat Improvement Center (CIMMYT) in Mexico in 1966 and, a year later, to the founding of the International Institute of Tropical Agriculture in Nigeria and the Centro Internacional de Agricultura Tropical in Colombia. A new International Crops Research Institute for the Semi-Arid Tropics is being jointly considered by the government of India and a consortium of donor agencies. An International Potato Center is being established in Peru. Discussions are under way which may lead to the establishment of an International Laboratory for Research on Animal Diseases to speed the development of control mechanisms for trypanosomiasis and east coast fever — diseases of primary economic importance in sub-Saharan Africa. Simultaneously, studies are in progress which may lead to the organization of an animal production research institute for that region.

The list of nations taking advantage of the unique new services of the institutes to further their own development plans is growing rapidly. Among the nations using the institutes most directly are India, Pakistan, Ceylon, Korea, Vietnam, Thailand, Malaysia, Indonesia, Mexico, Colombia, Ecuador, Algeria, Tunisia, Morocco, Turkey, Lebanon, United Arab Republic, and Zaire. Scores of other nations are served in less direct ways. There are perhaps a dozen nations which are exploring with the various institutes means by which the institutes can become involved in accelerating national efforts. Over 60 nations on all continents have arranged for technical

personnel from their national institutions to receive training at the institutes.

Also, in the past 10 years, awareness has been growing among national and international assistance agencies of the value of the international centers as new tools which can be imaginatively used to support programs of the developing nations. During the past 3 years, the list of financial supporters of the institutes' activities has grown: it now includes Belgium, Canada, Denmark, the Federal Republic of Germany, Japan, Netherlands, the United Kingdom, the United States, Canada's International Development Research Centre, the Inter-American Development Bank, the United Nations Development Programme, the World Bank, the Ford Foundation, the Kellogg Foundation, and The Rockefeller Foundation. Today, 28 nations, international assistance agencies, and private foundations have come together to consider support of international institutes and programs. This has been accomplished through the organization of the Consultative Group for International Agricultural Research, co-sponsored by the World Bank, FAO, and the United Nations Development Programme.

As interest grows in international agricultural research institutes, there is increasing discussion of the international-institute approach as it might be applied to other major problems. Some groups are considering fostering small-scale industry by development of machines, devices, and techniques that would permit nations to industrialize yet take advantage of abundant labor. Others are weighing means to attack environmental problems, particularly in the industrialized nations of Europe and North America where an apolitical scientific approach seems urgently needed. Then there is the fundamental problem of stabilization of population growth rates — a problem to which nations are understandably sensitive and which might best be studied in institutions controlled by distinguished citizens of the nations served. Judging from such growing interest in fields other than agriculture, one may anticipate that similar non-agricultural institutes will soon appear on the world scene.

A number of special capabilities and characteristics of the agricultural institutes appear to have contributed to their successes during the past decade. Ten will be considered today. Individually, most are not new. On the other hand, the simultaneous combination of all of the attributes in a single institution clearly is unprecedented.

There have been commodity-oriented research institutes in existence for over half a century. Among them are the Experiment Station of the Hawaiian Sugar Planters' Association and the Pineapple Research Institute, both in Hawaii. We all know of India's Central Rice Research Institute and her

other commodity-oriented research groups. The French Government sponsors international institutes, based in Paris, which deal in depth with a number of the major plantation crops. Interdisciplinary attack on agricultural development problems has been a feature of the U.S. land-grant colleges since their establishment. Several examples could be drawn from the nations of the British Commonwealth and elsewhere. In short, the "invention" of the international agricultural research institute in 1960, drew on the combined experiences, over the past half century, of many institutions and individuals.

To repeat, it is the combination in one institution of all of these characteristics that contributes to any success or special capability that an institution may have in effectively serving large numbers of the world's nations.

What then, are the characteristics that are attracting so much attention by so many nations and by so many of the world's national and international assistance agencies?

Any present list of important attributes of international institutes must be based primarily on the activities of IRRI and CIMMYT; these are the only institutes that have cooperated with sufficient numbers of nations long enough to allow a judgment to be made. But, it can be expected that newer institutes must develop similar characteristics if their programs are to be effective and if they are to merit similar support by the nations served and by assistance agencies.

First, the institutes are independent, being governed by autonomous boards of trustees. And at any institute the majority of the trustees are distinguished citizens of the nations served. The question is raised often as to who owns and operates the institutes. The answer is, quite clearly, the boards of trustees. Admittedly, the institutes originally received most of their support from private foundations. Nevertheless, they were called "foundation institutes" erroneously because from the outset they have been responsible to their boards of trustees. At each institute, the host nation has two or three representatives on the board *ex officio*; this practice is desirable because it gives the nations which have granted extraordinary rights and privileges to institutes on their soil an assurance that the activities of the institutes are not in conflict with their national interests. At least half the other board members are distinguished authorities from the nations served. Consequently, there is maximum

likelihood that the focus of the institutes' efforts will be on the major problems of those nations.

Should there be any question about the involvement of Asian authorities in the International Rice Research Institute, or representation of citizens of these nations among the trustees, one need only look at the list of eminent Asian and other leaders who have given their time to guide IRRI.

Boards of trustees can cause the emphasis to shift at any time to meet changing requirements, or not to shift. One example may illustrate this point. At the 1970 meeting of the Board of Trustees of CIMMYT, the staff asked if they should attempt to respond to the many statements in the popular literature that the problems of agricultural production had been solved by the "green revolution," that there were so many actual or possible adverse effects of the increased productivity that net benefits to nations should be questioned, and that the "second generation" problems of income distribution, migration to the cities, marketing and storage, and other related factors were of first importance.

After considerable debate, the trustees concluded that while many of these problems deserve attention, CIMMYT should continue to stress increases in productivity and the extension of benefits to those regions where yields had not yet begun to climb. The board advised against use of staff time to engage in a battle of rhetoric but rather to continue the battle to raise yields and incomes in the rural areas. Consequently, CIMMYT has continued to address its efforts to the "first generation" problem of higher productivity which is so fundamental to increasing income and employment on farms and in the rural trade centers.

The first characteristic of the institutes — a unique one — is that their programs are guided by distinguished citizens drawn from the nations the centers serve, and therefore efforts of these independent institutes will be focused on problems of first importance.

Second, because the institutes are governed by autonomous, self-perpetuating boards of trustees and are staffed by the best talent available regardless of nationality, and because the doors of the institutes are open to people of any interested nation, they are increasingly considered by the nations they serve to be apolitical institutions. They represent no particular ideology; they are instruments of no national policy; their staff members represent only the institute. Because the institutes have generally been considered politically neutral, scientists of the nations served as well as those of the various donors have been able to work together in almost any combination.

Third, institutes have (or should have) clearly stated goals against which progress can be measured. For the International Rice Research Institute, the goal was to help the nations of Asia to increase their national average rice yields. It would have been much more comfortable to have settled for less comprehensive goals such as the solution of major problems through research, the training of personnel for the nations, or even the creation of a community of scientific activity related to rice. It was clear from the outset that IRRI's staff should develop a remarkable record of solution of major problems through research (which they have). It was stipulated that IRRI should train substantial numbers of technical personnel needed by national institutions (which they have). It was recognized that, in the course of time, the staff should develop a list of outstanding contributions to the scientific literature (which has occurred). IRRI was expected to develop an unprecedented level of effective international cooperative activity (which now exists). But, even if the institute were to do all of these things and the rice yields were *not* to go up in Asia, it was clear from the outset that the entire operation could be multiplied by zero. The institute would be an out-and-out failure. A well-organized, well-run, hardworking institute was not the ultimate goal. Improved productivity of Asia's rice farms was the goal.

It is a tremendous tribute to the staff of the International Rice Research Institute that they accepted this challenge from the very beginning, even though they recognized that the responsibility for increased production in any nation is that of the nation itself: only the individual nation can set the policies, organize the institutions, and reach the farmers in an effective way. No international institute can do this. But an international institute can help with the solution of the problems, train the personnel, provide services of various kinds, and demonstrate and argue for new approaches to the improvement of farming. And this IRRI has done. It has set an example which other institutes will be hard pressed to match. We can be thankful for that example.

Fourth, an institute can quickly mount carefully organized simultaneous attacks on problems of major importance to the countries of the region served. Some solutions will emerge from work done in the institute's own laboratories or in its own experimental fields. Other solutions will be obtained by national institutions and still others will result from cooperative work between the institute and organizations of the nations with which it is associated. But the point is that the interdisciplinary staff of an institute can organize a campaign — an international campaign if necessary —

to get solutions to major problems. And, since its goal is to raise national average yields it must leave no significant problem untouched. Otherwise, it will fail. National average yields cannot go up unless the nation's farmers are adopting new systems. Farmers will not adopt unless the technology is complete and permits higher productivity. Nor can higher yielding systems be put into practice unless they are profitable, and this requires incentive prices and ready markets. It means that fertilizers, pesticides, and credit must be available where needed. No effort to get national average yields up can be successful unless all elements are considered and unless all corrective action needed is in fact taken.

Fifth, institutes, properly functioning, can emphasize speed of operations. When in the summer season of 1962 IRRI's experimental plantings were severely damaged by a then unknown disease, IRRI put out a plea for an authority on virus diseases. Within a few weeks the response came from Japan. Dr. Tosi Taki Iida came to IRRI, worked with the staff for only 18 months, and in that time he and the staff found there were, in fact, four virus diseases involved. By identifying these diseases quickly and determining the insect vectors involved, IRRI scientists were able to start a simultaneous search for plant resistance and for chemical controls of the vectors.

Both IRRI and CIMMYT have routinely used at least two experimental plantings a year; at IRRI the number has approached three a year.

When a problem occurs in one of the nations served and outside help is needed, it usually can be arranged quickly either through visits by the institute's staff or by an authority from another nation — wherever the greatest expertise resides. In one case, East Pakistan was assisted with work on virus diseases by a virologist from Colombia. Whatever the problem, and wherever it may be, the institutes are often in a unique position to be able to arrange promptly for the right authorities to deal with it.

Sixth, the institutes have an unusual degree of flexibility in meeting the requests of nations. This is revealed in the paper by Dr. A.C. McClung which describes some of the imaginative ways in which assistance agencies and nations have made use of the IRRI flexibility. An institute can receive grants from any source either for support of its continuing research and training programs, or for special projects. It can tailor its training programs to the specific needs of nations and even of individuals, as will be described later. An institute can contract to provide specific support for national programs, including provision of interim leadership if need be, given only a request from the nation, necessary funds for the undertaking, and approval of the institute's board. It can work with any person of any institution anywhere if it is appropriate and useful to do so. There is little

or nothing that is useful to do which it cannot undertake. Importantly, the institute can cooperate with interested nations on a scientist-to-scientist as well as on an institution-to-institution basis, and in fact it insists on doing so. This particular factor has been extremely important to the success of national endeavors as well as to those of the institutes. Cooperation on scientific matters has been kept on the highest plane/and, for the most part, informal. When a particular problem calls for a meeting or workshop involving the leading authorities on a subject, arrangements can be made for those authorities alone to work unobstructed by presence of individuals who would have little to contribute.

Seventh, the institutes can facilitate the development of an international community of effort on any problem or group of problems. Because of their unusual flexibility, their apolitical nature, and because of friendships which develop between institute staffmembers and those of institutions in the nations served as well as in the centers of specialization of the industrialized countries, any available combination of talents can be brought to bear on any problem or issue with a minimum of difficulty. The record of the past 10 years demonstrates very clearly a general willingness of scientists anywhere to cooperate in undertakings which obviously are important to large numbers of people.

The efforts to bring together the world's information on the nutrition of the rice plant, on insect problems, on rice genetics, and on rice breeding, have involved concerted efforts of authorities from many nations to analyze and interpret available information as it relates to future needs.

Through international cooperative field tests, experimental varieties from national programs as well as from institutes are exchanged and evaluated.

Indeed it can be said that both the tremendous successes of national production programs of the Asian nations and those of institutions which have worked with them can be attributed in large part to the dynamic community of effort which has been elaborated over the past decade. That high degree of cooperation needs to be elevated still more, perfected, and extended to many more of the world's problems. It is a major key to human advance.

Interestingly, the institutes are rapidly becoming centers for many kinds of activities. Much has been said of the benefits to the nations the institutes were set up to serve. The institutes also have demonstrated that they can be instrumental in fostering and facilitating direct relationships between nations and assistance agencies. And not unimportantly, cooperation among donor agencies through the institutes seems to be improving with many

unsuspected and unplanned benefits. As the world's scientists and leaders become acquainted and friendships form, cooperation naturally intensifies. This is a healthy development, but only a start has been made.

Eighth, institutes can tailor the training of personnel to the specific needs of the national institutions and of the individuals involved. This has long been a missing element, slowing if not inhibiting the progress of national institutions and programs. Previously there was almost exclusive reliance on scientific training of personnel in the industrialized nations. Such education and training could not be as closely related to the needs of the individual and his institution as all would have liked. since the agricultural problems of the temperate climate countries and of those in the tropics naturally are different. Institutions in the two regions are dealing with the agricultural development process at different stages of its evolution.

With the emergence of the institutes and their sole mandate to assist the countries interested in their services, young people could for the first time get in-service training of 1 to 2 years, learning from distinguished professionals the management of crops and of the agricultural system. And they could learn under conditions similar to those in their home countries. Such in-service training is not simply of the "get-your-hands-dirty" variety, it involves field and laboratory experience of the same degree of sophistication as that which a physician gets as an intern.

Those qualified to seek advanced degrees have been encouraged to do so. Many Asians have taken advantage of the opportunities offered to them by the College of Agriculture of the University of the Philippines. The Indian Agricultural Research Institute and IRRI have undertaken a joint program of Asian rice specialists at the Ph.D. level. Many universities in the technically advanced nations have cooperated in new ways in the higher training of crop and animal specialists, often allowing students to take graduate course work at the university and to undertake research for their theses at one of the institutes. Such training is of the utmost value and it is hoped that in time similar arrangements can be made involving the several institutes and universities throughout the world.

Training at the institutes has not been limited to preparation of research scientists. Rather, there has been recognition that nations need a full range of talents for their institutions. In recent years institutes have pioneered in the development of training of "production specialists" — preparation of individuals who know from experience how to manage crops and animals for high productivity. They simultaneously are provided a

knowledge of genetic strains, of disease prevention and control, and of management practices, as they all relate to ecological and economic conditions of the farming system. Such production specialists must have, as general practitioners, an ability to diagnose farm problems and to prescribe remedies. They must know where to turn for solutions to problems they themselves cannot handle — usually back at the experiment stations. The old concept of extension workers as purveyors of information is of limited value to nations that must instruct a whole generation of farmers in the use of a much more sophisticated system of farming.

Both the institutes and the organizations with which they cooperate are rapidly learning the needs of the nations and how to train the people required. The institutes concentrate on training the trainers but increasingly this type of activity must be carried out in the national institutions themselves. The numbers of technical people to be trained and retrained is simply too great for the centers to handle, and the cost would be prohibitive.

Institutes also offer opportunities for young research workers who already hold the Ph.D. degree or its equivalent to obtain experience on actual problems for periods of 1 to 3 years.

While not in the training category, institutes do offer some more experienced scientists opportunities to broaden their horizons by joining their staffs for periods of time which suit the individual's convenience.

Ninth, the institutes permit knowledge and understanding to become institutionalized. In the past, international assistance efforts and even those of national organizations have too often been characterized by rapid turnover of personnel assigned to research and development programs. This had led to lack of continuity of effort, frequent change of goals, and loss of expertise as individuals move from assignment to assignment.

The core staff of each international institute is made up of career people, individuals who likely will remain on the job for long periods of time provided their performance is as expected. And as the institute and its cooperators advance their knowledge and improve the materials with which they work, these tend to be concentrated at the international institute and in a few of the national organizations which simultaneously are becoming strengthened. Information and material are not lost as individuals switch positions or retire. And because of the long periods of service of staff members at an institute, the scientists become acquainted with advanced work being done anywhere in their fields of specialization. Consequently, national organizations can turn to the institutes with their problems whenever

necessary, knowing that they will receive reliable and up-to-date information or materials and that the quality of them will be high by world standards. The institutionalization of a growing body of knowledge and understanding is certainly a major and unique contribution of the institute.

Tenth, and finally, institutes can maintain their continuity of effort, employing career staff members, even though contributions of the donor agencies must of necessity be on a year-to-year basis. Because of the broad base of financial support for the institutes, each donor can be reasonably assured that it is contributing to a responsible, continuing effort of a magnitude and type which it would find difficult to develop and sustain on its own. This particular factor is undoubtedly one which is contributing to the support of institutes by a growing number of national and international assistance agencies. Together they can create and sustain an organization which individually they could not. The nations and people in need are the beneficiaries.

All of these ten characteristics of international institutes are important. Many of them are not new, but the organization of the institutes as philanthropic, autonomous, self-perpetuating, international, apolitical research and training centers is an innovative mechanism which makes it possible to incorporate all of the characteristics into a single entity.

An understanding of these unique features and how to make maximum use of them can be important to all nations that could benefit from the services they offer. The lending programs of the international banks should become much more effective as a more substantial technological base becomes available to undergird the development projects for which loans are made; this increasingly is appreciated by bank directors and management.

Many opportunities still exist to identify new working relationships between the institutes and FAO. Personnel of the institutes, of UNDP, and of FAO are beginning to understand the potentials.

National and international assistance agencies, including the international banks, are playing increasingly useful roles in bringing to the institutes an understanding of the development needs of the nations. They continue to innovate in the use of the institutes' services in meeting the needs of national programs. And, they increasingly are aware of the need for stable support for the resident research and training programs of the institutes since only from a firm and ever-more-useful base can the direct and indirect assistance to nations be elaborated.

Finally, the administrators and staff of the international institutes must understand the importance of developing these unique characteristics and capabilities to the limits of their potential effectiveness. It calls for dynamic leadership, a tremendous amount of imagination, and dedication to the single goal of all of the nations and assistance agencies with which the institutes are associated. The goal is to increase the productivity and profitability of farming especially on the large numbers of small landholdings, in the expectation that rising incomes and a vitalized rural sector including trade centers will be the result. If productivity and incomes can be raised in the rural sector, there is hope that much larger domestic markets for products of urban industry can emerge. As substantial numbers of rural people become more effectively involved in the market economy, agriculture — the basic industry of agrarian nations — hopefully will contribute to the balanced economic development to which most nations aspire. But nations are made up of people and the concern of the international institutes, like that of the national organizations they serve, must continue to be to provide a better future for the individual farmer and his family wherever that is possible.

Clearly, the invention of the international research and training center has given nations and assistance agencies a new resource which, imaginatively used, should greatly accelerate national progress.

Throughout this paper, there has been an intentional emphasis on institutes in the service of the developing nations. For it is only by *national* progress that the institutes themselves or the agencies which support them will be measured. There obviously can be no letup in technical and capital assistance to those nations in need; the institutes are not a substitute for national efforts. Financial support to the institutes by assistance agencies is not a substitute for direct assistance to the nations. The two kinds of support must be highly complementary.

Creation of the international institute has been described as among the world's greatest gifts to mankind, particularly to future generations. Certainly the record of the International Rice Research Institute suggests that future historians may accord the institutes that distinction. IRRI has had brilliant leadership from Dr. R.F. Chandler and he has been supported by talented and dedicated scientists. The entire staff of the IRRI, professional and non-professional, can take pride in having contributed so much to so many in such a short time. All should derive great satisfaction from this tremendous first decade, from the magnificent example which has been set for institutes elsewhere, and from the hopefulness which is sweeping away helplessness wherever new agricultural systems are being effectively employed.

Rice improvement through international cooperation

D.L. Umali

Rice is the staple food of simple folk, the hundreds of millions for whom rice constitutes four-fifths or more of the diet. Thus the problem of adequately meeting the ever-increasing demand of rice consumers is far from simple. The complexity of this primary world food problem stems neither from the fact that it is the staple food of more than half of the world's population, nor from the fact that this population apparently increases faster than the rate of increase in rice production. Instead, the technical, economic, social, and physical problems that continually beset rice producers the world over make rice production an international problem. As such, it demands national, regional, and global measures which can only be effected through international cooperation.

It is rather surprising that the need for international cooperation in meeting the problem of rice production through rice improvement was properly understood and fully appreciated only lately, just about two decades ago. In 1949, to be more precise, the first international body, the International Rice Commission was created by the FAO member governments to promote international understanding and cooperation in dealing with the technical aspects of rice production, protection, conservation, and consumption

Although research in rice has been undertaken by the various rice-growing countries of South and Southeast Asia since the turn of the century, cooperative research has been of recent development. Rice selection work started in Indonesia in the early 1900's. At that time work was largely concerned with mass selection at one station. Between 1920 and 1940, testing over a broad range of soil and climatic conditions

was conducted at several regional research stations. One of the first rice research programs in Asia began early in the century at the Agricultural Research Institute in Dacca, Bangladesh. These research efforts resulted in new rice varieties and in improved techniques for the Bengali farmer. In India, rice research has been carried out in Tamil Nadu and Bengal since 1910. Now over 100 experiment stations conduct research at one level or another. The largest, best staffed, and best equipped of these, the Central Rice Research Institute at Cuttack, Orissa, which was established in 1946, conducts both basic and applied research. Rice research in Ceylon which started in the 1940's, largely focused on selection and purification of local strains. In 1950 when breeding attracted the attention of the Ceylonese, a new rice breeding station pursued a program of crossing high yielding introduced lines with local materials. The varietal improvement aspects of these programs have only recently been integrated into the coordinated rice improvement programs within the region.

In the Philippines, rice improvement activities began as early as 1909 when the University of the Philippines College of Agriculture started introducing new varieties from the neighboring countries, notably Indonesia, India, and Taiwan. Work on varietal selection and subsequent crossing with local strains followed. Rice research was undertaken largely by the U.P. College of Agriculture and by the Bureau of Plant industry at its Maligaya Rice Experiment Station in Muñoz, Nueva Ecija. Only after 1952 was cooperative rice breeding work begun among Filipino rice researchers. The U.P. College of Agriculture, the Bureau of Plant Industry, and the Bureau of the West African Rice Research Station at Rokupr, Sierra Leone, designed Improvement Program. To date the most outstanding contribution of this breeding program is the variety C4-63 which was developed at the U.P. College of Agriculture and released in 1966. Its high yielding ability coupled with very good eating quality has made it widely accepted among farmers outside the Philippines.

