The International Rice Research Institute

Annual Report 1966

Minerals grasped from the earth, and carbon from the air, are converted by the rice plant into food for people. The plant transforms inorganic elements into edible substance; its fruit is one of the great sources of energy for mankind, and for more than half the human race the quality of life, and indeed life itself, is dependent on its abundance or scarcity.

The rice scientist aspires to make the rice lands of the world produce more grain. The plants must function at top efficiency and make productive use of the available sunlight; the roots must not seek in vain for what they need from the soil; the depredations of pests and disease must not deprive man of his harvest.

The International Rice Research Institute is a joint venture by The Rockefeller Foundation and the Ford Foundation in cooperation with the Government of the Philippines. It was incorporated in 1960 and dedicated in 1962 when the research program began.

This annual report, the fifth to be issued by the Institute, presents a detailed account of the work done in 1966, in the hope that the findings will be extended and developed and thus contribute to increased rice production throughout the world.


IR8

The International Rice Research Institute
Annual Report 1966

Los Baños, Laguna, Philippines, 1967 Mail Address and City
Office: IRRI, Manila Hotel, Manila Cable Address: Ricefound

THE INTERNATIONAL RICE RESEARCH INSTITUTE 1960

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* Left during year.
† Arrived during year.

Crop Weather—1966*

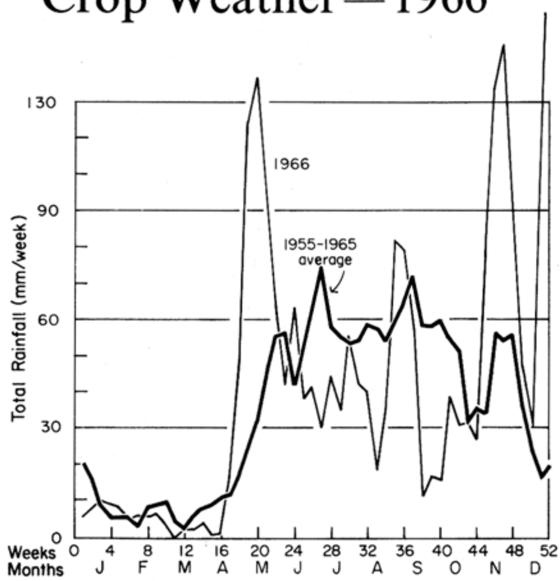


Fig. 1. Annual rainfall curve (3-point moving average) for College, Los Baños, Laguna.

The weather during the 1966 crop year has been relatively normal, having some favorable and a few unfavorable deviations from recent averages. Figures 1 and 2 show the curves for rainfall and solar radiation for the College, Laguna station, about 700 m from the Institute buildings.

The amount of total rainfall for the year was exactly normal but the distribution was irregular. Through November 1, 1966 rainfall amounted to 1,658 mm compared with 1,651 for the 7-year mean. The monsoon began early, however, and rains in the first week of May compensated for two distinct dry periods in early August and early September. The water deficiency in the main growing season was not sufficient to damage the rainfed rice crop but the dry period in early September was disastrous for early plantings of upland rice which were filling at this time. Higher than normal rainfall in early November was accompanied by the only typhoon of the season and this adversely affected late varieties in the main crop. The dry period in September and the relatively dry October favored harvest and maturation of the principal experiments. Dry periods favored land preparation for a number of upland rotation crops.

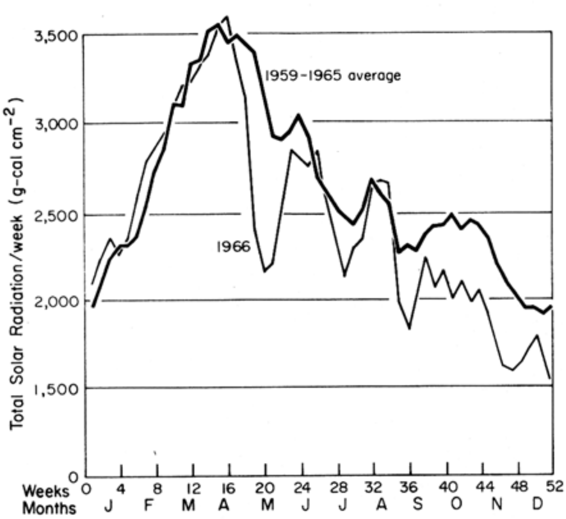


Fig. 2. Annual solar radiation curve (3-point moving average) for College, Los Baños, Laguna.