In West Africa, rice research dates back to 1953 with the establishment of the West African Rice Research Station at Rokupr, Sierra Leone, designed to serve the four British colonies of Sierra Leone, Ghana, Gambia, and Nigeria. For 9 years, research was conducted on varietal improvement diseases, acid sulfate soils, and rice quality. Initially, the work was led by British scientists with Africans from all the colonies joining the staff or visiting the station for training and study tours. This promising international approach to rice research was given up in 1962, when the cooperative funding was halted following the gaining of independence by the West African colonies. National programs took over. Cooperation continued

largely through the exchange of small amounts of germ plasm and published reports in English among the various research centers.

In French-speaking Africa, a program of rice research was conducted before 1960 in Zaire at Yagambi and several other centers. Somewhat later, in 1961 in the Senegal and in 1968 in the Ivory Coast, rice research was in the hands of the French overseas organizations such as the Institute de Recherches Agronomiques Tropicales et des Cultures Vivrieres, Institute de Recherches Agronomiques de Madagascar, and Organization Recherches Scientifique et Technique de'l Outre Mare.

Most Latin American countries have had rice research projects of one level or another for many years before the introduction of the high-yielding varieties from Asia in the late 1960's. Their acceptance of the new varieties has been as wide as anywhere else in the world. Mexico, Cuba, Colombia, Venezuela, Ecuador, and Peru have over 25 percent of their rice area planted to these varieties. Approximately 500,000 hectares of high yielding varieties were grown in 1971 in Latin America. Unfortunately, much of the new technology does not apply directly to the temperate rice-growing regions of southern Brazil, nor does it fully apply to the vast upland rice areas of that country. But interest is keen, and the future may yet see Brazil more strongly involved in international collaboration. A strong cause for optimism is the distinct possibility that breeding lines that developed in the joint IRRI-Korea program may have value in the temperate regions of southern Brazil. One of the more interesting and active new developments in rice research in Latin America has been that in Peru where emphasis has been given to adopting the new rice varieties from Asia to Peruvian conditions. Yields of 11 to 12 tons per hectare have been reported from plant types similar to IR8 and other varieties of Asian origin. Developments in Latin America evidently parallel closely those of other parts of the world.

There is no doubt that long before the establishment of the International Rice Commission, substantial achievements in rice research had been made. This research which was undertaken independently, without coordination, in the various rice-growing countries and regions of the world set the stage for the program of international cooperation later on.

Based on the recommendations made at the International Rice Meeting in the Philippines in 1948, after the preparatory international meetings in the USA in 1946 and 1947 and in India in 1947, the International Rice

Commission was established in 1949. The first IRC session was held in Thailand in 1949. Three technical working parties were subsequently established: Working party on Rice Production and Protection in 1950; Working Party on Rice Soil, Water, and Fertilizer Practices in 1951; and Working party on the Agricultural Engineering Aspects of Rice Production, Storage, and Processing in 1960. International cooperation for rice improvement was inaugurated through these three working parties of IRC. The meetings of IRC served as a forum for discussion and as a basis for framing suitable recommendations on rice improvement in the various rice-producing countries as well as on the formulation and conduct of cooperative projects. In addition, the *IRC Newsletter*, a quarterly started in 1952, served as a vehicle for the dissemination of recommendations and knowledge gained through an exchange of information as well as results of rice research.

The first milestone of international cooperation in rice research was the cataloging of the world's genetic stocks of rice in 1950. This effort inevitably led to the setting up of international centers for the maintenance of these stocks and seed exchange at five places: Cuttack, India; Bogor, Indonesia; Habiganj, Bangladesh; Hiratsuka, Japan; and Fort Collins, USA.

The problem of improving fertilizer response among indica rice varieties which were regarded as inherently low yielders was initially approached through hybridization with japonica varieties in the Indica-Japonica Hybridization Project which began in 1951. Much information useful for breeding by crosses between indica and japonica rice varieties came from this project and three varieties were developed for commercial use: ADT 27 in India and Malinja and Mahsuri in Malaysia. But the failure to undertake final selection at increased fertility and an inadequate understanding of fertilizer response limited the outcome of this project.

In view of the immense importance of sufficiently trained plant breeders for successful rice breeding programs, FAO conducted international training courses in 1952 and 1953 at the Central Rice Research Institute at Cuttack.

To test varietal response to different levels of fertilizer and to promote the breeding of highly responsive varieties, international variety x fertilizer interaction studies were conducted from 1959 to 1964 in several Asian countries, notably India, East Pakistan, Ceylon, and the Philippines, as well as in the United States and Japan. Some characteristics of highly responsive varieties were reported from Japan. Research in Ceylon indicated better chances of identifying highly responsive varieties in crossing among indicas. The variety H4 was cited as a notable example.

The successful introduction of recommended varieties from one country to another and the increasing need to reduce the number of recommended varieties, because too many hinder seed multiplication and seed distribution programs, led to international cooperative variety trials on a climatic regional basis from 1956 to 1959. The importance of breeding for insensitivity to photoperiod was brought out in the context of adaptation to a wider range of ecological conditions.

The search for an effective control for the rice blast disease, a serious menace to rice which is aggravated by the heavy use of fertilizer, prompted the international uniform blast nursery test which was initiated in 1961 by the IRC in many temperate and tropical countries. Much valuable information on the sources of resistance to blast disease has been used in breeding and in the identification of the principal races of blast in rice-growing regions.

The rice production statistics of tropical Asia show that up to the early 1960's production increases depended largely upon increases in area rather than on higher yields per unit area. New directions were needed in rice breeding to obtain higher yields. Moreover, various other problems in rice production required international and fundamental research. Thus the need for an international research institute to cover the various aspects of rice improvement adequately was strongly felt and stressed by the IRC member countries at the IRC session in Tokyo in 1958.

The most significant milestone in the progress of rice research in tropical Asia was the founding of the International Rice Research Institute as the first significant joint undertaking of the Ford Foundation and The Rockefeller Foundation with the full cooperation of the Government of the Philippines. The outcome is an indelible part of contemporary history — the successful breeding of the now famous high yielding varieties starting with IR8, known as the "miracle rice," and followed in succession by IR5, IR20, IR22, and more recently, IR24. High yielding varieties have made such a great impact, directly and indirectly, on rice production and rice improvement, that the founding of the IRRI may well be recorded as the greatest success story of the past decade. It is now a 10-year-old institution under the outstanding leadership of Dr. Robert F. Chandler, Jr. The potential for service it holds for mankind gives the rice-eating peoples every reason to be optimistic in a world anxiously engrossed . the life-and-death race between food production and population growth.

The effectiveness of IRRI in promoting international cooperative rice research lies in its innovative policy and strategy of organizing and managing research. It instituted problem-solving techniques in research using an intra-and inter-disciplinary team approach. In all my years of close association with IRRI, I have always felt the strong sense of teamwork among its staff members. Undoubtedly the IRRI scientists have learned to understand and appreciate the value of esprit de corps. To my mind the dedicated commitment and the feeling of oneness among IRRI staff members and trainees in various parts of the world account for much of the institute's success.

IRRI was not content to rest on its early laurels. In time, hand-in-hand with its recommendation of high-yielding varieties came a package of improved cultural practices developed at the institute. Both improved varieties and practices were the result of meticulous sifting and selection through a monumental bulk of research findings from individual experiment stations and demonstration farms inside and outside the Philippines. IRRI felt, and rightly so, that technology must be shared to be of consequence. This sharing was facilitated by the network of scientists on the IRRI staff and their trainees whose programs and activities constantly coordinated their expertise and experience to make possible the unprecedented breakthrough in rice production.

Towards the effective use of its available resources, IRRI has underscored the need for concentration of its resources, assiduously avoiding a proliferation of these in pursuing worthwhile objectives. It has made clear distinctions between technical and managerial competence. Good technicians may prove to be poor managers. On the other hand, a good manager without technical expertise will not be in a position to provide effective leadership in substantive fields of activity. IRRI has done a good job of identifying both of these qualities in the selection of its staff for leadership.

With its well-chosen leaders, IRRI has shown how to establish and organize not only an international institution but also a cosmopolitan community. It has shown how to develop an institution into a center of excellence. It has adopted a continuous program of improving its standards of leadership and management designed to prepare its younger staff members for leadership positions through academic training and field experience.

IRRI has likewise set a good example in developing new attitudes among scientists as effective participants in cooperative research programs. Evidently, IRRI has succeeded in inculcating on its staff and trainees the need in cooperative research for a sense of personal commitment, competence and a sense of mission and courage. IRRI scientists

have learned the patience to observe and the humility to learn. There is great merit in having the humility to learn from others, even from the so-called common people. One should endeavor to go to the villages and meet the people. There, one will be surprised at the amount of stimulation and even inspiration that can be drawn from them. IRRI scientists have learned to become development-oriented rather than merely subject-matter-centered. It is well for scientists to become accustomed to thinking in terms of development policies if they are to deal competently with development as a whole. One cannot, for instance, divorce cultural practices from economics, production from marketing, marketing from trade, and the "micro" from the "macro" elements of an industry. IRRI scientists are to be commended for their courage in meeting the verbal onslaughts of their critics. They are not afraid to be controversial and radical in their proposals of new varieties and techniques. They win over those suspicious of change by persuasion and action. They have not been cowed by "nationalistic" hecklers who see in their efforts traces of an "imperialistic" design.

You will agree that the prestige of the IRRI as an institution has not really been built only by the new high-yielding varieties that it has released to the world. Its good name has been built upon its reputation as an "island of competence." It has successfully made itself the prototype of an institution staffed with a highly competent team of experts selflessly dedicated to the development of the rice industry. It has shown the world that it is not merely a rice research agency but a development agency as well.

The IRRI director has manifested not only distinctive administrative and leadership abilities which have been responsible in developing the IRRI in the first decade of its life into the oustanding international institution that it has become; as a science statesman, he has also developed a masterful strategy of coping with the changing moods and circumstances surrounding fund donors, as well as with the political pressures that are invariably exerted upon any administration. He has promoted meritocracy, not bureaucracy.

IRRI is a good example of how an international research institution should function in order to be truly viable and effective. As a research institution, it realized early enough that to attain its objectives more effectively, it should not limit its activities to research. It extended its concern to the training of people who would be expected to participate in the programs of increasing rice production in the various rice-growing countries. It also set up its own extension and communications programs which bring its new technology direct to the farmers for testing and demonstration. From this extension program, it obtains feedback on the

other problems arising out of this new technology. It conducted demonstrations on this technology as well as action programs covering bigger areas of the village so that the economic and social infrastructure necessary for increasing rice production may be better identified. In addition to all these, it has sponsored international conferences, seminars, and forums for discussion of the pressing problems, not only of production but the whole rice industry in a balanced proportion. IRRI deserves credit likewise for its recognition of the need to establish a strong link with research and academic institutions, initially with the University of the Philippines College of Agriculture, from the day of its founding.

In a manner of speaking, there are few, if any, problems of rice production which can be regarded as new. The components of the problems are much the same as they were earlier. These problems, however, have drastically changed in three dimensions: size, urgency, and complexity. IRRI will no doubt continue its meaningful role in resolving these problems or in intensifying whatever efforts it has already exerted towards this end. Examples of areas in which IRRI can take the leadership are not hard to find. For instance there is a key technical problem, the agro-ecological aspect of production that calls for an international cooperative approach.

At no other time is the role of the rice germ plasm bank in breeding more fully appreciated than at present. Its significance is particularly felt in the breeding world in the field of resistance to pests and diseases which has already achieved some appreciable degree of success in a few of the new improved varieties. The collection, maintenance, and evaluation of rice germ plasm must be increased. FAO will further intensify its cooperative effort with IRRI in this undertaking.

The fact that total production per head is expanding slowly in spite of the encouraging progress in cereal output in the Asia region is an indication of the magnitude of the efforts that have to be made if consumption levels are to be raised without recourse to importation. Efforts I am sure, will be continued to spread the techniques related to high yielding varieties of cereals to the production of other foodstuffs like beans, vegetables, rootcrops, eggs, milk, and meat, demands for which will increase as income rises and as population expands. The precariousness of the progress in Asia is also manifested by the production results of 1971 which indicate that the growth of agricultural production in the developing countries of the region is in the order of 2 to 3 percent which would be

substantially less than in recent years and barely in line with population growth.

At this point we must be reminded that the progress and ultimate contribution of the green revolution will be determined by how its benefits are shared. Its full impact will be felt in the next decade when the sharing of the technologies in rice production will be institutionalized among the rice-producing countries. The need for new technology is nearly universal, not limited to any particular country or group of countries. In organizing and institutionalizing the sharing of technology in rice production, the role of the IRRI should not be limited to the assembly and dissemination of knowledge but must include the adaptation of a given technology to a country, for, after all, agricultural technology in general is location specific. The 1970's call for a much more systematic sharing of technological resources among countries than has been done in the past.

The agricultural breakthrough presents a serious social implication. It is regrettable, as claimed, that the benefits of the green revolution have generally gone to others than small farmers in unirrigated areas.

With the ample technology now available to increase food production, the problems of the rice industry in many developing countries will be much more political and less technological. The removal of the constraints and the ultimate solution of the problems of the rice industry will depend on the political will of national leaders to see that enlightened policies are formulated and implemented. The rate of adoption of the high yielding varieties in Asia and the Far East ranges from 1.0 to 50 percent. The rate and extent of this adoption have been onfluenced by a number of factors, including physical, ecological, institutional, structural, administrative, and economic pressures and consumer preferences. Adequate attention to all these factors requires a strong political will of national governments to get agriculture development programs moving in the right direction.

The growth in size, urgency, and complexity of the production problems of rice is being matched by corresponding changes in the policies, organization, management, and program of the work of IRRI. I am sure that IRRI recognizes that its program and the second-generation problems to which the new technologies are giving birth cannot be treated in isolation from the problems of unemployment, social injustice, malnutrition, population growth, and pollution of the environment. It must also take note that the purpose of the green revolution is not merely to produce more food or achieve rice self-sufficiency. Its real purpose is to promote development in terms of producing quality food at lower prices and raising the incomes of the rural dwellers. This aim implies that the development

of the rice industry is not merely a matter of improving technology or increasing yield per hectare or improving handling, processing, marketing, and trades; other objectives affecting the farmer must be observed in the wider context of the well-being of the rural communities.

I am inclined to assume that IRRI in the near future would be able to mobilize resources in the formulation of a planned regional and international cooperative program to increase rice production. I do not mean that IRRI has to be the global planner, for I doubt whether governments would accept the prescription of IRRI in such a capacity. Rather, I envision an important function of IRRI as an advisory one — to governments or countries. Its role will be that of an impartial analyst, identifying alternative policy actions of rice production programs in any given situation and analyzing the effects or consequences of these in relation to national development objectives and regional and international development strategies.

IRRI will be in a position to advise in the summing up and analysis at regional and international levels of the implications of national policies and objectives of rice production programs and those of other food crops and to anticipate potential conflicts and complimentarities of national policies. It can thus alert and advise governments on the regional and international consequence of the national policies. To carry out this function effectively and gain the confidence of governments and the public at large, IRRI will be capable of anticipating at an early stage the technological needs, as well as the economic and social changes, in the region. This function can be exercised at national, regional, and international forums, by the director himself, and by teams and task forces created to cope with certain problems and situations. It appears that there is a need, therefore, for IRRI to create a policy team of experts composed of a development economist, a top rate agriculturist, and a social scientists who will help the institute perform this advisory or policy role.

The growth in size, urgency, and complexity of the rice problems of this decade will require a shift in the Institute's approach to technical assistance from a project-oriented to a country-program-oriented system of operation. How can this arrangement be achieved? The basis of this shift will be the development of carefully planned and executed country programs. The central core of such a program will always remain in the individual governments themselves because they must plan, and implement their own national production programs. The role that IRRI will play is ensure that the government concerned has full access to the needed information so that a coherent, well-integrated program can be

formulated. Into this program IRRI can well fit itself particularly in projects in which the local capabilities can best be developed and used and where the counterpart institutional framework is adequate and agreed upon at the highest political level.

The country programming exercise on rice production can then be the basis for intercountry or regional or global cooperation programs. There are basic elements in a country program that can best be solved in a regional cooperative program, the development of which has been neglected. Such regional cooperative programs should be those with wider applicability and those that stimulate the maximum complementary efforts and cooperation by others, whether in terms of national action or of technical and financial assistance from other donors. The country programs can also be the basis of global or international development strategies.

There is no doubt that no other institution devoted to rice has done as much in research and extension as IRRI. If IRRI decides to widen its horizon of service to include the advisory or policy role suggested above, I am certain that IRRI will be cautious in expanding its staff; otherwise, it might burden itself with heavy bureaucracy that can set back its operational efficiency. With its present size and staffing pattern it is quite efficient and highly effective. Beyond a certain level of staff composition, the additional personnel will just take the time of the other man. With country programming, IRRI can mobilize and make full use of the trained local people in the rice-producing countries. IRRI must take care that it does not do everything for these people or commit their mistakes for them. It can also reorganize its personnel into teams that will be responsible, for instance, to a priority problem like the control of tungro disease of rice. The team which is derived from the present professional staff will attend to the policy and planning for this problem. For the team's program and operation, task forces or individual experts will be enlisted to attend to specific objectives and activities.

With this organization, IRRI can adequately perform its five-fold role embracing policy making or advising, research, information and extension international forums, and harmonization and action-oriented (including field and village) programs. Of course, in the discharge of these responsibilities, IRRI will not try to do everything without a sense of proportion and without distinguishing priorities in time and substance. With this kind of involvement of IRRI, it will then be possible to achieve more speedily effective international cooperation in providing humanity more food to eat.

Modern rice research in India and its impact

B.P. Pal

India possesses nearly one-third of the world's rice area. Since rice is India's most important crop, it is natural that when scientific agricultural research began in the early years of this century, a large number of centers in India took up its study. But many were characterized by inadequacy of resources including trained personnel. There was also at that time a lack of opportunity for scientific communication between researchers isolated in the various experiment stations. In spite of the difficulties, commendable work was done at several rice experiment stations including Coimbatore, Karjat, Chinsurah, Raipur, and Nagina. Eminent scientists like Parnell, Ramiah, Parthasarathy, Hector, and Alam provided high-level leadership. The earlier work naturally enough tended to concentrate on the breeding of new varieties to suit the regional conditions of soil and climate, and the local cultivation practices. Selection of superior genotypes from the mixed local populations was followed by planned hybridization. The chief objectives were high yield, uniformity in height and maturation period, and quality as determined by local preferences. Some of the successful varieties bred during the earlier period like GEB 24, Co. 25, T 141, and Latisail are still popular today in some parts of the country.

But since a vast area of rice is grown in one, two, or even three seasons a year in India from low-lying areas to relatively high altitudes in the mountains and hills, the research resulted in a plethora of so-called improved strains and bottlenecks in seed multiplication and distribution occurred. Also the rice breeding programs were not sufficiently coordinated with or supported by advances in related disciplines such as agronomy, plant pathology, and entomology.

The wide gap between the increasing human population and a relatively static rice production in the major rice-producing countries began to attract special attention immediately after World War II. The rice supplies of the world fell far short of the need of the half of the world's population, for which rice is the staple food. To deal with this critical situation, the concerned member governments of the FAO established the International Rice Commission in 1949. Thus an international body came into existence charged with the duty of promoting international understanding and cooperation and dealing with the varied technical aspects of rice production. IRC and its three working parties met once in 2 years and provided a forum for mutual discussion, for drawing up recommendations for improvement of rice production, and for the formulation and conduct of cooperative projects.

Meanwhile significant changes were taking place in the rice growing countries. Thus India after it became independent in 1947, gave high priority to agriculture as reflected in the formulation and implementation of several major irrigation projects, the commissioning of fertilizer plants, and the establishment of an adequate infrastructure for agricultural research, education, and extension. The Central Rice Research Institute established at Cuttack in 1946 for carrying out basic and applied research on all aspects of rice culture was an important part of this infrastructure.

The ambitious project sponsored by FAO to hybridize indica and japonica varieties was of special interest for India. It was based on the assumption that the tropical ecotype of the cultivated rices, indica, lacked genes for fertilizer-responsiveness and that this attribute had to be bred into the Indian varieties by hybridization with japonica varieties from the temperate regions which were known to be nitrogen-responsive and highly productive. Simultaneously, another project with similar objectives financed by the Indian Council of Agricultural Research was implemented between 1950 and 1958, the Central Rice Research Institute being again the coordinating agency. Work under these projects led to the identification of the varieties ADT 27 and Mahsuri (the former developed in India and the latter in Malaysia). But aside from these limited gains, the japonica indica hybridization program did not achieve outstanding results because of lack of adequate understanding of the factors governing fertilizer response, e.g. the competitive nature of the tall and

leafy plants which suppressed the full expression of the potential of shorter and less leafy types. In spite of the lack of full success, however, this project was significant as the first major effort to highlight the deficiencies of tropical rice and to envision the development of high-yielding, fertilizer-responsive varieties by fostering international cooperation for the solution of monsoon Asia's rice production problems.

Another event of international importance in the world of rice was the setting up of the International Rice Research Institute with the objective of utilizing scientific advances for increasing rice yields in the tropics.

In connection with IRRI's work, mention must be made of basic research in production physiology done by several scientists in Japan on the role of morphological attributes in photosynthetic efficiency, nitrogen responsiveness, and high grain production. The importance of short culms and erect leaves had been emphasized by the Japanese scientists. This research however did not have a direct impact on tropical rices until the spontaneous dwarf mutant, Dee-geo-woo-gen, was discovered in Taiwan. This mutant is a landmark in the development of world agriculture. It was the decisive factor in the reorientation of rice research in monsoon Asia. The potentials of dwarf varieties like Dee-geo-woo-gen and their usefulness for tropical regions, however, remained dormant until the establishment of the International Rice Research Institute.

Scientists at IRRI made a global collection of rice varieties in an effort to understand the reasons for low yields in tropical Asia. The merits of dwarf rice varieties like Dee-geo-woo-gen, identified in Taiwan, and Taichung Native 1, bred in Taiwan, became immediately obvious. The concept of plant type has been crystalized and the breeding program at IRRI has been completely oriented in favor of developing dwarf rice varieties similar to Taichung Native 1. The celerity with which the new plant type concept has been enunciated and the speed with which the program relating to evolution of dwarf rices were implemented are a testimony to the dynamic leadership of IRRI.

Scientists in India have enjoyed the benefit of a close association with the IRRI since its inception. The director, associate director,

and other scientists from IRRI visited India several times between 1962 and 1964. Indian scientists participated in the symposia organized by IRRI on rice genetics and rice blast disease during 1963. G. V. Chalam, a senior officer from the Government of India, secured a small quantity of seed of Taichung Native 1, during a visit to IRRI in 1964, and introduced it into India. This variety was tested under different agro-climatic conditions and was recommended in 1965 for cultivation in various parts of India. The celerity with which the introduced variety had been tested and seed quantities multiplied constitute one of the best examples of speedy implementation of agricultural programs in India. While Taichung Native 1 illustrated the value of dwarf plant types for securing high yields, it became controversial because of severe disease and pest problems encountered in its cultivation.

Apart from introduction of Taichung Native 1 through IRRI, breeding materials developed at IRRI have been made available for studies in India. The first batch of materials of this type were made available to C. Subramaniam, the Minister for Agriculture, during his visit to IRRI in 1964. Since then, IRRI has been supplying breeding material for observations and studies by Indian rice breeders. One of the experimental lines (IR8-288-3) introduced into India was identified to be significantly better than Taichung Native 1 and it was recommended for release by the All-India Coordinated Rice Improvement Project during November 1966, a few months ahead of its being named IR8 by IRRI.

The introduction of Taichung Native 1 into India set in motion several organizational changes in order to step up the research effort on rice. There was no question about the high yielding ability of dwarf rice varieties like Taichung Native 1. Acceptance of a single variety over the widely different agro-climatic and socio-economic environments that prevail in India was at the same time not to be expected. Based on the model of the successful hybrid maize program in India, a coordinated research project on rice was ushered in by the Indian Council of Agricultural Research with the objective of lending direction to the research efforts in various rice experiment stations in the country. An imaginative hybridization program involving exotic dwarf rices, on the one hand, and the indigenous consumer-preferred and pest- and disease-resistant varieties on the other, was drawn up in the inaugural meeting held at Cuttack in November 1965. This program, designated the All-India Coordinated

Rice Improvement Project, with its headquarters at Rajendranagar, Hyderabad, has been responsible for the evolution of appropriate multi-locational testing procedures and fostering the development of multidisciplinary research throughout the country. With time, AICRIP emerged as the primary rice program enjoying the confidence of rice researchers and motivating them toward a common goal by pooling the technological resources scattered at more than 125 rice experiment stations all over the country.

While AICRIP, since it inception, enjoyed close collaboration with IRRI, this relationship was formalized only in 1967. During that year, a contract of technical and financial assistance was entered into between U.S. Agency for International Development, IRRI, and the Indian Council of Agricultural Research, under which four senior scientists employed by IRRI were located at the coordinating center of AICRIP to pursue research in agronomy, pathology, entomology, and physiology, and to work with Indian scientists in the evolution of production-based, multidisciplinary rice research programs. The scientist assigned to AICRIP by The Rockefeller Foundation was designated as the joint coordinator by the Indian Council of Agricultural Research, and as the group leader of the IRRI scientists. From time to time, scientists from IRRI have been visiting AICRIP and other Indian rice research centers as consultants. The Project Coordinator (Rice) of AICRIP and other Indian scientists have been participating in the annual program review meetings of IRRI and sharing research information obtained in India. A number of junior scientists in various Indian rice experiment stations have undergone training at IRRI from 1967 in various fields of specialization. In spite of diversity in funding — Indian Council of Agricultural Research, state departments of agriculture, agricultural universities, The Rockefeller Foundation, U.S. Agency for International Development, IRRI, the Ford Foundation, etc. – AICRIP has operated as a single program.

Cooperative research in rice breeding in recent years has led to the identification of several dwarf rice varieties covering a wide range of attributes. The variety Jaya, released in 1968, has consistently out-performed IR8 by 5 to 10 percent in grain yields and is also a week earlier in maturity. Another high yielding variety, Vijaya, released in 1970, provides not only better grain type but also

resistance to green leafhoppers. The variety, Ratna, also released in 1970, has excellent grain quality and is 2 weeks earlier in maturity than IR8. More recently, two varieties with exceptional grain type, IET 1991 and IET 1039, have been identified and are included in demonstration tests all over the country. IET 1991 matures in 130 days while IET 1039 is a week later. Among the early maturing varieties, the performance of Cauvery has been consistent and good. Among the 14 varieties released by the Central Variety Release Committee, 11 have originated from the breeding programs within the country, while three — IR8, IR20, and Pankaj — were introductions from IRRI.

Early maturing dwarf rice varieties suited for upland conditions and possessing grain dormancy, which prevents weather damage, have been identified. Breeders hope these varieties will be adapted to cropping patterns in north and northeast India.

Progress in breeding for resistance to bacterial leaf blight, tungro virus, and gall midge has been commendable. Several promising selections thus identified are being included in the farm tests during the kharif season in 1972.

Apart from developing dwarf varieties, several useful breeding procedures have been developed. Among the more important of these are the pre-planting selection for dwarf plant types and the evaluation of yield potential in the tall local varieties. In the primary crosses effected between tall varieties and the monogenic dwarf varieties employed in the breeding, three-fourths of the populations are expected to be tall in the F_2 generation. Selection in the F_2 population must obviously be based upon plant vigor. The performance of dwarf F_2 plants under these conditions is not good, when it is influenced by the shading of adjoining tall plants. It has been demonstrated, however, that it is possible to identify and separate dwarf F_2 plants even before transplanting so that the F_2 population predominantly consists of dwarfs. Eliminating the shading problem permits the dwarfs to manifest their genetic yield potential fully. This procedure has been extremely useful in evaluating individual dwarf plants, in minimizing the area planted to F_2 populations, and in obtaining better selections in later generations. The variety Jaya was developed in record time on the basis of selection of 300 vigorous dwarf F_2 plants from a dwarf F_2 population of several thousand in the cross, Taichung Native 1 x T 141.

Although many tall indica varieties have been involved in the primary crosses attempted at IRRI and India, it has been only a few

of the tall varieties like Peta, T 141, T 90, and GEB 24 that have led to the identification of high production dwarf rice varieties. It is therefore logical to assume that wide differences exist among the tall varieties for combining ability with the dwarfs. Obviously the genetic potential for high yield exists in several tall varieties, but this potential is not realized because of their poor plant type. Experiments on propping the tall varieties in open cages to permit an even exposure of foliage to solar radiation and to eliminate lodging and culture under wide spacing, and heavy fertilization led to the identification of elite tall varieties with high genetic yield potential which are now being used in hybridization. These varieties may eventually provide dwarf varieties whose productivity even exceeds that of Jaya.

In the early days of the propagation of dwarf varieties of rice, heavy fertilization had been recommended. This led to the misconception that the dwarf varieties perform well only under superior management and that indigenous varieties should be preferred under low levels of management. Data from agronomic tests at numerous locations over several years conclusively demonstrated that varieties that have good plant type outperform most tall varieties in grain production at all levels of nitrogen management, although the margin of difference is wider at higher rates of fertilization. This observation is really no occasion for surprise for scientists; but it helped in convincing the policy makers and obtaining their full support for the high yielding variety program in rice.

Photoperiod-insensitive dwarf varieties, in general, are earlier in maturity than conventional varieties. It was therefore recommended, in the early years of the program, that a major part of fertilizer application should be as a basal dressing to promote high tillering. Field experiments conducted since 1967 clearly belied this expectation. Topdressings of nitrogen have been shown to have a distinct advantage over complete basal application of nitrogenous fertilizer, in all soil types. While it might be expected that basal application would have the advantage of proper incorporation, under farm conditions, extensive losses of nitrogen occur because poor water management allows much nitrogen to be leached and the plant uptake is relatively poor during the early growth period. In other words, by timing the nitrogen applications

with the period of active tillering, losses of added nitrogen are minimized.

The importance of simple agronomic practices like shallow planting of seedlings to promote heavy tillering, and water management during topdressing of nitrogen, have been demonstrated so as to obtain greater efficiency of the added fertilizer.

Zinc deficiency as a major limiting factor in rice production in high pH soils has been amply demonstrated. Earlier research at Uttar Pradesh Agricultural University identified the problem of the so-called "khaira" disease as zinc deficiency. Deficiency of this element is widespread in many regions of India. The practice of application of zinc sulfate to the soil or spraying zinc-based compounds in correction of this deficiency has now been established in many parts of the country.

Entomologists have demonstrated the efficacy of chemical control of the rice gall midge with granular insecticides. Since granular insecticides are expensive, rational use of these would depend upon the magnitude of yield losses that occur in different locations and seasons. Investment in plant protection based upon the use of sophisticated chemicals is definitely warranted in some locations and seasons where even a 200 percent increase in grain yields have been obtained compared with the unprotected plots.

The complexities in the host-pathogen relationships, pathogenic variation, and epidemiology of bacterial leaf blight disease have been investigated in great detail. It has been established that isolates of *Xanthomonas oryzae* collected in different locations of India exhibit marked differences in pathogenic specialization. Several varieties thought to be resistant in Philippines are susceptible in India, presumably due to the greater virulence of the Indian isolates. A variety from West Bengal, BJ 1, exhibits by far the broadest spectrum of resistance to the isolates of the pathogen collected from different parts of the country. Even more important, studies at Hawaii (under a cooperative research project of IRRI) indicate that BJ 1 is resistant to a great many isolates sampled from many countries. International

screening tests thus provide an insight into the potential variation in the disease organism and permit inferences on the longevity of resistance.

Genetic control of the resistance to bacterial leaf blight in the cross IR8 x BJ 1 has proved to be very interesting. A common set of epistatic-hypostatic loci with different doses of complementation of basic genes controls the reaction to three different isolates of the pathogen so that screening tests need employ only one of the critical isolates. Thus, for instance, if the reaction is resistant to the isolate 146, resistance to the isolates 14 and 89 is automatically assured.

The existence of tungro virus was not authenticated in India until 1967. It did not take more than a couple of years for this disease to assume epiphytotic proportions in three states of north India — Uttar Pradesh, Bihar, and West Bengal. Studies in India revealed additional sources of resistance to tungro virus in Latisail, Kataribhog, Ambemohar, and Kamod. Strainal variation in rice tungro virus has been clearly pointed out by Indian scientists at AICRIP. The serious epiphytotic of 1969 has been attributed to a more virulent strain of tungro virus, and later studies indicated the existence of at least four distinct groups of tungro virus strains in India. Among the donor cultivars, Kataribhog is unique in preventing multiplication of even the most virulent strain of tungro. An interesting aspect of tungro virus is the "recovery" of infected plants following additional applications of nitrogen. It has been established that the resistance to tungro virus in the variety Latisail is governed by two dominant genes. The initial seedling reaction, when only one of the genes is present, is susceptible. Subsequently, however, the plants recover at the adult plant stage.

The acceptance and popularity of the new dwarf rice varieties vary from state to state. By far the best coverage has been in Punjab, Haryana, and western Uttar Pradesh. In the states of Punjab and Haryana, which were hitherto considered regions with strong preference for the superior grain type, IR8 and Jaya covered 60 percent of rice area in 1971 and no serious pest or disease problems have been encountered so far. This region therefore presents a very favorable climatic environment for high production. In some aspects, this is a spill-over benefit from the "wheat revolution" that occurred earlier

in these states. The superior technology which has been accepted and exploited has apparently led to a change in the attitudes of the farmers in bringing about similar changes in rice. A significant contribution to the central pool of foodgrains has been made by these states.

West Bengal and Kerala are two states with great density of population and for this reason, they have been drawing on the central pool for their food supplies. During the past few years, the popularity of dwarf rice in the boro season of West Bengal has grown greatly and consequently, the state is nearly self-sufficient in rice production. In both the states, the most popular varieties are Jaya and IR8.

The popularity of dwarf varieties has been on a steady increase in most other states, too. With the availability of increased choices of varieties, offering wide alternatives in maturity period, grain type, pest and disease resistance, it is not inconceivable that 50 to 60 percent of the country's rice area can be covered with dwarf rice varieties in the near future. The adoption of high-yielding varieties in Andhra Pradesh varies with the seasons. While the coverage has been extremely poor during the kharif season, dwarf varieties have been steadily gaining ground during the more productive rabi season. In West Godavari, the dwarfs covered 60 percent of the area during rabi 1971, and over 90 percent of the area in rabi 1972. In this region, Jaya is the predominant variety, though Ratna is gaining ground because of superior grain type.

The major obstacle in the spread of new varieties until recently has been the relatively poor grain type of the previously available dwarf rice varieties. This is now a thing of the past. Consumer-preferred varieties like Ratna, Vijaya, IET 1991, and IET 1039 will no doubt become very popular in the near future. The basic problem now is the failure to attain, in farmers' fields, a good part of the high yield potential expected from the new varieties. Several reasons can be cited for the low yields in the farmers' fields.

First, the need for improved cultural practices must be better recognized: shallow planting of seedlings to promote good tillering is important; thorough incorporation of added basal fertilizer is necessary to minimize the losses of nitrogen; neglect of water

management during early growth period restricts the tillering and tends to result in a paucity of productive panicles.

Second, the recommendation of an unrealistic package of practices is a deterrent to farmers. In the spread of new technology, extension workers tend to enumerate the ideal combination of practices without adequately understanding the corrective measures when an ideal practice cannot be followed. For example, when a farmer is forced to plant old seedlings, the only correction that is necessary is to plant the seedlings closer and to apply more fertilizer.

Quite often, the plant protection is ill-directed and ill-timed. The concept of springing into action at the incipient stage of insect attack is yet to be learned by farmers. In other words, the vigilance of farmers could be a substitute for costly prophylactic sprays. Cost-benefit ratios of granular insecticides remain unfavorable for most areas, except in a few endemic areas.

Third, the unsatisfactory level of resistance to pests and diseases of most of the present varieties is another crucial factor. The problem of pests and diseases would doubtless become more serious under good management conditions. The level of resistance that exists in most dwarf varieties to bacterial leaf blight, tungro virus, and leafhoppers is unsatisfactory, but that should not be considered a deterrent to the spread of the better varieties in view of their other advantages. None of the varieties so far released is resistant to rice gall midge. Leaffolders, armyworms, and cutworms are becoming increasingly menacing. With the evolution of varieties resistant to these pests and diseases, the spread of new technology should be much faster. It cannot be said, however, that all high yielding varieties are susceptible to all diseases and insects. Most dwarf varieties have a better reaction to blast than the local ones and the reaction of IR20 and Vijaya to tungro virus is better than that of other varieties and, in addition, Vijaya has good tolerance to leafhoppers.

Fourth, weak links between research, extension agencies, and farmers have been a major factor hindering the full impact of rice research on production. Regulations in the past prevented the supplying of seed of pre-release rice varieties to farmers. Since research in most states rests with the universities, and extension with the departments of agriculture, opportunities did not present themselves for extension workers to be fully familiar with the potentials of new varieties until the varieties had been released. While research programs have been

strengthened with the initiation of coordinated projects, the gap between research and extension remained wide. To bridge this gap, new programs of adaptive research, involving on-the-farm-testing of pre-release varieties and implementation of a massive "minikit" program to introduce a select few of the more promising varieties have been started in 1972.

Fifth, marketing and credit facilities must be strengthened. A great incentive for rice production in Punjab and Haryana is the guarantee of a suitable procurement price and organization of procurement by the Food Corporation of India. Since most of the rice produced in the states is not locally consumed, greater rice production would have been meaningless without a well-organized marketing system. In this respect, rice is the cash grain crop in Punjab. There is no comparable program of organized markets in many other states.

Sixth, better ways to supply seed of new varieties are a primary need. Although the coverage under new varieties appears small, percentagewise, taking the whole area into account, nearly half of the world's rice area under dwarf varieties is located within India. The magnitude of the seed multiplication programs and systems of taking these new seeds to innumerable rice farmers would thus be evident. The National Seeds Corporation is a government undertaking, which multiplies new varieties on a large scale. To plant 7 million hectares of rice with the new varieties in the year 1971-72, farmers all over the country would use approximately 280,000 tons of rice seed. The contribution of rice seed by the National Seeds Corporation during the year 1971-72 was not over a few thousand tons, while the quantities of seed handled through various departments of agriculture was about 20,000 tons. It appears therefore that much is left to the initiative of farmers. By operation of massive seed increase programs, seed of recently developed superior and more acceptable varieties would be available to more farmers, thus providing a greater coverage.

While a dramatic increase in wheat production occurred during 1968 and in later years, records of rice production (Table) indicate no such changes, even though dwarf varieties were introduced into the country at about the same time as the dwarf wheats, and the accomplishments of rice research in varietal improvement are of no smaller magnitude. One is often asked why the impact of rice research has not been of the same dimension as that of wheat research. Implicit in this question is whether there is any basic deficiency in technology or whether ancillary problems associated with the cultivation of rice provide

insurmountable difficulties in achieving marked production breakthroughs in rice. The most obvious difference is that wheat is a rabi crop cultivated under better climatic environments. Second, the major problem with wheat has been rust diseases, to which the introduced and indigenously developed dwarf wheats are rather resistant. Rice, on the

Area under high yielding varieties in India.

State/Union Territory	Area in high yielding varieties (000 ha)						High yielding varieties (%)
	1966-67	1967-68	1968-69	1969-70	1970-71	1971-72	1971-72[b]
Andhra Pradesh	275	350	205	522	599	900	26.5
Assam	2	21	61	101	148	196	9.8
Bihar	67	256	270	324	405	486	9.3
Gujarat	a	54	27	28	81	89	18.5
Haryana	-	4	10	20	30	50	18.7
Himachal Pradesh	-	-	5	18	32	36	-
Jammu & Kashmir	8	51	119	121	132	142	64.0
Kerala	70	21	220	239	283	400	45.7
Madhya Pradesh	53	32	132	209	220	300	6.9
Maharashtra	76	68	129	185	214	285	21.0
Meghalaya	-	-	-	1	2	6	-
Mysore	30	45	75	121	162	225	15.4
Nagaland	-	-	-	a	a	1	1.5
Orissa	46	121	146	170	245	400	8.8
Punjab	7	17	27	61	101	250	64.3
Rajasthan	a	1	5	10	16	30	25.2
Tamil Nadu	153	442	639	1142	1518	1575	58.6
Uttar Pradesh	69	150	331	561	689	797	17.5
West Bengal	26	131	266	459	567	800	16.2
Andaman & Nicobar	-	-	-	1	1	2	-
Chandigarh	-	-	-	a	a	a	-
Dadar & Nagar Havali	-	-	-	a	a	a	-
Delhi	a	a	2	3	1	2	-
Goa, Daman, Diu	3	8	9	9	12	14	-
Lacadive, Minicoy and Adminidivi Island	-	-	-	-	-	-	-
Manipur	-	-	-	4	8	12	-
NEFA	-	-	-	a	1	2	-
Pondicherry	3	11	5	23	24	26	-
Tripura	-	1	-	8	10	12	-
Total	888	1785	2681	4342	5502	7037	19.0

[a]Less than 1000 ha. [b]In relation to total area in rice.

other hand, suffers from a complex of pest-disease problems. Examining the nitrogen-responsiveness of dwarf wheats in comparison to dwarf rices, one finds no difference and this implies that there is nothing inferior in the new technology of rice as compared with that of wheat.

The manner in which the extension program for wheat has been implemented is quite different from that of rice programs. In wheat, large quantities of seed of the new varieties were simultaneously introduced in Punjab and western Uttar Pradesh, so much so that a wide spectrum of farmers was simultaneously exposed to the new technology. The cultivation of wheat in Punjab before the introduction of dwarfs has been, by itself, well advanced. The size of the new program with wheat thus provided wide coverage. In rice, extension programs have not been as clearly established in favor of the new varieties. Introduction of the "minikit" program with rice is the first step in the direction of securing reactions from many farmers at the same time.

Indian rice research has had an impact on other countries. Production programs aimed at resistance to gall midge in Ceylon, Thailand, and Indonesia rely on the materials developed in India. By transferring the resistance (which borders near immunity) from Eswarakora to varieties like W 1263, Indian scientists made available these materials for large-scale hybridization and screening programs in these countries.

The identification of BJ 1 as a variety resistant to bacterial leaf blight, and confirmation of resistance in this variety to the isolates of pathogen collected from different countries is a good contribution to the programs of breeding for resistance. Dwarf varieties developed for resistance to bacterial leaf blight, using BJ 1 as a donor, are being included in the international screening tests.

Collection of primitive varieties from northeast India and assessment of these materials for reaction to pests and diseases has proved to be extremely fruitful. A large number of varieties resistant to rice gall midge have been identified and these have been included in the international screening tests in other Asian countries. Data from the screening tests conducted in Indonesia during 1971 revealed that the materials identified as resistant to gall midge in India give concordant reaction in Indonesia.

While none of the cultivated rices in the germ plasm collection of IRRI carry resistance to grassy stunt virus, a single collection of *O. nivara* made available from India exhibits a high level of resistance to this virus disease. Breeders at IRRI have since transferred the resistant gene from this wild rice into dwarf varieties.

New confidence is evident in the rice programs of today in India. The researchers are sure that they could identify a problem and get solutions for it in a reasonable period of time. The work on problems of tungro virus and gall midge well illustrates this point. Tungro virus was not known in India until 1967 and the first epidemic was reported in 1969, but Indian programs have already evolved dwarf, tungro-resistant varieties that are being put out in country-wide demonstrations during kharif 1972. With regard to gall midge, the donors for resistance were identified before 1960, semi-commercial varieties were identified by 1966, and dwarf high-yielding varieties that are resistant to the gall midge were developed by 1970. These are being tested on farms during 1972. Citing yet another example, none of the dwarf varieties recommended before 1968 possess an attractive consumer-preferred grain type. In 1968, a dwarf variety, Hamsa, was released by the Andhra Pradesh Agricultural University because of good grain type, but it had a low yield potential. During 1972, two dwarf varieties, IET 1991 and IET 1039, with exceptionally good grain type and high yield potential, have been identified and brought under tests in cultivators' fields.