In spite of the lower than average rainfall during the main season, solar radiation values were also slightly lower than normal. The relatively dry September and October months were not accompanied by correspondingly higher solar energy totals for the period and were actually about 19 percent below normal. This factor was a serious deterrent to achievement of high yields in the main wet-season rice crop.

* The general climatic and soil environment at the Institute was described in the 1965 Annual Report.

Director's Introduction

The most significant achievement of the year was the thorough testing and the eventual naming of a rice variety by the Institute. From mid-1965 through 1966 the selection, designated as IR8-288-3, was tested thoroughly in India, Pakistan, Thailand, Malaysia, and the Philippines. Originally it was tested on experimental farms only, being compared not only with the best local varieties but also with many other promising selections from the Institute's breeding program. Before the year ended, IR8-288-3 had been tested on private farms also in each of the five countries mentioned above. Furthermore, seed of this selection has been sent to over 60 locations all over the world.

Although the results at all locations have not been received as yet, the yields in the above-named 5 countries were truly phenomenal. New yield records were established on experimental fields in all of the countries. During the dry season, yields in India and the Philippines topped 10,000 kg/ha, and even during the cloudy monsoon season yields in all countries ranged from 5,000 to as high as 9,000 kg/ha.

This selection has yielded well over rather widely varying climatic conditions. For example, in the Sind District of West Pakistan, with a total rainfall of only 1.71 inches during the past 12 months, irrigated IR8-288-3 produced over 10,000 kg/ha. It has performed well from near the equator to beyond 30° north or south latitude.

The Institute produced over 74 metric tons of IR8-288-3 seed in July 1966 and over 60 tons of this was planted in the Philippines. The rest was sent to other countries. When the Philippine crop was mostly harvested and additional yield data had been received from other countries, the Institute decided to name the variety. On November 29, 1966 press releases were sent out announcing that the Institute had officially named its first variety, which henceforth would be called IR8.

The seed committee, when discussing the release of this variety, recommended to the Institute that the same system used in the case of this variety be continued with future varieties, *viz.* the letters "IR" followed by a number.

Among many other things, the Varietal Improvement Department is engaged in adding to IR8 those qualities that it needs to be even more outstanding. These qualities include greater disease resistance and improved grain appearance and quality.

Another significant achievement of the Institute is a broad one, but one which will soon have an impact on rice yields throughout tropical Asia, and eventually throughout the world. Reference is made to the changing appearance of experimental rice fields in all the countries where major cooperative programs are in operation. If one had visited any of the tropical rice stations of Asia 3 years ago he would have seen mostly tall, low-yielding tropical rice plants. Fertilizer applications would have been low and essentially all varieties would have lodged before harvest time. Today things are different, not only in the

FOR ITS CONTRIBUTIONS TO THE NATION'S RICE PROGRAM, the Institute was recently presented by the Philippines Department of Agriculture and Natural Resources with a Certificate of Award. President Marcos of the Philippines, accompanied by Vice President and Secretary of Agriculture Lopez, is shown presenting the certificate to Dr. Robert F. Chandler, Jr., director of the Institute.

fields but in the minds of the scientists. On every major rice experiment station in India, Pakistan, Thailand, Malaysia and the Philippines, one sees many experiments using the new, short, non-lodging varieties. Fertilizer applications have increased threefold and yields have soared to establish, as mentioned earlier, new all-time records.

The high yields obtained by Institute agronomists in 1965 on our own experimental fields have been eclipsed during 1966. In the dry season, IR8 yielded 10,130 kg/ha, and in five different experiments yields exceeded 9,000 kg/ha. To our knowledge, these are the highest yields ever obtained in Los Baños. In the continuous cropping experiment, from which we obtained a 3-crop yield total of 17,800 kg/ha in 1964-1965, 20,178 kg/ha was produced in 1965-1966. This may or may not be a world record for a 12-month period but it is certainly close to it. In any event, we are essentially certain that it has not been equalled anywhere in Asia.