While resistance to a single pest or disease as often developed could be used to fulfill a shorter range objective, future programs will concentrate on combining resistance factors from diverse sources into one variety. These tasks will be accomplished during the 1970's with varying degrees of success. Even when this is done, one can never be certain that the job is completed since the pathogens and pests do change. In self-fertilized crops like rice, while it is easy to secure highly specific reactions to pests and diseases, the longevity of the accomplished resistance is always a matter of conjecture. There is already evidence that the populations of rice gall midge are differentiated into biotypes. When resistant varieties saturate an area, selection would tend to operate in favor of multiplication of a

biotype to which the variety has no resistance. Anticipating such changes, breeding programs must rely upon diverse sources of resistance. With the change in the pest, new varieties relying upon resistant factors from different donors have to be kept available on the assembly line so that the scientist always has something ready to give the farmer to meet the new situation.

The new rice technology and patterns of rural life in the Philippines

Gelia T. Castillo

Since anniversaries are occasions for memories, I must recall a well-known Filipino educator who visited this institute 10 years ago. While he marvelled at the handsome buildings, at the same time, he was skeptical as to what the IRRI could do about the traditional crop. "Somehow," he said, "I find it difficult to see the connection between this 20th century structure and the man who plants rice." But despite the pessimistic prognostications from several quarters, mostly from social scientists, the response of our rice farmers, as is now well-known, was beyond expectation. And judging from all the conferences and the growing volume of literature on the subject, the preoccupation of critics has shifted from the skepticism about the acceptability of the new rice technology to concern about the so-called Pandora's Box which its widespread adoption has supposedly opened. In many ways this phenomenon, journalistically labelled the "green revolution," is like Uncle Sam with respect to foreign aid — damned if he does and damned if he doesn't. But whether it's Cornucopia or Pandora's Box, nowhere else can one find a livelier, more intriguing setting for the study of the "green revolution" than in the Philippines — the birthplace of miracle rice. It becomes even more fascinating because, after a century of rice shortage, we had a rather short-lived self-sufficency which was heard around the world. But this is not a paper on why we have a substantial rice shortage at the moment. It is rather a discussion of the direct and indirect effects of the new rice technology on the farmer and his outlook on rice farming, the consequences on some village institutions and practices and the interaction between land reform and the new rice technology.

Since I am not gifted with a fertile imagination, what I have to say has been distilled from 50 papers and reports of village-level studies conducted among lowland rice farmers who have an average of 3 years formal schooling and

are mostly share-tenants cultivating an area of about 2 hectares in different rice-growing areas in the country. The theme of this celebration, Rice, Science, and Man, is most appropriate, for the products of science have finally reached the farmers' fields and affected the life of the men who grow rice.

Because the new high yielding variety was introduced as a commodity which cannot be left to the grace of God, farmers in fact gave it tender loving care which they seldom or never gave traditional varieties. The contrast was observed even among farmers who grew both types of varieties. Starting from a farm planted to traditional seeds, the farmer moved into a combination of traditional and improved local varieties, then he ventured into traditional and high yielding varieties and now he is on a different plane using only one high yielding variety or a combination of high yielding varieties. When asked what varieties they will plant for the next crop, a not unusual reply is: "I don't know; we're still waiting for a newer and better variety." It is amazing for example how IR8 dropped out of the picture almost as quickly as it had come in. But instead of reverting to the traditional varieties, farmers have picked up the newer high yielding varieties. Even after the recent outbreak of tungro virus disease of rice, the choice was still overwhelmingly in favor of the high yielding varieties.

Because of the more exacting requirements of the high yielding varieties, a change in work ethic and time consciousness has occurred. Far from leaving their fields to God, farmers are devoting more time and thought to the management of their farms. They admit that more frequent farm visits pay off in better yields because problems of the crop can immediately be diagnosed and remedied. As extension workers have observed, farmers growing high yielding varieties are in the field every day including Sundays and holidays, from early in the morning to late in the afternoon. An entirely new rhythm in rice production was brought about including changes in cropping pattern and the need for adjacent farms to synchronize varieties and planting calendars. There are even those farmers who are beginning to think that rest and the siesta after lunch means time wasted and that valuable time ought to be spent on productive work. Although there is a common complaint about farmers not appearing on time for village council, Parent-Teacher's Association, and farmer's meetings, they are not only punctual but early for tasks like transplanting, harvesting, and weeding.

In place of superstition, they have acquired a vocabulary of modern input terms ranging from the names of the new varieties to "Dol granule," "2,4-D," "Folidol," "Ratoxin," "12-12-12," "urea," and "Furadan." They have also developed the sophistication to make the finer distinctions between varieties on the basis of different characteristics such as lodging, height, tillering capacity, disease resistance, shattering, etc. Considering the kind of rice they were growing 6 or 7 years ago, it is noteworthy that the varietal characteristics they presently dislike are those *very tall plants with late maturity and low tillering capacity.*

Varietal and input trials in farmers' fields function as the farmers' introduction to the concept of experimentation. Although experiment station plots are wonderful for showing what is possible, they are less credible as to what is probable. There is nothing like seeing things in another farmer's field to convince oneself of good performance under local conditions. Measures to reduce risk took the form of multiple variety planting just in case the new one did not work out. Early adopters planted small areas to high yielding varieties but the lagging majority who took a "wait and see" attitude followed suit on a bigger scale after they witnessed results from their more adventurous neighbors.

As a sociologist, I grew up in graduate school thinking that it is necessary to change attitudes in order to change behavior but the early experience with IR8 has shown the reverse possibility. A group of farmers who initially were averse to using IR8 eventually planted it after a number of "forced compliance" measures were applied — credit given only when IR8 was planted, seeds provided free by landlords, expenses paid by landlords and the usual crop share guaranteed if production declined, and threat of ejection for non-compliance. After the first crop, farmers' attitudes toward IR8 became very favorable. The change in behavior brought about the change in attitude mainly because IR8 proved itself in terms of yield performance.

Improvements in livelihood within the past 5 years are attributed by the farmers to increased yields which have in turn heightened the ceiling of their yield aspirations and expectations. While before, 1.8 t/ha was regarded as their highest possible yield (1.2 t/ha was the national average for a long, long time) nowadays one encounters farmers who say that if one has not obtained at least 4.5 t/ha for four successive crops, he had better go back to school (meaning rice school). When a group of farmers, scientists, and extension workers were compared with respect to their average yield predictions 5 years hence, farmers made the highest prediction, 6.5 t/ha.

Extension workers predicted 5.2 t/ha and the scientists, apparently the least optimistic of the three groups, predicted 2.9 t/ha.

Even the concept of what makes a progressive farmer has changed. As recently as 1963, absence of debts was his most important characteristic. Credit, then, was resorted to mainly for consumption and emergencies. At present, one has to borrow money in order to make money in farming. Being indebted for production purposes has ceased to be socially degrading and "give us credit" is now the farmers' battlecry. For the first time in their lives, many farmers have had the experience of transacting business with the rural bank, and possession of a bank book is a newly found status symbol. A few even dream of becoming money-lenders when they become better off.

Once the farmers had been made aware of constantly changing technology and the need to acquire skills, knowledge, and resources to cope with all these changes, the agricultural extension worker (the farm management technician) assumed a very critical role. All the studies that have examined his role in the diffusion and adoption of the new rice technology have singled out his importance either negatively, because of his conspicuous absence, or positively, because of his conspicuous presence.

Before, it did not matter that the extension worker was hardly around because there was not much he could extend anyway. Now a first-rate extension man is not just an extender of information. He functions very much as a management input, a risk reducer, and a vital link with institutional sources of credit, modern inputs, and services. The ideal farm management technician, from the farmer's view is one who is competent, has frequent contact with farmers, and is a good adviser or consultant. This is indeed a change from the days when courtesy and friendliness were regarded as the most important virtues. One of the easiest ways to establish rapport with the farmers now is to demonstrate mastery of the new rice technology. In other words, the extension worker is now being judged professionally, not just personally. It is not enough to be a "nice guy." Farmers believe his sincerity only when he is dependably available when his presence and advice are needed at different stages in the farming cycle. The question asked of him when he arrives in the village is: "How long will you stay here? " The old system of here-today-and-gone tomorrow has never worked before and it never would.

One of the steps taken to equip the farm management technician for the increased demands of his job is a program of "changing the change agent" based on the simple assumption that one cannot teach what one does not know. Besides competence in subject matter and manipulative skills, a by-product of this approach is usually a new work ethic essential to match the farmer's

awakened enthusiasm. Sometimes the training program and actual field experience is so successful in inculcating the gospel of better performance irrespective of the 8 to 5 o'clock routine, that trainees become "rate busters," when they return to their organizations. The resulting inability to apply what they have learned because of limited resource or administrative obstacles pushes them to move to other jobs where their work ethic can be better satisfied. One study found an inverse relationship between technical competence and the number of years the farm management technician had been in his current position and a direct relationship between the length of time he had been a farm management technician and possession of attitudes characteristic of an authoritarian personality. Apparently the longer he remains on the job, the more authoritarian he becomes and the less likely he is able to improve on his knowledge of rice production. A "rusting effect" seems to inhibit learning.

As far as village life is concerned, increased incomes have brought along a few more chairs, sewing machines, transistor radios, beds, hollowblock walls, wooden and concrete stairs (instead of bamboo), galvanized iron roofs, dining tables, a gas stove, and even an additional bedroom in some instances. In the meantime, household size has increased mainly due to additional births. For those who worried that increased incomes would just go to more fiestas, there is a very slight increase in the number of households celebrating fiestas, but the amounts spent except in few cases were not as unreasonable as stereotypes about Philippine barrios lead us to believe. They are not spending a year's income on 2 days of feasting.

When asked in what ways people in the village differ with respect to social status, the reply in 1963 was mostly, "There are no differences among us here. We are all poor."With the opportunities currently available to improve their livelihood, there was increased attention on differences observed in terms of those who take advantage of the opportunities and those who bypass such alternatives. As the farmers stated: "Some are lazy; some are industrious. Some work hard even when they already have, while others don't have and yet do not try." Another perceived source of status difference was whether one was a farmer-cultivator or a mere farm laborer. The "lowest guy on the totem pole" was he who had no land to work on and was therefore dependent on available but unstable farm jobs.

Along with the material improvements in the household is the increase in motorization and village mobility through motorized pedicabs, motorbikes, and trailers pulled by hand-tractors. Since these vehicles are not inexpensive, one wonders how they have been acquired. At harvest time, a few sacks of rice easily take care of the down payment and the daily

earnings from passenger and hauling services help meet the installment payments which are reportedly completed at the end of 2 years. As the villagers remarked: ' Nowadays people do not want to walk anymore."

Besides doubling as a means of transportation, these hand tractors are used for custom plowing and harrowing. A general consciousness of the large investment in these and other agricultural machines has led to new norms governing their use. There has been an apparent decline in the *bayanihan* system (mutual exchange of labor), and a growth of more business-like contractual relationships. A definite hiring price for tractor services is becoming customary. When asked if tractors are borrowed under the traditional exchange of labor practice, farmers smiled and said: "Only if ones' own tractor breaks down does he attempt to borrow someone else's." The tacit understanding is that at some future date the other party will reciprocate. This implies that if a farmer does not have a tractor, he has no basis for the exchange. Sprayers are borrowed for free by friend, relative, compadre, or neighbor only once or at the most twice, but not for always. The net effect has been for farmers to want to purchase or rent equipment so that they can use it regularly without the embarrassment of borrowing.

Even the age-old practice of having neighbors and relatives perform the weeding operations in the field so that they also have the privilege of harvesting the same field is coming under scrutiny by the farmer. He now sees the advantage of specifically hiring labor to perform the weeding so he could obtain timely, effective, and better-supervised services. Under the traditional arrangement, the farmer is somehow kept by long-standing personal relationships from demanding a new quality of work. Actually the system of paying in rice rather than in cash has also been found to be expensive for there is a custom of measuring the harvester's share in more tightly packed cans than the farmer's share. Hiring labor to perform weeding, however, means more cash outlay which is hard to obtain.

Another local custom which has also disappeared is the romantic practice of planting rice to the accompaniment of guitar music. Of course this could have been romantic only to the tourists taking pictures by the roadside. Guitar music was actually provided for a very functional reason — to keep in time and to regulate the spacing of plants as they were transplanted. What replaced the guitar is the planting board with strings and distancing specifications such as 20 x 20. Haystacks which had been the setting for local movie love scenes are disappearing in double-cropped areas. There is no time nor place for them in the rush to prepare for the second crop.

Improvements in rice production may have played a part in the politicalization of the village. Although the Santa Claus — political dispenser

role of the politician is still expected, there is a growing realization among barrio people that these politicians cannot do anything about barrio problems and that this inability is associated more with higher government officials like the congressman, the senator, and even the president. On the other hand, the need for unity and cooperation among themselves is being acknowledged. In fact, the propensity for organized group action at the barrio level is gradually being awakened. The barrio people realize the futility of going it alone even for general bargaining power and sometimes take to the streets to demonstrate and picket. But because Filipino farmers, except for the Ilocanos, are very individualistic, organizing them for any sustained time requires a great deal of outside stimulation and support. The more encouraging results come from small farmers' associations centered on irrigation and credit problems. They function as a three-way risk-reduction scheme with the farmers, the extension worker, and the rural bank. Without the technician, the bank would not lend money especially to farmers who have no collateral; without the extension worker, farmers are reluctant to venture into substantial credit agreements particularly for long-term irrigation investment. So with the extension worker's faith in the production technology, in his own competence, and in the eagerness of the farmers to improve their lot, he serves as a guarantor both to the farmers and to the bank.

In many ways the new rice technology has contributed to the demise of the farmer's social and geographic isolation because he now has to depend on the outside world for inputs, credit, markets as well as technical advice. The traditional self-sufficiency of the village is moving into multiple links with outside institutions.

Another important development is the emergence of expertise in new farming methods as a criterion for leadership in the village. Such expertise has been acquired from exposure to technical training in the barrio or elsewhere because seminars, rice schools, and training programs for such farmer leaders have become commonplace.

On the home front, the wife's position as the uncontested treasurer of the Filipino family appears to be a bit threatened. A study in 1963 reported that in 91 percent of the households, the wife handles the family money. In 1969, this figure dropped to 83 percent with 3 percent more control by husbands and 3 percent more joint husband-wife control over finances. One can only surmise that with increased yields there is a little more money to exercise control over and with the need for more careful farm management and increased use of purchased inputs, the farmer finds some reason to take over. For their children, despite the newly found potentials in rice production,

farmers' aspirations have become increasingly more toward college education and white-collar occupations such as teaching and government employment. Only a few wish farming on their children.

As far as land reform is concerned the new rice technology has direct implications because it is a key ingredient in the productivity aspect of the program. It has often been argued that a farmer who does not own his land does not have the incentive to produce more because the increase in harvest would have to be shared with the landlord. So far, investigations of the relationship between tenure status and productivity or innovativeness do not support this contention. Share tenants, lessees (fixed rental arrangement), and owner-operators do not differ significantly with respect to yield per hectare or tendency to adopt modern rice production practices. Perhaps the original notion about what motivates farmers to increase production is premised on the wrong assumption. It is possible that a share tenant has greater incentive to produce more precisely because he has to share the products with his landlord while the owner-operator keeps whatever he produces. Incidentally, the landlords who shifted to leasehold have bigger landholdings, have more education, are more politically inclined, have the most number of tenants, and tend to have other sources of income besides their land. The landlords who remained on the sharing system have lower education, smaller landholdings, and fewer tenants. Where many tenants work under one landlord, the tenants as a group seem to have had more courage to ask for the shift to leasehold. When there are only one, two, or three tenants per landlord the tenants have great reluctance to break away from their established personal relations with the landlord. As a matter of fact, those who remain share tenants profess satisfactory relations with their landlord; they prefer a good sharing arrangement to leasehold and also prefer assured tenancy to ownership of the land they farm. Share tenancy is considered good because the landlord shares farming expenses and provides inputs. If yields are high, the tenant's share is also large. Lessees on the other hand, favor the leasehold system because of the bigger share from the harvest and the freedom to operate the farm more independently. This assumes that they could obtain production credit from sources other than the landlord. So far, the institutions which are supposed to take over the functions of the landlord are lagging behind. For example, many of the lessees have no working relationship with the farm management technician who is a principal element in the land reform program whether for technical advice or credit links. But despite problems in implementation, the existence of a land reform law has given the share tenant an option which has increased his bargaining power even when he has remained a share tenant.

If one were looking for problem areas, as most people are, it may be found among the lessees who are unable to obtain credit either from the landlord or from institutional sources. Farmers who already have better irrigation, higher yields, and greater propensity to adopt new practices also have higher aspirations, expectations, and demands for even more and better services. Chances are, they are also the group who will get what they want. Farmers' associations tend to draw membership from those who are a little bit better off in many ways and when credit, technical assistance, irrigation pumps, etc. are channeled through them, the non-joiners are left out even more. A dividing line between the timid and the entreprenueurial is created when opportunities present themselves and village people can no longer remain equally poor. Some will be better off than others. In thinking about these problems, it must be borne in mind that those who are a bit better off (*mabuti*) are only a little bit better off (*mabuti-buti*). They are not rich by any means because at the village level, hardly anyone is really rich by any standards.

Regarding the new technology, the enthusiasm for introducing them is not always matched by an equal sense of responsibility for action at all levels when things go wrong like irrigation failure, poor yield performance, misuse of insecticides, and disease outbreaks. The farmers are at least entitled to an explanation of what hit them.

Family planning, the other component of the development equation, has yet to have the impact at the village level that the new rice technology has. Not that the concept of family planning is unacceptable, rather the services are hardly available except in cities and town centers. Furthermore, despite the obvious relationship between the two, family planning and agricultural development programs tend to proceed separately and independently of each other.

There are those who have misgivings about the changes taking place at the countryside. They seem to be rather worried that more money is circulating and that the village is becoming heir to problems of modern man such as environmental pollution, a quicker pace of life, the passing away of traditional customs, and worship of material goods. What we sometimes forget is that only the affluent can afford the arrogance of rejecting the products of affluence. Our villages, should by all means, be given the opportunity to afford such arrogance. As it is, affluence is certainly not one of their problems.

Finally, accompanying the changes discussed is a general indication that the days of the lord master, and oppressive patron are numbered, if not almost

over. As one community leader said to a social action worker. "Five years ago, when you first came, you knew that we would not have had the courage to even stand before the landowner and demand anything. People just agreed to whatever he commanded even though we didn't always understand. Now that we know our value as individuals, that we too have rights and privileges, we just felt we must have courage."

The economic consequences of the green revolution in Asia

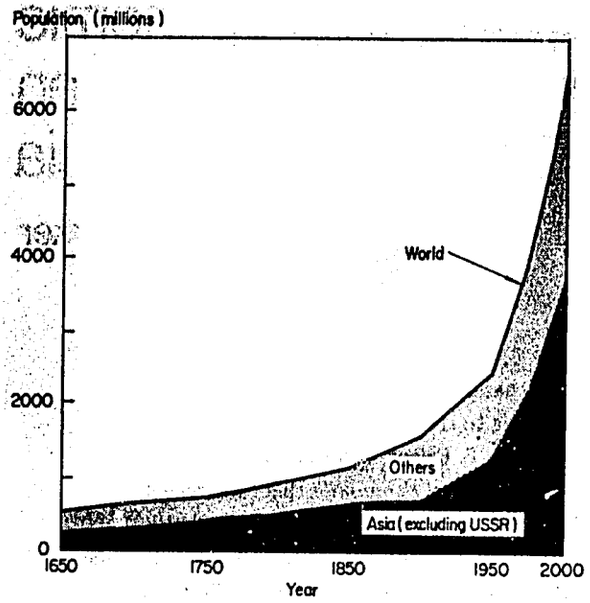
Randolph Barker

The "green revolution" has become a common and sometimes controversial concept referring to the changes taking place in agriculture in the developing world. Walter P. Falcon observed in a recent article in the *American Journal of Agricultural Economics* that "the recent flood of literature on the green revolution has a certain similarity to the theologians' writings on God: both are concerned with existence, consequences, and salvation, and both are equally contradictory in their conclusions."

The potentials, limitations, and consequences of the green revolution are becoming more clearly defined with the passage of time. The main controversy centers on whether or not the gains in output needed to support rapid industrialization must be achieved at the cost of greater disparities in rural life. This dilemma has important implications for the direction of research undertaken by organizations such as the International Rice Research Institute.

I would like to look at the progress, problems, and future prospects for the green revolution in Asia and in particular at the interaction between the socio-economic issues and technological change.

The concept of a revolution in agriculture is not new. The first recorded agricultural revolution took place from 8000 to 4000 B.C. This 4000-year-long revolution — a flash in the glacial movement of man's early history — occurred when many inhabitants of the Middle East, China, and the New World shifted from a life of nomadic wandering dependent upon hunting and gathering to a relatively sedentary life in small villages supported by the cultivation of domesticated plants and animals.



1. World population growth, 1650–2000.

The consequence of this revolution was a rapid increase in population: 16-fold from 8,000 – 4,000 B.C., and another 10-fold between 4,000 B.C. and 1798 A.D. At that point Malthus predicted that population had reached its limit. He proved to be a poor prophet. The agricultural revolutions of the 19th and 20th centuries allowed world population to quadruple (fig. 1).

During the 19th century vast areas of land came under cultivation throughout the world. The great granary of the Punjab was opened through irrigation. The rice surplus areas of Burma, Siam, and Indochina began to be fully exploited.

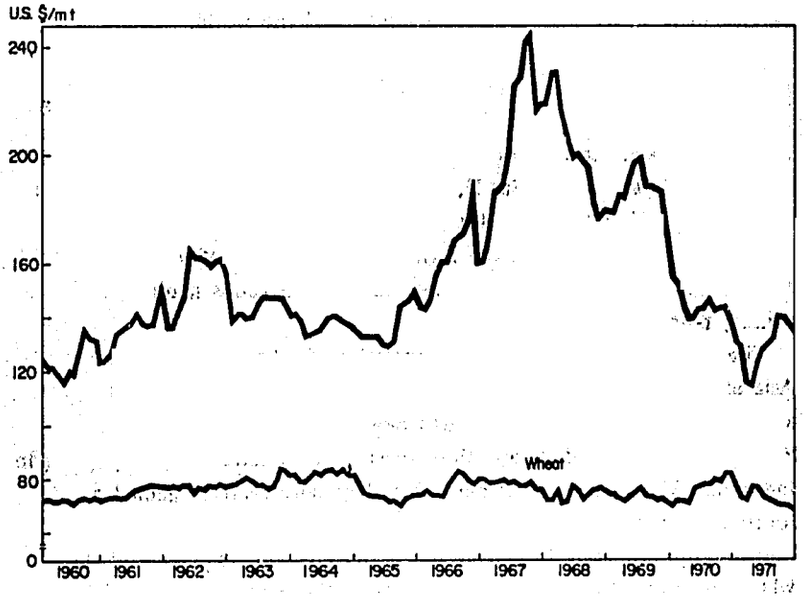
At the turn of the century, the application of modern scientific technology to agricultural production in the advanced countries of the world marked the beginning of the current era of agricultural development. Modern inputs – new seed, fertilizer, chemicals, and mechanization – were substituted for traditional inputs – land and labor. The spread of this phenomenon from the developed to the developing countries of the world we now refer to as the *green revolution*.

The introduction of modern agricultural technology in the advanced countries during the first half of the 20th century widened the

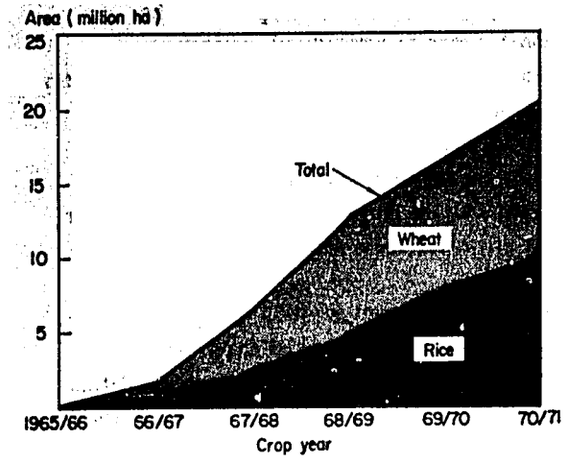
gap in agricultural productivity between the developed and the developing world. Traditional means of agricultural expansion were adequate to meet the food requirements of a rapidly growing population in the developing countries until after World War II. The growing disparity between the price of rice, the staple food of Asia, and the price of wheat, the staple of the western world (fig. 2) provides a measure of the change in equilibrium during the post-war years. Prior to World War II the world prices for these food grains were nearly equal.

The drought on the Indian subcontinent in 1965 exaggerated the disparity still further. More food was imported from developed countries, and the world rice price rose sharply. Many concluded that the fate which Malthus predicted for the western world 2 centuries ago was now imminent.

The population problem facing Asia is immense as figure 1 suggests. But the consequences of the delay in the modernization of agriculture in the developing countries go far beyond a race between "the stork and the plow." It is now generally recognized that the modernization process itself is needed to create agricultural surpluses sufficient to support



2. Prices of rice (Thai export price, 5% broken, F.O.B. Bangkok) and the price of wheat (American No. 2 hard winter, C I F United Kingdom).



3. Estimated area planted to high yielding varieties of wheat and rice in the less developed countries.

rapid industrial development. The challenge of the green revolution must be placed in the context of facilitating total economic development in the less advanced countries of the world.

Efforts to create a modern agriculture in Asia began immediately after World War II, but met with mixed success due to the lack of emphasis on the development of a technology suited to Asian conditions. Introduction of the high yielding varieties of wheat from Mexico and rice from the Philippines in the mid-1960s marked a turning point.

The spread of the high yielding varieties of wheat and rice in Asia is shown in figure 3 and by country in Table 1. The initial acceptance of the new varieties was most enthusiastic in India, Pakistan, and the Philippines. More recently they have become popular in Indonesia, Malaysia, and Vietnam. But they have scarcely gained a foothold in the traditional rice exporting countries of Thailand and Burma. Approximately 13 percent of the rice area and 33 percent of the wheat area in South and Southeast Asia were planted to the new varieties during the 1970—71 crop year, the total area in each crop being just over 10 million hectares.

Table 1. Area planted to wheat and rice and to high yielding varieties of wheat and rice in South and Southeast Asia, 1970/71. (Source: D.G. Dalrymple, "Imports and Plantings of High Yielding Varieties of Wheat and Rice in Less Developed Nations," *U.S. Dept. of Agriculture, Foreign Agricultural Development Report 14*, Feb. 1972)

Country	Total crop area (000 ha)	High yielding varieties (000 ha)	(%)
	WHEAT		
South Asia			
Afghanistan	2966[a]	232	7.8
Bangladesh	126	10	7.9
India	17892	5892	32.9
Nepal	388[a]	98	25.3
Pakistan	6061	2949	48.7
Total	27433	9181	33.5
	RICE		
South Asia			
Bangladesh	9913	460	4.6
Ceylon	651[a]	29	4.5
India	37433	501	14.7
Nepal	1174[a]	68	5.8
Pakistan	1503	626	41.7
Total	50674	1684	13.2
Southeast Asia			
Burma	4976	201	4.0
Indonesia	8237[a]	932	11.3
Laos	769	54	7.0
Malaysia (W)	541	132	24.4
Philippines	3113	1565	50.3
Thailand	7600	162[b]	2.1
Vietnam (S)	2599	502	19.3
Total	27835	3548	12.8

[a]1969–70. [b]Rough estimate.

The principal input associated with the high yielding varieties is fertilizer. Table 2 shows the change in nitrogen input per hectare in three regions of Asia from 1961–62 to 1969–70. An upsurge in fertilizer use occurred after 1965–66. The amount of nitrogen applied per hectare in South and Southeast Asia, doubled between 1965–66 and 1969–70, but is still only a fraction of that being used in the more advanced agricultural economies of East Asia. The potential for fertilizer use per hectare is more limited in monsoon Asia than in the more temperate East Asian countries due to the heavy cloud cover.

Table 2. Nitrogen use per hectare of crop area in Asia from 1961/62 to 1969/70 (Source: FAO Production Yearbooks).

	Nitrogen applied (kg/ha)		
	1961/62	1965/66	1969/70
South Asia[a]	2	4	8
Southeast Asia[b]	3	4	9
East Asia[c]	115	122	155

[a] Ceylon, India, Nepal, Pakistan (E & W). [b] Burma, Indonesia, Malaysia, Philippines, Thailand, S. Vietnam, [c] Japan, Taiwan, Korea.

Another measure of achievement is growth in production. In the production data, however, it is always difficult to separate the effect of weather and inputs. The growth in rice production in South and Southeast Asia between 1960–64 (before the failure of the monsoons in the Indian subcontinent) and 1968–70 was 2.8 percent. The growth in the previous 7-year period (1953-57 to 1960-64) was 3.5 percent. It may seem from these aggregate statistics that nothing has happened. Yet it is evident from the previous data and from reports throughout rural Asia that significant changes are taking place.

The shift in many countries from a growth dependent upon expansion in land area to a growth based upon increased yield per hectare represents one important change. Table 3 shows the contrast between two countries where the new technology has been extensively adopted, India and the Philippines, and two countries where the new technology has gained little acceptance, Burma and Thailand. A significantly larger portion of output growth has been achieved through a rise in crop yields in the former than in the latter countries. Lack of pressure on food production, the quality requirements of an export market, and the unfavorable environment for dwarf varieties were all factors that led to the low initial acceptance of the high yielding varieties in Burma and Thailand.

Variability in the physical environment is the major reason for the difference in acceptance rates for the new technology not only between countries, but also within countries. The effect of difference in physical environment is contrasted clearly in the performance of the high yielding varieties of wheat and rice (fig. 3 and Tables 1 and 3). The new Mexican wheats have been grown principally in a relatively

Table 3. Proportion of output growth explained by increased crop yield among four Asian countries. (Source: FAO Production Yearbooks).

Country	Crop	Crop area in high yielding varieties 1970/71 (%)	Output growth (%) Annual 1960-64 to 1968-70	Proportion explained by increased yield
India	Rice	15	2.0	57
	Wheat	33	7.9	70
Philippines	Rice	50	3.1	91
Burma	Rice	4	1.2	39
Thailand	Rice	2	5.3	47

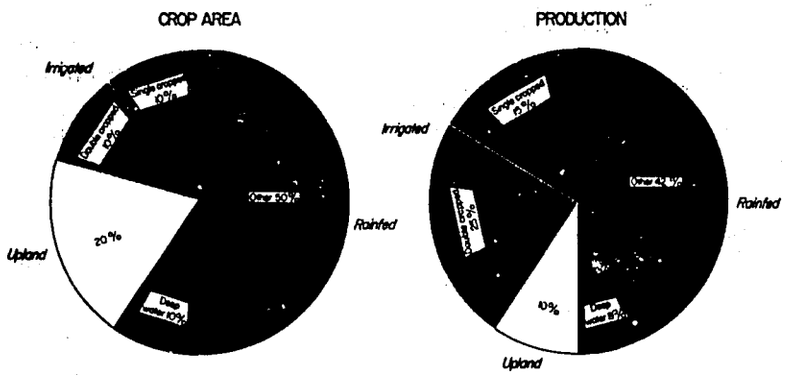
homogeneous area of Northern India and Pakistan which is favored by fertile soils, high solar energy, and extensive irrigation development. It is not uncommon for farmers in these areas to double their yields with the new seeds and adequate doses of fertilizer.

This area is a favorable environment for rice as well, and the same outstanding yield responses have been observed in regions such as the Sind in Pakistan, the Punjab, and the Tarai in Northern India. Unfortunately, however, these areas represent only a small fraction of the total rice growing area in Asia.

Most rice is grown in regions of high seasonal rainfall, where in the absence of good water control, water supplies are uncertain. Only about 20 percent of the rice area is irrigated (fig. 4), and even this area is not completely free from the effects of flood and drought. The degree of water control varies greatly among irrigation systems in the region.

In the large flood plains of South Vietnam, Central Thailand, Bangladesh, and Lower Burma the dwarf varieties are not suited to the deep water conditions. In the rainfed and upland areas, however, the new varieties perform just as well or better than local varieties. In the Philippines the new varieties are already being planted on 45 percent of the rainfed area.

The high humidity in the main rice growing season in the tropics coupled with the use of modern production practices provides an ideal environment for the development of diseases and harmful insects. Susceptibility to the tungro virus, for example, was responsible for the failure of attempts to introduce IR8 and IR5 into Bangladesh, and for the recent setback in Philippine rice production. The



4. Rice crop area and production by specified land type in South and Southeast Asia.

appropriate use of chemical control measures is both costly and complicated. Providing the correct information to farmers exceeds the capacity of the existing research and extension network.

Despite the many obstacles presented by an often hostile environment, much progress has been achieved. The decline of world rice prices to their earlier levels has caused some scholars and policy makers to question the self-sufficiency-at-any-cost goals of some of the developing countries. Technological progress in the food grains, as compared with other agricultural commodities, is reflected in the rising price of products needed to create a more balanced nutritional diet such as vegetables and pulses. The need for greater research emphasis on crops other than rice and wheat is now widely recognized.

Clifton R. Wharton, Jr., writing in *Foreign Affairs,* was among the first to catalog in his now famous Pandora's Box all the possible problems emanating from the introduction of high yielding varieties. Some of these have already been discussed. The disparity in the way that the benefits of the new technology have been shared has become increasingly controversial. The issue is succinctly stated in the opening paragraph of a recent book by Francine R. Frankel, *India's Green Revolution:* "During the first three five-year plans, India's approach to agricultural development was characterized by a commitment to two co-equal, yet often irreconcilable goals; the economic aim of

achieving maximum increases in agricultural output to support rapid industrialization, and the social objective of reducing disparities in rural life."

The disparity arises from the fact that the new technology, introduced into a heterogeneous physical and cultural environment, produces different results in terms of its effect on individual income and employment opportunities. Some regions and some individuals within regions prosper while others are disadvantaged in a relative if not in an absolute sense.

The disparity is further re-enforced by government policies designed to give priority to areas that would show the greatest potential for gains from the application of new technology. It is not surprising that this approach has emerged in view of the failure of early post-war efforts to achieve the growth in agricultural production needed to encourage economic development.

India and the Philippines have had the longest experience with the high yielding varieties, and therefore the effects have been studied more thoroughly in these countries than elsewhere. There is, of course, difficulty in drawing comparisons between countries of such different size. The Philippines, which has less than one-tenth of the rice growing area of India, might be likened to one of India's more favorable rice growing states in terms of its resource endowments. The sharing of benefits in India is normally viewed in the context of big farmers vs. small farmers. Only a small portion of Indian farms are operated by tenants, although the tenancy rate is high in some areas. Big farmers (with 5 hectares or more), it is argued, have gained relative to small farmers because they have ready access to the credit needed to purchase inputs. As a result of the big-farm bias, the high yielding varieties program is said to be quickening the process of economic polarization in the village.

The empirical evidence on this question appears to be mixed. For example, the new technology not only benefits persons with capital, but persons with irrigation. And in India more than 80 percent of the irrigated farms are less than 5 hectares in size – that is, in the hands of small farmers. Generally, observers agree, however, that the high yielding varieties program is hastening the decline of the traditional patron-client structure, and that measures must be taken to protect the interests of small farmers and landless laborers. The creation of the Small Farm Development Agency and the Scheme for Marginal Farmers and

Agricultural Laborers included in India's Fourth Five-Year Plan is evidence of the government's concern on this matter.

In the Philippines the equity problem is viewed in the context of landlord-tenant relationships. Share tenancy is widespread. The rice farm operating unit is typically 2 to 3 hectares. The large majority of Philippine farmers would be classified as small by Indian standards. Farm size as an issue has little meaning except with regard to the unequitable distribution of holdings among landlords.

The landlords encouraged the rapid spread of the new technology among tenant farmers because both would benefit under the share tenure arrangement. The landlords provided two crucial services — they extended credit and they shared the risk. For their services, the individual landlords, who are comparatively few in number, receive large benefits. There is, however, little evidence to suggest that the landlords have gained, overall, relative to the tenants.

The Philippine Government has also expressed concern over the issue of equity. In 1964 it adopted a land reform code designed to shift share tenants first to leasehold (cash rent), and finally to owner-operator status. The program has met with limited success. Apparently the government lacks the resources to assume the credit and risk-bearing role of the landlord.

At first glance, the difference in the institutional structure of farming has produced rather different results in the Philippines as compared with India. But there are some striking similarities. In both countries there is a wide disparity in the ownership of the factors of production. Both countries are experiencing the gradual decay of the traditional patron-client system. Both are finding it difficult to fill the vacuum being created in the social structure. The key constraint growth in productivity and a more equitable sharing of benefits is provision of credit to small farmers.

Employment is another potential source of disparity. In its initial stages the green revolution has increased the demand for labor. Some observers say it is also encouraging mechanization. Tractors and combines purchased by large farmers and landlords can be used to displace landless laborers and tenants, thus aggravating the employment problem. At the extreme this will lead to a bimodal structure of agriculture consisting of a small, efficient, and highly mechanized food producing sector and a large subsistence sector.

Local government policies and those of aid-donor agencies as well have encouraged the sharp rise in tractor sales in many Asian countries.

But the historical experience of Japan and Taiwan, and the more recent experience of many tropical Asian countries indicates that labor-saving mechanization, and in particular, the use of tractors, is not an essential component of an efficient and productive agriculture. In many instances mechanization is complementing rather than substituting for the use of labor. But government policies can be adopted, if desired, to control the pace of introduction of labor-saving technology without dampening the production potential of the high yielding varieties.

The mechanization controversy represents only a small part of the employment question. The promise of the green revolution lies in its capacity to create an agricultural surplus that will generate off-farm employment and capital investment. A relative decline in food grain prices makes it possible to maintain low wages without a loss in real income. It is too soon, however, to observe this effect on stimulating industrial employment; higher agricultural production and income can have a direct impact on rural non-farm employment as already indicated by a limited number of studies.

The green revolution has resulted in considerable progress in food grain production in many areas, but the major gains have been made under favorable environments and among farmers who were better situated financially. No apology is needed. Ten years ago it was uncertain whether progress of this magnitude could be made under any environment. A successful first step allows us to outline the path ahead more clearly.

The introduction of the new technology has accentuated the need for institutional reforms. New priorities for research are necessary. The prospects for the future of the green revolution are tied to the success of both of these endeavors.

The implementation of institutional reforms is the prerogative of each independent government. The recent historical experience of the West contributes few institutional innovations to contend with the massive problems of population and poverty that now face many of the developing countries.

Biological and mechanical technology can be designed not only to increase productivity, but also to alleviate some of the existing disparities. It is in this area that the International Rice Research Institute and other research organizations in Asia are already beginning to play an important role.

The release of IR8 in 1966 established a new potential rice yield. Rice research since that date has been directed primarily toward the removal of constraints to permit a larger number of farmers to achieve the potential of the new technology. The first task was to improve the grain quality of the high yielding varieties, and to a large extent this has been accomplished. The problem of developing insect and disease resistant varieties is considerably more complicated and offers no quick or lasting solution. But the emphasis currently being given to this research is justified in terms of its potential payoff. Resistant varieties that require less chemical protection reduce the risk and cost for big and small farmers alike. If crop loss is less likely, farmers will be encouraged to apply a higher level of inputs such as fertilizer.

Greater attention is now being given to the selection and breeding of varieties for tolerance to drought, deep water, and poor soil conditions. Field research has been undertaken to test varieties under rainfed and upland conditions and to develop a package of inputs suited to these conditions. Work is also under way to increase the protein content of rice. Most Asians receive over half of their total protein from rice. Therefore, raising the protein level by as little as 10 percent would be a significant achievement.

Dr. Athwal has already described the above mentioned projects in greater detail. It is sufficient to state here that by building more into the seed itself, the new technology can be spread over a wider physical and cultural environment. Just how much can be packaged into a single variety has yet to be determined.

Mechanical innovations can also be designed to complement desired institutional changes. Unfortunately, much of the mechanical technology available in world markets today is unsuitable for use in tropical Asia for a variety of technical and economic reasons. Through engineering research, machines are being designed that minimize the use of imported components, that can be produced locally at low cost, and that suit local needs.

The development and extension of technology tailored to the wide range of environmental conditions found in Asia will require a considerably greater investment in national research programs. Investment in irrigation and other agricultural infrastructure will continue to be necessary. Although there is a danger that these investments will be inadequate to cope with the problems, it is hoped that the achievements of the future will affect the lives and fortunes of many of those as yet untouched by the green revolution.

Outlook for world rice production and trade

J. Norman Efferson

The situation for world rice production and trade is volatile. As has been illustrated by developments in the Philippines in the last few months, supply-demand relationships can change rapidly and long-existing trends can be reversed in short order. These abrupt changes, however, are no excuse for not attempting to develop broad approximations of potential changes for use in national, regional, and world planning. It should be kept in mind that such approximations do not represent the same degree of accuracy that is possible for the physical scientist in determining the potential change in yields of two different varieties or in determining the impact of a pesticide on plant growth.

From 1965 to 1970, world production of rice increased from slightly more than 240 million metric tons of paddy to nearly 300 million tons (Table 1). The over-all increase was caused primarily by the expansion of production in Asia; Asia normally produces about 90 percent of the world's rice crop. In this region the area planted to rice increased about 6 percent from 1965 to 1971, or around 1 percent annually. Thus, part of the increase in production in Asia was the result of the expanded area planted while the remainder was the result of increased yields. In other regions, rice area remained relatively constant and most of the increased production was the result of higher yields. Preliminary estimates of paddy rice production for 1971 (Table 1) indicate that world rice production declined almost 2 percent from 1970 levels. This drop was due primarily to declines in mainland China, Pakistan, Japan, and Brazil, which more than offset major gains in India and Indonesia.

Table 1. Paddy rice production 1964 to 1971[a] (Source: U.S. Department of Agriculture).

Country	Production (million t)							
	1964	1965	1966	1967	1968	1969	1970	1971[b]
Mainland China	85.0	87.0	82.2	86.4	88.6	92.5	97.5	94.0
India	58.6	46.0	45.7	56.4	59.7	60.6	63.7	66.0
Pakistan	17.8	17.7	16.4	19.0	20.1	21.3	20.0	19.0
Japan	15.7	15.5	15.9	18.1	18.1	17.5	15.9	13.6
Indonesia	13.0	13.6	14.1	14.3	16.2	17.5	17.5	18.6[d]
Thailand	11.1	10.8	13.5	11.2	11.2	13.4	13.3	13.4
Burma	8.2	8.1	6.6	7.7	8.0	8.0	8.1	8.2
Brazil	7.6	5.8	6.8	7.0	6.4	6.9	6.3	5.0
Philippines	4.0	4.1	4.1	4.4	4.4	5.2	5.3	5.2
United States	3.3	3.5	3.9	4.1	4.7	4.1	3.8	3.8
South Vietnam	5.2	4.8	4.3	4.7	4.4	5.1	5.7	5.8
South Korea	5.4	4.8	5.3	4.9	4.4	5.6	5.6	5.8
Total	235.0	222.0	219.0	238.0	246.0	251.0	263.0	257.0
World total[c]	257.0	245.0	243.0	269.0	273.0	286.0	298.0	294.0

[a] Year beginning Aug. 1. [b] Preliminary. [c] Excludes North Korea and North Vietnam. [d] Adjusted based on Rice Trade Intelligence, FAO, Feb. 10, 1972.

World rice production increased about 18 percent from 1965 to 1970, but the annual increase was not uniform. Production jumped 11 percent from 1966 to 1967, remained at the 1967 level in 1968, and then increased another 5 percent from 1968 to 1969. Most of the production increase occurred in the 3-year period from 1967 to 1969.

Some observers have attributed the increase in rice production in recent years largely to the introduction of the new improved varieties plus the additional inputs and intensified extension work supplied with these varieties. A closer look at the timing of the increases and at the areas in which they occurred leads to the conclusion, however, that much of the increased production was due to factors other than the new varieties and the additional inputs. Table 2 presents a summary of the area planted to the high-yielding varieties in major rice-growing countries of Asia. It should be noted that the most substantial increase in production, from 1966 to 1967, occurred before the high-yielding varieties were widely planted. Between 1969 and 1970, when planting of the high-yielding types expanded greatly, total production increased only slightly and it declined in 1971.

Most of the world's rice depends upon natural rainfall and moisture. In much of Asia, this rainfall is the product of the monsoon season between May and October. If the monsoon rains are on time and of the right amount, and if the storms are not too severe or destructive, the crops are good; if not, yields are low. Much, if not most, of the rice production increase that has occurred in Asia in the last 6 years should be credited to favorable weather during the latter years of the period along with the 1 percent annual increase in crop area. The rest of the increase can be credited to the high-yielding varieties; the additional volumes of fertilizer, pesticides, and other inputs used; the intensified extension education programs; and the development of improved irrigation systems to provide more stable water supplies in the wet season and, occasionally, a second crop in the dry season.

To make sound decisions about future programs, countries where rice is a significant crop must evaluate future world rice production trends carefully. The headlines and thirst for spectacular journalism in recent years appear to have caused overemphasis on the contributions of the new varieties of rice to the production increase in recent years.

Table 2. Area planted to high-yielding varieties of rice in less developed countries (Source: U.S. Dept. of Agriculture).

	Area (000 ha)					
	1965-66	1966-67	1967-68	1968-69	1969-70	1970-71[a]
				South Asia		
Ceylon[b]	-	-	-	7	26	29
India[c]	7	888	1784	2681	4371	5501
Nepal	-	-	-	42	50	68
Bangladesh	-	*d*	67	154	264	460
Pakistan	-	*d*	4	308	501	626
				East Asia		
Burma	-	-	3	166	144	201
Indonesia	-	-		198	344[e]	932
Laos	-	*d*	1	2	2	54
West Malaysia	-	42	64	91	128	132
Philippines[c]	-	82	702	1012	1354	1565
South Vietnam	-	-	*d*	40	202	502
Total	7	1012	2625	4701	7386	10070

[a] Preliminary. [b] Excludes improved local varieties. [c] Includes improved local varieties
[d] Less than 1,000 ha.

As a result, there is a danger that this may lead some policy makers to erroneous conclusions and to programs that may be detrimental to maximum development. The new varieties along with additional inputs and better farm practices have played a large role in increased production and have also served as a catalyst of major changes in other areas, such as transportation and storage. These contributions will be important in the future. But, as spelled out by Staub and Blaze in their recent paper on genetic technology and agricultural development in *Science*, genetic technologies provide necessary, but not sufficient, conditions for agricultural development, and other factors must be considered.

In Asia, variable weather is likely to continue to be the most important influence on the production of rice. Low-production years will occur occasionally just as they have in the past. Also, in any given rice area in monsoon Asia, the maximum impact of the improved varieties, added inputs, and new methods can be obtained only when more and more of the region is provided with effective water control and irrigation. This will take time.

These observations are not meant to deprecate the contributions of the new varieties and the other research results which have been so important in recent years. The development of the short stiff-strawed, photoperiod-insensitive, nitrogen-responsive rice varieties is the most significant achievement in world agriculture since the introduction of hybrid corn. It is likely to go down in history as the most significant contribution to the welfare of mankind in this century. But it is not the ultimate solution. Continued and expanded research and education in all phases of rice production and marketing will be needed to keep pace with the growing needs for more food.

Most of the world's rice is consumed in the countries where it is grown. Traditionally, only 4 to 5 percent of total milled rice production moves into international trade. This proportion has held relatively constant in recent years. Total world rice exports amounted to about 6.5 million tons in 1968; 6.3 million tons in 1969; and from 7.0 to 7.1 million tons in 1970 and 1971 (Table 3).

In recent years, the United States has usually been the leading exporter, shipping 1.7 to 1.8 million tons yearly. Thailand was second with

Table 3. World rice exports (Milled basis) by major exporters. (Source: U.S. Department of Agriculture.)

Country	Exports (000t)			
	1968	1969	1970	1971[a]
United States	1,847	1,850	1,695	1,493
Thailand	1,068	1,023	1,029	1,542
Mainland China	1,025	900	885	700
Japan	*b*	341	618	800
UAR	497	499	654	800
Burma	352	549	630	700
Italy	186	179	347	370
Cambodia	191	85	220	225
Australia	97	121	109	120
Total major exporters	5,263	5,547	6,'87	6,550
World total	6,469	6,255	7,131	7,000

[a] Preliminary estimates, based on "World Rice Trade in the 1970's," Robert Beiber, *The Rice Journal*, Feb., 1972. [b] Less than 1,000 metric tons.

about 1 million tons a year. In 1971, Thailand regained its traditional position as the world's largest exporter of rice. It shipped almost 1.6 million tons compared with 1.4 million tons for the United States. Mainland China has been the third largest exporter, shipping from 800,000 to 1 million tons a year, and Burma fourth 400,000 to 700,000 tons a year. Japan recently moved sharply into the rice export picture and in 1971 replaced Burma as the fourth largest exporter, with 800,000 tons. From 1968 to 1971, UAR, Italy, and Australia had small but significant percentage increases in exports.

Of the annual volume exported from rice-surplus countries, about half of the total exports moved to food-deficit countries in Asia. The latter included Indonesia, East Pakistan (Bangladesh), Ceylon, South Korea, Malaysia, South Vietnam, Hong Kong, Singapore, and, in some years, the Philippines. An additional 15 percent of world exports moved to specialty markets mostly in Europe and the Near East. The remaining 35 percent moved to scattered markets mostly in Africa and Latin America.

After averaging about 7 million tons annually in the early 1960's, world rice exports dropped to 6.5 million tons in the late 1960's, and in the early 1970's moved back to about 7 million tons a year.

Thailand has been considered the pacesetter in world rice markets because in recent years it has usually been the world's largest exporter, it has delivered a larger variety of qualities of rice to meet the different demands of importing countries, and it has met price and quality competition when and where it has developed. Thailand traditionally exports seven major grades of milled white rice, four major grades of broken white rice, two major grades of glutinous milled rice, and several grades of parboiled rice and cargo or brown rice. Thailand also delivers, to order, special grades to meet the individual demands of specific customers.

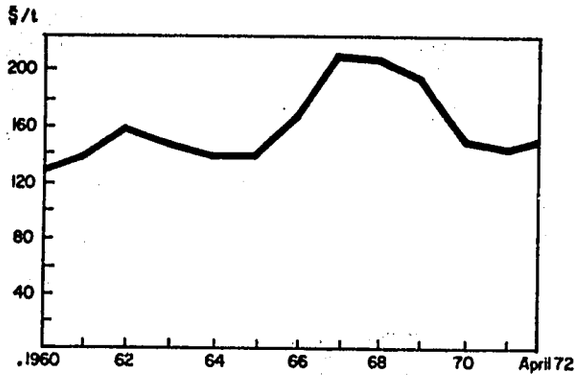
Recent monthly export prices for 100 percent first-grade white rice (the standard for highest-quality milled rice) and for 5 percent broken-grain, white milled rice (the usual grade demanded by purchasers requesting good quality long-grain white rice) are presented in Table 4. The export prices of long-grain 5 percent brokens from 1960 to April, 1972, are shown in figure 1.

From 1960 to 1965, world rice prices were stable at around $160 per ton f.o.b. for high quality long-grain well-milled rice with less than 5 percent broken grains; at $140 per ton for medium quality, medium-grain or long-grain rice, reasonably well milled with 5 to 10

Table 4. Export prices[a] for white rice f.o.b. Bangkok, 1969 to 1972. (Source: U.S. Department of Agriculture).

Year	Price ($/t)											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						100 % 1st Grade						
1969	192.60	192.60	199.68	198.90	205.80	212.16	213.00	205.05	201.12	199.80	200.40	192.96
1970	166.20	164.40	156.24	152.40	152.40	159.60	160.80	163.68	160.20	160.50	159.60	156.00
1971	157.20	142.20	132.32	130.80	111.24	195.20	147.00	149.52	168.80	151.88	146.16	147.45
1972[b]	148.70	139.10	140.05									
						5% Brokens						
1969	181.20	178.80	185.28	183.60	190.80	197.76	198.60	188.40	186.68	185.40	186.00	178.56
1970	154.20	151.20	143.04	139.20	139.20	141.60	142.80	145.68	142.20	142.50	141.60	138.00
1971	139.20	125.10	115.20	112.80	123.84	127.20	129.00	131.52	136.20	133.80	130.80	127.80
1972[b]	133.81	129.50	130.50									

[a] Milled rice, includes export premium, export tax, and cost of bags. Packed in bags of 100 kg net. [b] Preliminary.



1. Rice export price, f.o.b. Bangkok, Long-grain white rice, 5% broken grains. Source: U.S. Dept. Agr.

percent broken grains; and at $120 per ton for undermilled low quality short-, medium-, or long-grain rice with around 25 percent broken grains and for the usual parboiled 10 percent broken-grain-off-color types. Good quality broken rice sold for about $90 per ton.

From 1966 to 1968, world rice prices increased substantially to about $230 per ton for high quality types, $200 per ton for medium quality types, $170 per ton for low quality types, and $100 per ton for good quality broken rice. These were peak prices since the war-shortage years of the mid-1940's.

World rice prices began to decline in 1969 as supplies became more abundant in both importing and exporting countries. As indicated in Table 4, the price of good quality, 5 percent broken-grain white rice declined from around $200 per ton in mid-1969 to a low point of around $115 per ton in early 1971. During this period low quality, 25 percent broken grain types and parboiled qualities declined from $160 to $100 per ton and good quality broken grains dropped to $60 per ton. Since the low point in April and May 1971, export prices have strengthened, and prices in early April 1972, were around $135 per ton for 5 percent broken-grain white rice, and $80 per ton for good quality broken rice. Assuming normal weather conditions in Asia in 1972, rice prices should hold at current levels. If there are serious weather problems in major production areas, prices could go up. If there are abundant crops, prices could drop slightly, but the demand situation is such that additional supplies are likely to be readily absorbed at 1971 price levels.

The dominant influence on world rice markets in the last 2 years has been Japan. The situation in this country is a classic illustration of the impact of specific policies regarding rice on national and international production and trade.

Japan's most important food is rice. Before World War II, the per capita consumption was more than 140 kilos yearly. Currently, consumption is about 100 kilos and it is expected to go down to around 90 kilos in the next few years as more and more wheat is consumed. In the past Japan produced most but not all of the 11 millions tons of milled rice it consumes annually. Annual imports from 1960 to 1965 averaged about 225,000 tons. In 1966, total imports were around 800,000 tons and in 1967, 500,000 tons. The imports were mostly from Taiwan where the semi-sticky varieties preferred by the Japanese are produced.

Because of food shortages in the 1930's and 1940's, rice has been important in the political history of Japan, and Japanese rice policy in recent years has been aimed at self-sufficiency. The government has been active in all phases of rice production and marketing. Since 1960, the government has increased the support price for rice every year. The support price in 1970 was $383 per ton of brown rice. It was increased again in 1971 to $395 per ton of brown rice, which amounts to about $410 per ton of milled rice. This price is about three times the current world price for this quality of rice.

With these incentives, Japanese farmers responded, as do farmers throughout the world, by greatly intensifying their production. In the late 1960's, large surpluses gradually began to develop. The surpluses were intensified by Japanese barter purchases of rice from mainland China in 1967 and 1968 in return for sales of Japanese machinery to China. By October 1968, the Japanese rice surplus before the beginning of the harvest season reached 2.7 million tons. In 1969, the carryover was 5.6 million tons. By October 1970, it has reached 7.3 million tons, or more than enough rice to supply the entire import needs of all rice-deficit nations.

Rather than lower support prices or introduce direct production controls, Japan has attempted to reduce the surplus by indirect approaches: indirect subsidies to encourage land-use shifts out of rice, use of 1 to 2 million tons of rice annually for feed, expanding industrial uses, and exporting on a long-term, low-interest-rate basis. These steps have been partially successful.

Bad weather in 1971 helped cut back production. Lower yields combined with an 8 percent smaller crop area due to the land diversion program resulted in a 14 percent decline in total production. It now appears that the carryover by October 1972 will be reduced to about 3 million tons or less than half the level of a year earlier. Adverse weather cannot be expected to occur every year, however. Production equal to or in excess of domestic demand can be expected from Japan in the next few years.

Although the surplus rice situation in Japan is likely to affect world rice trade for several years, it is not as serious as has been indicated by some observers. Japan in 1971 had enough rice on hand to supply all world export markets and it was willing to sell at reduced prices with long-term credit arrangements; nevertheless, the other surplus-producing nations still found export markets for their rice and prices strengthened in the latter part of the year.

Japan exclusively produces the short (or round-grain), semi-sticky (low-amylose) grain types. These rices are preferred by consumers in Japan, Taiwan, and South Korea. Most other consumers prefer the long-grain and medium-grain, high-amylose, non-sticky indica types. This preference is so strong in some markets that consumers will buy other cereals rather than short-grain rice if long-grain rice is not available. In other markets, consumers will pay up to twice as much per kilo for the long-grain as compared with the short-grain japonica rice. In still other markets, parboiled medium-grain and long-grain rice are preferred rather than raw white milled rice. The Japanese rice-milling industry does not have parboiling facilities.

The Japanese surplus rice supply will continue to compete directly with the short-grain rice production of Australia, UAR, Italy, and California (USA). It will compete indirectly with the low quality medium-grain and long-grain supplies of surplus producers for markets such as Bangladesh, Ceylon, and Indonesia where the price factor is so important and the need for food so urgent that consumers will use any quality of rice so long as it is inexpensive. It will not compete for the high quality markets of Europe, the Near East, Hong Kong, Singapore, Malaysia, or for scattered markets around the world where long-grain, low-amylose, or parboiled rice is desired. Thus, roughly half the world export markets for rice are not affected by Japanese surpluses, one-fourth are indirectly and partially affected, and the remaining one-fourth are seriously affected.

Some observers of the world rice situation have concluded that because of the new varieties, additional inputs, and intensified education program, rice production in both the importing and the surplus-producing nations will expand greatly in the next few years. They further conclude that world supplies will greatly exceed demand, resulting in a further substantial decline in rice prices to exporting nations and to growers in all other areas. For example, a recent statistical study by E. Roy Canterberry and Hans Bickel in the *American Journal of Agricultural Economics* concludes that rice surpluses will grow substantially through the 1970's and that traditional trading patterns for rice will turn virtually upside down. A study by the Harvard Advisory Group to Pakistan concludes that when proper adjustments are made for specialized, captive, and government-to-government rice exports, the world market for export rice in the early 1970's will amount to only 1 to 2 million tons annually and the expected f.o.b. export price will be around $80 per ton. A recent report by the U.S. Department of Agriculture points out that if rice production continues its upward trend, exporting countries will suffer from reduced sales, depressed world markets, and lower over-all receipts.

These studies were made by competent people. These and similar works should receive the scrutiny of everyone interested in possible developments in the world rice industry. In general, they are accurate in indicating the direction of the short-term trends. But they all overstate the case. The limited statistical data available are at best far from being complete or accurate. More important, these writers have not considered new developments which cannot be programmed into the computer.

One of the more important developments concerns mainland China. In the last few years mainland China has exported 800,000 to 1 million tons of rice annually. Mainland China is not a surplus food producer. The nation has a net food deficit of from 2 to 3 million tons of grain annually. Rice exports have been accomplished by moving rice from production areas and then replacing this rice with cheaper imported wheat. Under the price relationships between export wheat and export rice that prevailed from 1966 to 1970, mainland China could buy 2 calories of food energy in terms of imported wheat for 1 calorie of food energy in

terms of the rice it exported. Thus, under a rigidly-controlled economy, their usual practice was to sell about 1 million tons of rice annually and with this income buy more than 2 million tons of wheat.

World rice prices declined about 40 percent from 1969 to 1971. This change has adjusted the relationship between rice prices and wheat prices. Under declining world rice export prices and steady wheat prices, mainland China has fewer opportunities to convert 1 calorie of food to 2 calories by exporting rice and importing wheat. As a result, mainland China's exports of rice declined from 1 million tons in 1968, to 800,000 tons in 1970, and to 700,000 tons in 1971. If the current relationship between wheat and rice prices continues, rice exports from mainland China are likely to decline to half of the 1965-70 level or less. This will open export markets for rice to other surplus producers for around 500,000 tons of rice annually.

The second important development involves the largest rice exporter of the late 1960's, the United States. U.S. rough rice has a price support amounting to about $170 per metric ton of milled rice. This support price, however, is tied to a rigid acreage control program established so that government losses in low-price periods will be minimized. From 1966 to 1968, world prices were above the U.S. support level, and acreage restrictions were relaxed. With the increasing world surplus developing in 1969, restrictions were tightened. A 10 percent forced acreage reduction occurred in 1969 and an additional 15 percent cut occurred in 1970. A further 10 percent reduction was announced in August 1971 to apply to the 1972 crop, but it was later rescinded when shortages in Korea, Indonesia, and Bangladesh appeared likely to become more serious and it was thought there would be a need for larger shipments to these areas in 1972.

As a result of the forced acreage reductions of 25 percent in 2 years, U.S. export supplies which averaged 1.8 million tons in 1968 and 1969, declined to 1.4 million 1971. If world rice prices continue to be weak, further reductions in the U.S. acreage can be expected. As a result U.S. rice supplies will put less pressure on world markets, especially the lower quality markets in Asia.

These two potential downward adjustments in export supplies combined with the gradual reduction in Japanese surpluses all point to gradually lower export supplies than are indicated by the current statistical picture. Moreover, the rapidly increasing populations in Thailand and Burma, the major surplus producers in Asia, will make it

difficult for these countries to maintain their current level of export supplies.

In addition, the ability of the rice-deficit countries to reach their goals for self-sufficiency should be examined. Malaysia already has had second thoughts and now plans a level of 90 percent self-sufficiency rather than eliminating imports. For Malaysia, the quality of rice that can be purchased at a relatively low cost from nearby Thailand is such that self-sufficiency is not economic. The recent developments in Bangladesh have set back the self-sufficiency goals in this area by 5 to 10 years. Ceylon is not moving as fast in increased rice production as was once thought possible. The Philippines made detailed plans for becoming an exporter in 1969, but after an initial shipment or two found that its increased production was worth more at home than abroad and since then it has had production difficulties so that additional imports have been necessary. These examples all point toward a supply-demand situation that is not as critical as the 1968-70 statistical picture would indicate.

Self-sufficiency is a sliding target, not a rigid one. As production increases in the developing countries where good supplies have previously been sufficient only for a minimum diet, additional food will be consumed. In Pakistan, where reasonably accurate data are available, a substantial part of the increased wheat production resulting from the introduction of new varieties and additional inputs disappeared between the time it was produced and the time it was inventoried by the government. The answer proved to be a simple one. When the rural people were questioned, they said that with more abundant supplies they were now eating two or three meals a day instead of the usual one meal a day common before the period of higher yields. A similar situation is likely to develop in all the poor-diet, rice-deficit countries in Asia as additional supplies become available.

In Japan, the per capita consumption of rice has been decreasing at about 2 percent a year as their industrial prosperity provides the opportunity for a more diversified diet. In South Korea, where rice supplies have been short, production increases have been accompanied by substantial increases in per capita rice consumption. A recent study in South Korea on food consumption patterns indicates that the per capita consumption of rice will increase at a faster rate than domestic production with the availability of greater

supplies at a reasonable cost. This country imported more than 500,000 tons annually from 1969 to 1971. Similar trends are likely in other countries of the region. In the developing countries of Africa, a similar increase in the per capita consumption of rice has developed in the late 1960's and early 1970's.

Finally, the population of the developing nations of Asia, Latin America, and Africa where rice is an important food continues to increase by 2.5 to 3 percent a year. In Asia alone, there are about 50 million more people to feed every year. At average per capita rates of consumption, this number will require at least 5 million additional tons of milled rice each year.

Rice trade and rice prices, f.o.b., in the next 5 years will depend on the demand for rice from importing nations, the supplies produced by both importing and exporting countries, and general business, economic, and political conditions affecting trade between nations. Assuming that political conditions will not deteriorate and that reasonable trade between nations will be no more difficult than in 1971, three situations are possible.

— If Asian rice production increases at 4 percent a year or more, as happened in two of the last 6 years, the need for rice imports by deficit nations will decline and available export markets for surplus-producing countries will be severely reduced. Local and international rice prices will decline as supply outstrips demand. Assuming internal price control programs are not maintained in most countries, the lower level of export and domestic rice prices is likely to be the value of rice as a feed for livestock. Although the value will vary from country to country, depending on feed needs and alternative carbohydrate feeds available, it should be about $60 to $80 per ton.

— If, because of poor weather or other reasons, the over-all rate of the rice production increase in Asia is reduced to 2 percent a year or less, as happened in two of the last 6 years, the supply-demand situation will reverse itself to the 1966-67 situation. The demand for rice will greatly exceed the available supplies and prices will increase to $200 per ton and more. Asia will be on the brink of starvation.

— Most likely, the 1972-76 situation will be somewhere between these two extremes. The continued impact of the new varieties and added inputs will result in smaller percentage increases for individual

producers than in the 1968-70 period as the mass of producers react more slowly and less positively than the early adopters. In addition, weather conditions are likely to revert to normal, as in 1971, rather than be relatively favorable, as in the 1968-70 period. Also, the continued availability of the added inputs needed will depend on continued and expanded subsidy programs for these supplies. The "miracle rices" will not fulfill the expectations of the headline promoters, and these were never the expectations of the developers of these varieties. The impact of the improved varieties and new methods, however, will prevail to some extent regardless of the availability of inputs and the educational activities associated with their development. Under these conditions, and with increased population growth, changes in demand for rice from area to area, and the comparative advantage costs of producing rice in some countries versus other products in these same areas, rough estimates can be made as to rice trade and rice prices in the next 5 years.

First, although there will be changes from country to country in imports and exports of rice, a continued world export-import rice trade of 6 to 7 million tons a year is likely. The import needs of South Korea, Bangladesh, Indonesia, Ceylon, Malaysia, Hong Kong, and Singapore plus the occasional imports of the Philippines, and possibly India, in bad-weather years will hold demand up in Asia while the Near East, Europe, and some Latin American areas such as the Caribbean will continue to import rice. Thailand and Burma will remain the major exporters in Asia with the United States, Australia, UAR, Italy, and some Latin American nations supplying additional export supplies. In brief, international trade in rice is not likely to dry up.

Second, f.o.b. rice prices are likely to be from $90 to $110 per ton for low quality, 25 percent broken, undermilled raw white rice or parboiled milled rice, $110 to $130 per ton for medium quality types such as Thailand 5 percent brokens or U.S. No. 3 medium-grain, and $130 to $150 per ton for high quality, whole-grain, well-milled white rice, with slightly higher prices for specialty types such as basmati. These prices are on the low side; with temporary shortage periods, the export prices would be 20 to 40 percent higher than the indicated levels. There is an even chance that such shortage periods, caused by variable weather conditions, may occur.

Third, countries that establish support prices for rice higher than the equivalent of the above-listed export prices will need to plan production levels not in excess of local needs or they are likely

to be left with supplies that cannot be sold abroad without a loss. If costs are such that these target prices cannot be met economically without potential losses, then consideration should be given to diversification of production as rice yields increase so that the needed domestic supplies are produced on less and less land while soils better adapted to other products are shifted to higher value uses.

Fourth, in the short run, the next 3 to 5 years, expanded rice production in countries that are nearly self-sufficient but without a firm export base should be limited to the volume needed for domestic needs. If the crop can be produced to sell below the listed target export prices, then the development of an export market is justified. In this connection, however, it should be kept in mind that export quality rice is generally much higher in quality than that produced for domestic sale in most countries in Asia. The lowest export quality normally moving in international trade has a maximum of 25 percent broken grains, is well milled, and contains very little foreign materials. Most of the rice produced in the Philippines, Pakistan, Bangladesh, India, Malaysia, Ceylon, and Nepal, for instance, does not meet these minimum standards. To compete in the higher priced markets, which are the most profitable, well-milled long-grain, highly polished clean rice with practically no foreign materials and less than 5 percent broken grains is needed. Few rice areas in Asia have the proper varieties, the efficient harvesting, drying, and storage facilities, and the modern mills necessary to produce the quality of paddy that meets export standards.

Fifth, in the long run, 5 to 15 years hence, the demand for rice is likely to exceed potential production, because breakthroughs like the high-yielding varieties occur so infrequently. Thus, a sound rice industry, based on economic production and efficient management to supply domestic needs initially but with potential for future expansion, if needed, is likely to produce a foreign-exchange winner as well as make a domestic contribution to improved standards of living.

Maximizing food production through multiple cropping systems centered on rice

Richard Bradfield

Food is regarded by many world leaders as the most important problem confronting agriculturists in the next quarter of a century. It is probably most serious in the rice belt of tropical Asia since it has, even now, almost half of the people of the world, a high proportion of whom are poorly nourished.

Because of the magnitude of the problem it seems clear that most of the food required will have to be produced in the countries which need it. People must learn to feed themselves by their own efforts, using the resources available to them. Is this possible? I am convinced that in much of the area it is not only possible, but it is probably the only feasible way of doing it. Fortunately, most of the poorly fed people live in the tropics where food crops can be grown 365 days of the year. In many such places people are short of food because they have not yet learned how to use efficiently all the basic resources for food production available to them. This paper is a brief preliminary report of studies made here at IRRI on intensive systems of multiple cropping designed to make better use of available resources. In my opinion, these studies show considerable promise for meeting some of the needs.

Most of the people in Southeast Asia are rice eaters. From 60 to 80 percent of their food calories are derived from rice. The average per capita consumption is about one-half kilogram a day or approximately 150 kilograms a year. From 60 to 90 percent of the people live on farms, and for most of them, rice is the principal crop, and for many of them, the only crop. The cropping system is essentially a rice monoculture. The primary objective of the farmer is to produce all the rice needed by his family. Any left over is sold to buy the other essentials for his simple life. His farm is small, ranging in most places from 1 to 3 hectares and averaging

about 2 hectares. Yields of rice average 1200 to 1500 kg/ha. The average annual income usually ranges from $100 to $500. On this, a family of six to eight subsists.

Nutrition surveys conducted by the Food and Nutrition Research Center of the Philippines show how inadequate average diets are among the rural poor, especially among rural children. Arrested growth becomes serious at weaning time. The prevailing weaning diet is composed largely of a thin rice gruel flavored with coffee! Children from 9 to 66 months old average about 75 percent of normal weight. It takes 8 years for a child to reach the normal weight for 6-years-olds. About 45 percent of all deaths occur among infants under 1 year (25%) and children 1 to 4 years old (20%). Of those who survive, many are handicapped for life by the effects of malnutrition during these early formative years. Would that some economist, with the necessary skill and imagination, make an estimate of the costs to a developing country of these inroads on the health and efficiency of its most valuable resource. Lacking more precise information, I think it is highly probable that the cost of providing adequate nutrition at the start would be cheaper than the costs of malnutrition to society in later years.

Many distinguished scientists have written learned papers on many aspects of the world food problem. Many international conferences have been held at which the subject was discussed at length. There has been noteworthy action as well as talk.

Many private agencies and foundations, many national and several international agencies have sponsored action programs designed to alleviate conditions. Many of these have had tangible results already. Some have been so successful that they have been credited, and I think deservedly, with starting a "green revolution." We are fortunate in having with us at this symposium many of the leaders of this "green revolution."

We are here primarily to review, analyze, and assess the work which has been done here in the past 10 years in initiating an integrated attack on the problems of providing plenty of rice for the rice eaters of the world. This is a top priority assignment since rice feeds more of the people of the world than any other crop.

Now after having paid my respect to the "honorable rice," I shall talk about some of its nutritional deficiencies and its proper role in a better balanced food production system for the small rice farms of Monsoon Asia, with special emphasis on the Philippines where the supporting research has been done.

While rice is an excellent food it is not a perfect food. No single crop is. Rice is rather low in protein and, in some essential amino acids. It is also deficient in several minerals, especially calcium; and in several vitamins, especially vitamin A. To be well nourished, people need to eat a variety of carefully selected foods along with their rice which can well serve as the principal source of calories as well as several other nutrients.

Rice is peculiarly suited to the climate of tropical Monsoon Asia with its long periods of heavy rains. No other important food cereal requires as much water and no other can tolerate an excess of water as well. It has stood the test of time. It was the staple food and first cultivated crop in Asia 5,000 years ago. No other crop has supported so dense a population for so long. No crop has been esteemed so highly by the people who grow it and are supported by it. For these reasons it would be foolish to attempt to supplant rice with any other crop. Instead we must seek to saturate the demand for rice. I am sure that this can be done in time and that our colleagues in IRRI will not require many more decades to bring it about. Once this is done, the price of rice will fall as surpluses pile up, and farmers will become interested in growing other crops to *complement* rice in their cropping systems.

The transition from a wet paddy rice monoculture to a mixed cropping system in which three or four different upland crops are grown in quick succession after rice will be neither easy nor simple. Soil and water management problems will be formidable on some soils. The reasons will be obvious if we examine the climatic data (Table 1).

The monthly mean temperatures vary from a minimum of 25.1 C in January to a maximum of 28.8 C in May, an annual range of only 3.7 C. Minimum temperatures in January may be a little low for optimum growth of certain very sensitive crops, but are satisfactory for most crops. Theoretically, we should be able to grow crops 365 days of every year. Radiant energy is also low in January but is quite satisfactory for most of the year. It is of course highest in the dry season, from March through May. The rainy season usually starts about the middle of May and averages about 25 cm a month for the 7 months ending about December 15. The effective rainfall from January to mid-May is light and undependable, although there is an occasional rain of some significance. Management problems are complicated by the wide variations in the monthly rainfall from year to year. For example the 39-year average rainfall for the month of May is 6.2 inches. In 1970 it was less than 3 cm and in 1971 it was about 40 cm. One must be prepared to irrigate in dry months like May 1970 and to drain quickly in wet months like May 1972.

Table 1. Climatic data for Los Baños (30-year average).[a]

Month	Solar radiation[b] (kcal cm^{-2} month^{-1})	Monthly mean temperature[c] (C)	Monthly evaporation (cm)	Monthly rainfall (cm)	
				Range	Mean
		Early rainy season			
May	14.0	28.8	20.3	3–46	15.7
June	11.4	28.1	16.5	10–43	21.1
July	12.2	27.6	15.0	10–43	28.2
Aug	11.2	27.4	14.7	13–46	27.7
		Late rainy season			
Sept	9.9	27.3	13.5	8–71	26.0
Oct	12.2	26.8	14.2	5–53	22.6
Nov	10.8	26.4	11.7	5–53	26.4
		Early dry season			
Dec	9.0	25.5	12.5	8–36	14.7
Jan	8.5	25.1	14.2	10–15	5.8
Feb	10.2	25.6	16.8	3–13	3.0
		Late dry season			
Mar	14.4	27.1	22.6	3–8	4.1
Apr	14.2	28.7	25.7	3–10	4.1

[a]1917–1938 and 1947–1963.[b] Average for 1960, 1962, and 1963.[c] For approximate monthly mean minimum temperature subtract 4 C; for mean maximum temperature add 4 C.

Now that we have a picture of the environment in which the crops must grow, let us consider some of the criteria used in selecting the crops to be grown in rotation with rice:

— The crops selected should, as a group, supply all the nutritional elements deficient in rice.

— While rice is one of the most dependable of all the major food crops, it is subject to typhoons, diseases, insect pests, etc., which can seriously decrease yields. Crops which differ widely from rice, botanically, anatomically, and in cultural requirements, should be considered. A monoculture is hazardous for a 2-hectare subsistence farmer. Crops with the characteristics listed above would reduce some of these hazards and provide some crop insurance.

— We need crops with a wide range of growth periods (from 40 to 120 days) to enable us to use any time period which may become available for growing crops.

— We need crops which can tolerate short periods of excessive rain or drought.

— We need crops which are compatible with each other under various conditions in multiple cropping systems.

— Crops which have been long used as basic food crops in the tropics in different parts of the world will be less risky. If considerable research has already been done on all aspects of their production, protection, nutritional value, and acceptability as a food by diverse peoples, less additional research will be needed. Information on storage qualities, market demands, and a wide range of methods of utilization is often useful.

The following crops were selected for trial largely on the criteria cited above: soy beans, sweet potatoes, corn, sweet corn, sorghum, and several vegetables.

Soy beans are the best source of plant protein available. They have been widely grown in the rice belt of tropical Asia for thousands of years, especially by the Chinese, Japanese, Koreans, and Indonesians. These people know them and like them. They have developed many different ways of preparing them for the table. They can be eaten as a green vegetable or as a mature dry bean. A milk, very satisfactory for infant feeding, can be made from them by simple techniques. They contain about 40 percent of high grade protein and about 20 percent of oil, both of which are needed to balance rice in the diet. The nutritional value of soy bean has been widely studied for both humans and domestic animals. Soy bean meal is the principal protein source used to supplement corn in the huge animal industry of the United States. It is used in the rations of poultry, swine, cattle, and sheep. It is the largest U.S. export crop. Several countries in the rice belt of Asia and in Europe are importing soy beans from the United States. Much research has been done on production techniques and on the breeding of varieties for special purposes. They are grown successfully over a wide range of latitudes from 40°N to 40°S. A wide range of types and maturity dates are available.

The orange fleshed sweet potato such as the Centennial, Julian, and Jewel varieties recently developed in the United States is one of the richest food sources of Vitamin A. An average serving contains 5,200 units, more than the daily requirement of a robust 10- to 12-year-old boy. Few crops can match the sweet potato in the number of calories produced per hectare per day. It grows as a vine on the ground and is therefore damaged less by typhoons than rice or most other crops. The vines are widely used as food for people and as feed for livestock. It is the staple food of many people in Africa,

and the South Pacific islands. It is also highly esteemed as a food in southern United States.

Corn is second to rice as a food crop in the Philippines. It is widely grown in India, Indonesia, Thailand, and other countries in the rice belt. It is the most important crop in the United States and is the foundation upon which the huge livestock industry has been built. It is the staple food crop in most of Latin America. It can be used as food in both the immature and mature stages. Sweet corn is normally preferred for eating in the green or immature stage. Since the Filipino people are fond of green sweet corn and the market good, it was grown more often than mature field corn in our experiments at IRRI. The varieties usually grown were ready for the table in 60 to 65 days after planting while field corn required 90 to 110 days to mature.

Sorghum resembles corn in many respects. It tolerates both very wet and very dry conditions better than corn. There are many improved varieties available. Yields and nutritive value are comparable with those of corn. It is preferred over corn when it must mature early in the dry season. It is widely used as human food in Africa and India. In fact, it feeds more people than any cereal except rice and wheat.

Most temperate zone vegetables can be grown successfully in the tropics if suitable varieties are selected. A selection of 10 to 12 vegetables can be grown throughout the year. Eggplant, okra, cucumbers, onions, beets, radishes, watermelons, carrots, tomatoes, cowpeas, squash, and green beans have been grown successfully.

The main experimental unit at IRRI consists of eight one-quarter-hectare blocks. The eight blocks are separated by a levee about 1 meter wide and 25 cm high. The soil within each block was water leveled before planting to rice the first time. A furrow, about 75 cm wide at the top and 25 cm deep, was made every meter to facilitate drainage and irrigation. The beds formed in between the furrows varied in shape depending upon the needs of the crop to be planted.

Most of the cultural operations — leveling, bed and furrow formation, seed bed preparation, seeding, cultivation — were performed with a small, inexpensive, 6-horsepower hand tractor (Landmaster) with a few carefully selected attachments. It was light, well designed, and attachments were easy to change. Most tillage operations were performed with rotovator blades which

slipped on to the axle of the tractor. It was simple and inexpensive to operate and maintain.

Many have asked whether a farmer operating a 2-hectare farm is justified, economically, in investing in such a tractor in an area in which there is a surplus of farm labor available at low wages. We believe he is for the following reasons: The system has been designed to be operated by a farmer and his family. The area of the experimental unit is the same as that of an average rice farm. The farmer will continue to grow 2 hectares of rice each year as at present but, in addition, he will grow three or four other crops on this same land each year. In other words, he will harvest by hand 5 to 10 hectares of crops each year.

Farmers usually mechanize to save labor. Can he justify it for saving labor in a country with a surplus of labor and very low wages? Will not a small tractor on a multiple cropping farm aggravate the unemployment situation which is already serious? We are convinced that it will have just the opposite effect. We must remember that we are growing four or five crops a year instead of one or two. Many time-consuming operations, such as harvesting and marketing, thinning, seeding, weeding, spraying, hauling, operating the tractor, will still require hand labor. The labor required will be better distributed than at present for there will be a block to harvest and reseed nearly every week of the year.

One of the most important advantages of mechanization in multiple croping is to save or gain time for growing more crops. For example in the rainy season the heavy clay soil at IRRI is often dry enough to till for only a few hours between rains. With the tractor, a quarter-hectare block can be seeded in an hour. If a rain comes soon after the seeding is finished, the seeds will germinate and seedlings will appear above ground in 3 to 4 days. If this job had to be done by hand it would require 3 to 4 hours instead of 1 and the next rain would often come before the job was finished. After a heavy rain the soil may remain too wet for seeding again for 1 to 2 weeks. In the meantime weeds will germinate, the seedbed will have to be renewed and in addition, 1 to 2 weeks of crop-growing time will be lost. Another common question is whether most farmers would work as much as multiple cropping requires. There are all kinds of farmers. If an operation is highly profitable many farmers will find a way to get it done. Moreover, a multiple cropping system is flexible. If there is too much work for the labor force, the size of the unit or the number of crops grown per year can be reduced. Either will of course reduce profits as well as labor. The farmer can make a choice.

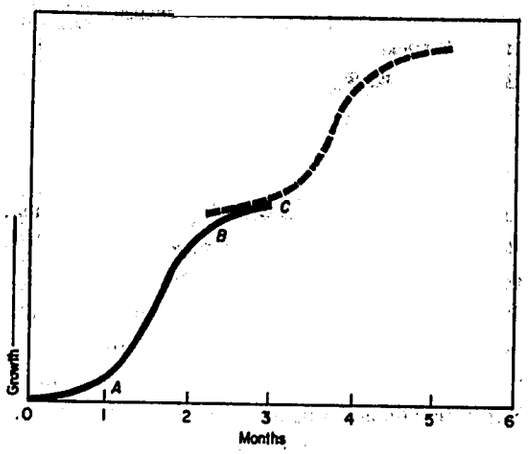
The next problem is to design efficient cropping sequences for growing different combinations of these crops. Two basic sequences are possible: relay cropping and intensive cropping.

Relay cropping is like a relay race with a second crop being planted as soon as the first has run its course and has been harvested. Usually a new seedbed is prepared and several days or even a few weeks may lapse between the harvesting of the first crop and the planting of the second. The culture of each crop is more or less independent of the other. As a result the techniques used in growing each crop are similar to what they would be with a monoculture. Large scale mechanization with conventional implements is possible and two or three crops per year are usually grown.

Intensive or maximum multiple cropping is designed for small, 1 to 3 hectare farms, on which farmers seek to maximize production by having one or more crops growing on every square meter of their land every day of the year. This involves *intercropping*, or planting a second crop after the first has started to mature but before it has been harvested. In this way crops can be grown on the same land for as many as 450 days per calendar year. This system will usually not produce as high yields per crop as relay cropping but since four to five crops can be grown in 365 days instead of two to three, the total yield of all crops per hectare per year will be greater. Because of the greater crop density, mechanization will be more difficult and more hand labor will be required.

Intercropping is one of the best techniques for gaining time to grow more crops. The basic principles are quite simple and easily illustrated by an ordinary growth curve (fig. 1).

Let us take a planting of corn as an example. Seed is planted at time 0 in hills about 1 meter apart in both directions. The seed will germinate ordinarily in 4 to 5 days. The seedlings will grow slowly for the first 2 to 3 weeks as shown by the section *OA* of the curve (fig. 1). At *A* they will be 20 to 25 cm high, will have three to five fair-sized leaves and a good root system, but will shade only a small fraction of the soil. They are now ready to make the rapid spurt of growth shown from *A* to *B*. At *B* the first planting is approaching maturity and the growth rate again declines. The crop's requirements for light, nutrients and water are less on *OA* and *BC*, than on *AB*. If a second crop, sweet potatoes, for example, is planted between the hills of corn at *B*, the period of establishment, *OA*, for sweet potatoes will be superimposed on the maturity period, *BC*, of the first crop when competition will be least. As a result the second crop will be established



1. Growth curves of two crops. Crop 2 (broken line) is interplanted in Crop 1 as the latter is starting to mature.

with but little harm to either. Crop 1 will be harvested at *C*. Crop 2 will, by this time, be ready for the "take off" stage and will be free from competition! If we were using the relay system, we would now plant Crop 2 after we had harvested Crop 1 at *C*. Gain by interplanting? About 30 growing days, half enough to grow a 60-day crop.

To be used efficiently, time must be accumulated in blocks long enough to plant and grow to maturity the crop with the shortest growth period, usually 50 to 60 days. Saving 25 to 30 days is seldom of much value unless a way can be found for combining it with another similar period to give a total of 50 to 60 days. If 25 to 30 days is accumulated at the harvest of the main crop *in temperate areas* it can seldom be used because it will be followed by a killing frost. This prevents the accumulation of usable blocks of time. In the tropics, if such a block of time is saved, the time of planting of the succeeding crop can often be advanced 25 to 30 days. If ways can be found for saving another period of 25 to 30 days it can be combined with the previous period later in the rotation, giving now a "usable block" of time of 50 to 60 days which is sufficient to grow a crop of early sweet corn, green beans or green soy beans, or one of several other vegetable crops.

Many crops mature earlier in the tropics than in the temperate zone. Certain varieties of sweet corn, for example, require 85 days from planting to harvest in the temperate zone and only 65 days in the tropics,

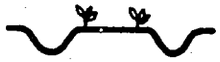
a difference of 20 days. This difference seems to be largely because the necessary number of heat units (degree days) can be accumulated in less time in the tropics. In any case it frees 20 days for growing another crop.

With these time-saving schemes in mind, a few multiple cropping schemes can be organized which will make use of the above principles. The cropping cycle must be adjusted to the climatic cycle because, as we have seen above, the crops selected differ widely in their reaction to water. Rice requires and tolerates more water than any of the other crops. The monsoon rains start at Los Baños between May 15 and June 1 on the average. They increase in frequency and often in intensity in July and August. It is difficult to get the soil dry enough to work without puddling during this period. If we could plant rice from May 15 to June 15 it would, on the average, get enough rain between May 15 to June 15 to get a good start. If the crop is established in this period it can be weeded before the heavier rains come. Since the varieties of rice planted require 110 to 120 days from planting to maturity, our crop would be ready for harvest between September 10 and September 20.

Since all our crop sequences are to start with rice, all will follow this same planting and harvesting calendar. A complete calendar for the first cropping sequence is given in Table 2. The types of beds and furrows used for each crop are shown in the sketches in Table 2. Each bed is about 1 meter wide and is formed from the preceding one with the minimum number of operations with the small rotovator. The cycle starts with the harvesting of the sweet potatoes. After the vines are removed the sweet potatoes are plowed out with a "middle buster" or static ridger. After drying for about 2 hours, the roots are graded roughly in the field into two grades: marketable and culls, then picked up in sacks or trays and hauled into the drying shed for further drying in the shade.

The soil is rotovated and leveled immediately. Furrows are then made every meter with the ridging rotors or static ridger. Fertilizer — 250 kg/ha of granulated 12-12-12 — is broadcast by hand on the top of the bed. The bed and furrows are then sprayed immediately with Treflan for weed control, then rotovated 5 to 8 cm deep to mix spray and fertilizer in the soil. Two rows of soy beans, 30 cm apart, are then drilled in the middle of the top of the bed. When the soys reach the 4 to 5 true leaf stage, the space between the rows is rotovated if needed. When the soy beans are about 1 month old they will usually require a 5 to 8 cm irrigation in the furrows.

Table 2. Typical cropping calendar.

Crop	Date of Planting	Date of Harvest	No. of days	Tillage operation	Yield (t/ha) Crop	Yield (t/ha) By-product	Price (US$/t)	Gross income (US$/ha)
1. Rice	June 1	Sept. 30	120		5.0	5.0	100	500
2. Sweet potato	Sept 1	Dec. 24	114		25.0	20.0	40	1000
3. Soybeans (dry)	Dec. 27	Mar. 17	85		2.5	—	100	250
4. Sweet Corn	Mar. 1	May 5	66		40000 (ear)	15.0	0.02 (ear)	800
5. Soybeans (vegetable)	May 1	July 1	60		6.0 (green pods)	6.0	0.10 (kg)	600
6. Rice	June	Sept. 30	120					

As soon as the furrows are dry enough, 250 kg/ha of 12-12-12 fertilizer is broadcast by hand in the bottom of the furrows. It is mixed in with rotovator, preserving the furrows. Sweet corn is then planted every 25 cm in the furrow with a jobber.

About 60 to 65 days after planting the soy beans, they will be ready to harvest at the green vegetable stage. Usually only one of the two rows is harvested at this stage. Immediately after this one row is harvested, 75 kg/ha of nitrogen, as urea, is applied in the furrow with the corn and the soil between the remaining row of soys and the row of sweet corn is cultivated throwing some soil into the furrow to cover the fertilizer. In 20 to 25 days the remaining row of soy beans will be mature enough to harvest. After it is harvested the sweet corn is rotovated again using the ridging rotors to "ridge it up." This will be the last cultivation of the corn crop.

About 10 days after the sweet corn has tasselled and about 10 days before it is harvested as green corn a hill of soy beans, 2 to 3 seeds each, is planted on the ridge between each hill of sweet corn. When the sweet corn is harvested 10 days later, the soys should be in the 2 to 3 true leaf stage.

It is now time to get ready to plant rice. Fertilizer — 300 kg/ha of 12-12-12 — is broadcast over the middle between the soy bean ridges, and then rotovated in, leveling the soil with a board attached to the back of the rotovator. This gives a smooth seedbed about 65 cm wide. Three rows of rice, 25 cm apart, are drilled on this seed bed usually between May 15 and June 1.

The ridge on which the soy beans are growing is usually cultivated once with the ridging rotors after the rice is planted. By July 1, the rice will be about 30 days old and the soy beans about 60 days old. The soy beans will be harvested as green beans leaving the rice crop without competition for the next 60 days when it is making its most rapid growth. It will not require much attention during this period except for an occasional hand weeding or spraying. An occasional irrigation may be needed if the rains do not supply enough water.

About September 1, the rice will start to head. At the end of the month it will be ready to harvest. It is now time to get any weeds left on the ridges and to plant the sweet potato cuttings on them. The water is drained off the rice so the soil on both the ridges and in the furrow at the bottom where the rice is growing can dry out for 3 or 4 days. This will reduce the damage to the structure of the soil. When transplanting the sweet potato cuttings, care must be taken to avoid trampling the ridges. Sweet potatoes grow best in a loose, well-drained and well-aerated

soil. After the sweet potato cuttings are transplanted a little water, about 5 cm, is put back on the rice for a couple of weeks. Then any remaining water is drained off to prepare the land for the harvesting of the rice. Most of the rice in the Philippines is harvested with a sickle. In this case the rice is cut 25 to 30 cm from the ground. This tall stubble will form a mulch under the sweet potato vines and will supply some of the potassium they need. By the time the rice is harvested the runners formed on the sweet potato cuttings will be 20 to 25 cm long, the root system will be well established and the new crop, now 30 days old, has passed 25 percent of its growth period growing on ridges in the *rice crop!*

A few days after the rice is harvested the sweet potato vines will form a dense cover over every square centimeter of land in the field. Few weeds can survive the competition. If worms threaten to chew up too many of the leaves it may be necessary to spray to control them. Otherwise the sweet potatoes will probably require little, if any, attention until late December when the crop is ready for harvest.

We started our cropping cycle with the harvesting of sweet potatoes about a year ago. We have grown crops of 1) soybeans, 2) sweet corn, 3) green soys, 4) rice, and another of 5) sweet potatoes is on the way. All crops except the first crop of soys have been intercropped. Sweet corn was planted in the furrows between the soy bean beds and the two crops grew together for 30 days. The second crop of soy beans was planted on the ridge between hills of sweet corn 10 days before it was harvested. Rice was planted between the two soy bean ridges saving 30 days. As the rice crop started to head, 30 days before harvest, sweet potato cuttings were transplanted on the ridges from which the soy bean crop had been harvested. As a result, when the rice was harvested about September 15 to 30 the succeeding crop of sweet potatoes already had a 30-day start. The total number of days of intercropping is 100 (30+10+30+30). The total crop growing days in the calendar year is 465 (365 + 100)!

All crops were sold retail at the prevailing local market prices, most of them on the farm, the rest on the local retail market. Typical prices, yields, and gross income per crop and per hectare are shown in Table 2. The gross income per hectare is a little over $3,000 per year. At this rate the 2 hectare farm would gross $6,000 per year.

I lived the latter part of 1971 in Honolulu. I was astounded at the price of many fresh vegetables on the local supermarket. At these prices the gross income from a hectare of sweet potatoes, yielding the same as in the Philippines, would be $12,000, a hectare of sweet corn $5,200, and a hectare of cabbage $11,500. All of these crops grow well in Hawaii.

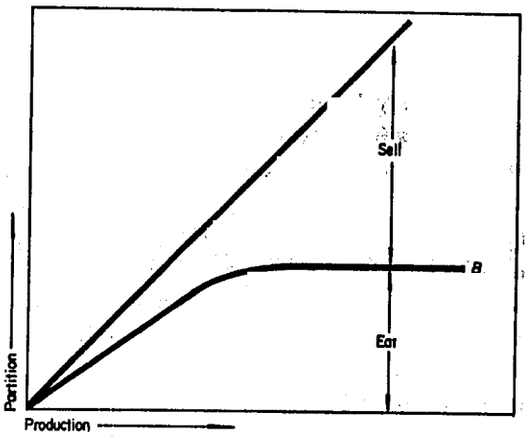
At their present level of affluence most of the vegetables consumed in Hawaii are not produced by her farmers but are shipped in from California, halfway across the Pacific. At the prices cited above multiple cropping should be a very profitable venture in Hawaii.

The primary goal of the average small rice farmer is to feed his family of seven well. Data supplied by the Food and Nutrition Research Center in Manila indicate that 450 g of rice, 100 g of dry soy beans (or 250 g of green soy beans), and 250 g of sweet potatoes (Centennial variety) would serve as a basic diet for a moderately active 55 kg man for 1 day. The crop yields cited in Table 2 would meet these needs for 365 days for the following number of families of seven: Rice, four; Soy beans (dry and green), 20; Sweet potatoes, 38. The sweet corn, 40,000 ears, would supply two ears per person per day for eight families of seven for 1 year. Sweet corn is not included in the basic diet and would serve as a bonus or reserve to supplement the other items.

Economists who study the statistics on food production in the rice belt of Asia are usually rather pessimistic about the ability of the farmers of the area to feed the people. Let us approach the problem at the farm level. From 60 to 80 percent of the people in this region live on farms. The primary goal of the average farmer is to feed his family well. If he can learn to produce enough food to feed his family well the national problem would be about 60 percent solved! If he could then learn how to produce enough food for one more family, the food supply problem of the country would be solved. From the calculations cited above this does not seem such a difficult goal for farmers who practice multiple cropping!

Many are greatly concerned about the "protein gap" and are pessimistic about the possibilities for closing it by conventional agricultural techniques. I share their concern about the seriousness of the "protein gap" especially among nursing mothers, infants, and children under 6. In view of our experience with protein production with soy beans in multiple cropping systems discussed above, however, I do not share their pessimism about the possibilities for producing the amounts needed on the farms of the area. If 60 percent of the population are farmers and if one farmer can produce enough supplemental protein to feed 20 families of seven for 1 year, where is the problem? I am also convinced that the percentage of animal protein recommended by nutritionists can also be supplied in the same way. I shall discuss this in more detail later.

Farmers usually dispose of the food crops they produce in three ways. They eat it, they sell it, or they feed it. The 2-hectare farmer will usually eat a high proportion of his production. A 100-hectare farmer will eat only a small proportion of his production and will sell or feed most of it. The small farmer is often referred to as a subsistence farmer and the large farmer as a commercial farmer. In most advanced countries most farmers are striving to become commercial farmers. In most underdeveloped countries most farmers are subsistence farmers and many of them will remain in that category for some time to come. In actual practice there is not a sharp line dividing these two types of farmers but there is continuous transition from one extreme to the other. The relationship is clear from the graph in figure 2. Production is plotted on the x-axis, and distribution of this production is plotted on the same scale on the y-axis. This plot will give a straight line through the origin and at 45 degrees with both axes. We are now interested in seeing how total production at any level is divided between home consumption or subsistence and commercial sales. From the argument above we would expect this curve to take the form of B. At very low levels of production, a very high proportion of all crops produced will be consumed by the farmer and his family. As production increases it will be split between home consumption and sales. Eventually the inelastic demand for food will reach a limiting value. As production increases still further



2. Changes a 2-hectare subsistence farmer might make in the disposal of his crops as production increases; family consumption increases to a limiting value which is maintained, and the proportion marketed continues to increase.

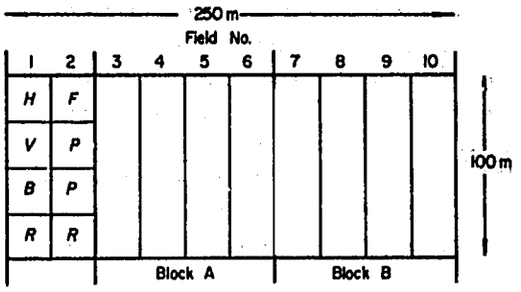
the increase will not all move into the commercial fraction but the fraction consumed at home will continue at its maximum value in the case of the small 1 to 3 hectare rice farmer. If we accept this view that as high a proportion of the production of the small farmer as is needed will continue to be used to feed his family, the distribution of the harvesting dates of his crops through the calendar year will be very important. His family will have to be fed every day of the year. Losses of food will be less and quality higher if it is consumed fresh as soon as possible after it is harvested. This will call for a suitable succession of plantings throughout the year for very perishable vegetables. Rice, soy beans, and sorghum can be stored from one season to the next and sweet potatoes can be stored without special attention for 2 to 3 months.

With most of the crops listed in Table 2, the proportion of the dry matter produced which can be handled by the human stomach is only about *half of the total.* The sweet potato vines, sweet corn fodder, rice straw, soy bean leaves and stalks, and sorghum fodder are good feed for livestock and if properly supplemented with off-grade potatoes, grain sorghum, off-grade soy beans and by-product molasses from nearby sugar mills, they can be converted by the proper animals into many highly prized and valuable animal products. These animals have to eat every day, too, so schedules of frequent harvestings is as important for them as for the family.

In Table 2, we presented data for a typical cropping sequence for one field for 1 year. We are ready now for a complete cropping schedule for each field or sub-unit. We need an overall view of the entire farm, all 2-1/2 hectares of it.

A sketch of the farm layout is given in figure 3. The 2-1/2 hectare units are first laid out into 10 fields — 100 m x 25 m — with an area of 1/4 hectare each. Two of these fields are subdivided further into four units each 25 m x 25 m. The house, vegetable garden, fruit garden, barn, reservoir and three small pastures are located on these two fields, 1 and 2. The other eight crop fields are laid out like the one described above. They are divided into two blocks, A and B, each having four fields.

The layout of Block A is shown in figure 4. The succession of crops is shown by the rectangles. The calendar months are shown at the top and the field numbers on the left. Field 1 has the same rotation described in detail earlier. The approximate time of planting is indicated by the



3. Layout for a 2.5 hectare multiple cropping farm (H = house lot, F = fruit garden, V = vegetable, B = barn, P = pasture, R = reservoir).

location of the broken line at the left end of each rectangle and the approximate date of harvesting at its right end. The second crop is shown in the second rectangle which is one space below the one for the first crop. The interplanting period for each combination of crops is indicated by the length of the overlap of these two rectangles since it shows the time of planting the second crop and the time of harvesting the first crop.

Note that all successions start with rice, but that a different crop follows rice (second crop) in each field. The third crop is the one that is most appropriate for following the second crop. A grain sorghum succession is shown in Field 4. Sorghum is planted on the ridge either 2 to 3 weeks before the rice is harvested or immediately after. As soon as the first crop is harvested, shoots develop on the stubble and produce a ratoon crop. Usually we are able to get three harvests of sorghum grain following a crop of rice. The last two crops are from ratoons.

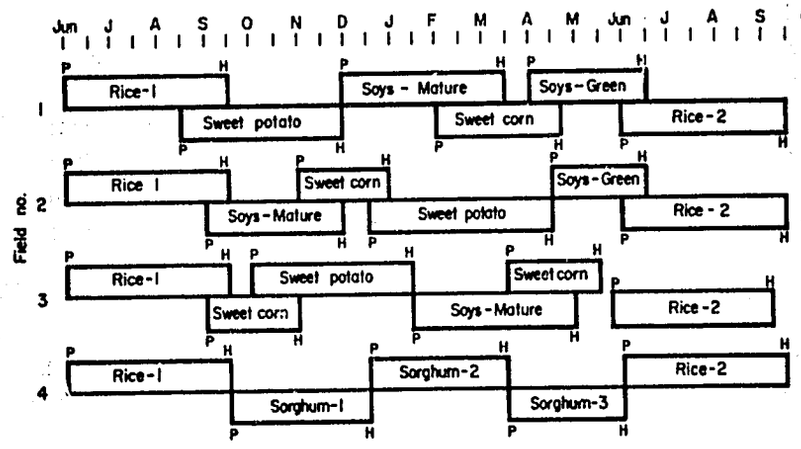
In general, the management of the various crops on the different fields was similar to that for Field 1 described above. The total number of fields of each crop grown each year is twice the number shown in the figure since Block B is an exact duplicate of Block A. A better time distribution of all operations can be obtained by planting the rice in Block B 2 to 3 weeks later than that in Block A.

A summary of the total production for the eight fields (2 ha) for 1 year is shown in Table 3. Several interesting relationships can be discerned. The yields per hectare are about average for the project. The prices for each crop are also about average. Note the comparison with prices in Hawaii. Note also that several crops gave a higher return per hectare than rice, usually in less time and with less work.

A summary of the annual production which can be obtained from a well-managed 2-hectare multiple cropping unit is shown in Table 3. The yields per hectare and the prices obtained for each are typical of those obtained in this study and show the potential of the environment. Rice is only one of five crops grown in the various rotations but all eight of the one-quarter hectare fields are planted to rice early in the rainy season and harvested in mid-September. The total yield was 8 tons, about twice what the average farmer in the area usually obtains. The farmer will need from 1.5 to 2.0 tons of this to feed his family and supply seed enough for the next crop. This will leave about 6 tons to sell.

As many as possible of the second crops in the four rotations are interplanted in the rice from 1 to 4 weeks before it is harvested. The rest are planted as soon as possible after it is harvested. Sweet potatoes, soy beans, sweet corn, and sorghum are each planted on two of the eight quarter-hectare fields. These crops are harvested in late November or December and another planting made immediately. The dates and crops grown in period IV and V are clear from Table 3. It is clear, from this table that an intensive system can produce on a 2-hectare farm all the rice that the farmer's family needs for home consumption plus a good surplus for sale and in addition three or four of four other crops which can supply the protein, vitamins, and minerals needed to balance the rice diet. The percentage of these crops consumed by the farmer's family will be smaller than for the rice crop and the percent of surplus available for sale or feed will be much larger.

Fields 1 and 2 which are subdivided into four parts each (fig. 3), in addition to contributing space for the house, barn, and small reservoir,



4. Annual sequence of crops on four fields showing intercropping.

Table 3. Estimated annual production from a well-managed 2.5-hectare irrigated farm in the tropics under intensive multiple cropping.

LAYOUT OF FARM

Homesite with fruit trees	0.10 ha
Family vegetable garden	0.10 ha
Pasture	0.30 ha
For diversified crop rotations	
8 x 1/4 ha fields	2.00 ha
Total	2.50 ha

ANNUAL CROP ROTATIONS

Rotation	*June 1 to Sept. 15*	*Sept 16 to Nov. 30*	*Dec. 1 to Feb. 15*	*Feb. 16 to Apr. 30*	*May 1 to June 30*
I	Rice	Sweet potato	Soybeans–M	Sweet corn	Soybeans–G.
II	Rice	Soybeans–G.	Sweet corn	Sweet potato	Early sweet corn
III	Rice	Sweet corn	Sweet potato	Soybeans–M	Cabbage
IV	Rice	Sorghum–1	Sorghum–2	Sorghum–3	

SUMMARY BY CROPS

Crop	*Fields (no./yr)*	*Area (ha/yr)*	*Yield (t/ha)*	*Total production (t)*	*Unit Price (US$)*	*Value of crop (US$)*
Rice	4x2 = 8	2.0	4.0	8.0	100.00	800
Sweet potato	3x2 = 6	1.5	20.0	30.0	40.00	1200
Sweet corn	4x2 = 8	2.0	35,000 (ears)	70,000 (ears)	0.02	1400
Sorghum	3x2 = 6	1.5	6.0	9.0	50.00	450
Soybeans–Gr.	2x2 = 4	1.0	6.0	6.0	0.10	600
Soybeans–M.	2x2 = 4	1.0	2.5	2.5	100.00	250
Cabbage	1x2 = 2	0.5	25.0	12.5	25.00	312
Total	38	9.5				5012

contribute to both the flexibility and diversity of the food and feed supply. The fruit garden can supply the bananas, papayas, guavas, and citrus needed for family consumption. The vegetable garden can supply a continuous succession of 10 to 12 vegetables that do not require much space. Some of the transplants needed on the larger fields can also be produced here. The three small pasture lots, irrigated and heavily fertilized, will be a continuous source of feed for the animals. If the livestock project proves attractive, the area of pasture could be expanded by converting one or two of the crop fields to pasture.

Some economists have questioned whether farmers with the low incomes and the short food and feed supplies prevailing in the rice belt can afford

to eat very much meat or other animal products or to invest much capital in an animal project. There are other considerations which may throw some doubt on this view. In producing most food crops, farmers produce, in addition and unavoidably, approximately equal quantities of dry matter in the form of crop by-products which cannot be eaten by people, but which have considerable values as animal feed. For example, the sweet potato crop can produce 20 to 25 tons per hectare of edible roots which are an excellent human food. At the same time it produces approximately an equal amount of dry matter in the form of vines. The tips of the vines are widely used as human food but the bulk of them are not consumed in this way. They are, however, a valuable animal feed. Some feeding experiments indicate that sweet potato vines have a feeding value about as high as alfalfa, "the queen of forage crops." Sweet corn fodder, soy bean vines, and sorghum fodder are all valuable as animal feeds. The farmer often has other waste products which he can neither eat nor sell directly but which can be converted into valuable products by animals. In addition, the animals will produce manure which he can use to fertilize his crop land. As was shown in Table 3 our 2-1/2 hectare farm will produce from 70 to 90 tons (fresh weight) of by-products of value as animal feed. In addition, these rotations will often produce surpluses of sweet potatoes, grain sorghum, soy beans, etc., which can be used for animal feed. The neighboring rice mills produce rice bran and the sugar mills, molasses, both of which are often cheap sources of digestible nutrients for livestock. It is much better economy to feed such products to livestock and to use the manure produced as fertilizer or for making compost than it is to compost these products directly.

Many farmers in the Philippines keep a few chickens, pigs, goats, cows, or carabaos at present for which they commonly buy some feed. With the more abundant feed supply produced by multiple cropping, the numbers of such animals kept can be increased severalfold. More animal protein than needed to supplement the plant protein in the family's food supply can thus be produced. In the Philippines, the pig is also regarded as an emergency source of cash. Pigs are always in demand at a good price. They are a compact product cheaply transported. It is estimated that between $300 and $500 worth of saleable animal products could be produced each year by the wise use of by-products which might otherwise go to waste.

One finds a few farmers in the rice belt who have already advanced beyond the stage described above. They have developed a kind of balanced biological cycle which, by making maximum use of all by-products, produces an even wider range of products with a minimum of inputs from outside the

system and, what is equally important, helps to maintain the productive capacity of the system for a long time. The farm layout shown in figure 3 above lends itself to such a development.

Except when on pasture all livestock would be kept in the barn. The animal quarters would be equipped with slatted floors and would extend over the reservoir and would be easily flushed off with a stream of water. All excreta would be washed thus into the reservoir where it would fertilize the water and greatly increase the growth of algae and protozoa. The reservoir would be equipped with baffles, like a septic tank, which would direct the course of the manure-laden water through the various sections of the reservoir. These would be stocked with fish which would feed on the plankton. Properly managed fishponds of this type can produce in the tropics as many as 1,000 kg of fish per hectare per year. The two (60 × 25 m) reservoirs would have an area of 1,250 square meters or one-eighth hectare. They should be capable of producing 125 kg of fresh fish per year. After the water completes its course through the fishponds it would be used to irrigate the various crop fields where any fertility left in the water would be used by the crop. This scheme makes maximum use of all crop residues by feeding them to livestock. The livestock use the available energy in these residues to produce some highly prized animal protein. The waste residues from this process then pass into the water of the reservoir and increase the production of plankton. The plankton is consumed by fish who convert a part of it into fish for food. The residue falls into the water and is recycled to produce more plankton. When its fertility is sufficiently reduced the water is used to irrigate and fertilize the crops in the larger fields. By a little research the output of fish could be greatly increased by increasing their food supply by either feeding them directly or indirectly by fertilizing the water in the reservoir to increase the production of plankton. In such a biologically balanced cycle an increased input at any point raises the level of the entire cycle until the limits of the environment are approached.