Another important achievement of the Agronomy Department was the identification of a weed control chemical which is highly effective at low levels of concentration, thus pointing the way toward truly inexpensive chemical weed control. The chemical is 2, 3, 5-trichloro-4-pyridinol, and not more than 200 g/ha is needed to give good control of grasses, sedges, and broadleaved weeds. This is the first highly selective herbicide tested by the Institute that shows real promise at a cost well within the reach of small farmers.

In South Vietnam alone there are over 2 million hectares of so-called acid-sulfate clays that are unproductive because of high acidity and sulfur content. The Institute's soil chemist has studied these soils at the Institute, and by adding combinations of lime and manganese dioxide, he has been able to promote normal plant growth. During 1967 he will conduct field experiments on acid-sulfate clays in several Southeast Asian countries to determine whether these same methods will have practical application in reclaiming these unproductive land areas.

The plant protection program is one of the most active in the Institute. The screening of vast numbers of varieties and genetic lines continues and we are still finding abundant germ plasm with resistance to all major diseases.

The bacterial leaf blight disease, so prevalent in the Philippines, Pakistan, and India, has received special attention during the year. It has been found that there are a number of different strains of the causal bacteria and that they vary considerably in virulence. However, some varieties have resistance to the most virulent strains, so the varietal resistance approach still offers the most practical means of control.

The entomologist is continuing his studies on the use of systemic insecticides for the control of the rice stem borer and other insect pests of rice. The work with lindane has been completed and attention is now being directed toward other materials. Diazinon is one of the most promising chemicals, which not only controls all species of the stem borer but reduces leafhopper populations sufficiently to exert considerable control over the incidence of virus diseases.

The Office of Communication had the largest class yet in the rice production specialist training program, numbering 29. Five came from countries other than the Philippines. The Filipinos, however, came from a wide range of organizations including the Agricultural Productivity Commission, the Bureau of Plant Industry, the University of the Philippines College of Agriculture, the Philippine Rural Reconstruction Movement, the Bicol Development Board, and several large private firms.

Another major advance in 1966 was the establishment of accelerated rice improvement programs in both East and West Pakistan. The Ford Foundation made grants to the Institute to cover the costs of these two programs. The activities include such things as supplying an advisor; research and testing in plant breeding, entomology, and soil fertility; the training of scientists abroad; travel grants for senior staff; the purchase abroad of needed equipment for key experimental stations; and supplying consulting scientists on a short-term basis. The training of extension workers in East Pakistan has been started. This was done locally in Pakistan, with IRRI staff assisting. It is expected that a similar program will be tried in West Pakistan in 1967.

One could go on citing the work of the Institute during 1966, but suffice it to say that the program in *all* departments continues at a good pace. Agricultural engineering is deeply engaged in a thorough and comprehensive study of the economics of power use in the tropics. The chemistry department is searching among the 10,000 varieties in our world collection for those that have an exceptionally high protein content. Also a search is being made for varieties with a genetic factor for high lysine, comparable to that of the maize variety that contains the "Opaque II gene" and which was discovered at Purdue University several years ago. The microbiology department has demonstrated biodegradation of gamma-BHC in flooded soils, thus offering an explanation for the lack of accumulation of this insecticide in rice fields. The statistics department is assisting the field research workers in many ways, including such things as developing better methods for describing the rice canopy, collecting statistics from rice farmers, and making principal component analyses of the agronomic characteristics of rice. The plant physiology department continues to explore the reaction of the rice plant to its environment with particular reference to solar energy, soil nutrients, and length of day. The agricultural economics department, although understaffed temporarily, has conducted some excellent studies on the costs and returns from rice crops managed over a range of intensities.

The Institute, as its special contribution to the International Rice Year, made a 25-minute color motion picture film, showing what the application of modern science and technology could do toward increasing rice yields.

Staff Changes

Two resignations and one replacement during the year were the only changes in the senior scientific staff.

Dr. Yasuo Natori, biochemist, resigned on June 30, 1966 to accept a responsible position in Japan. Fortunately, two assistant visiting biochemists were here when Dr. Natori left, so the biochemistry program was able to move ahead. Furthermore, Dr. Natori has been able to visit the Institute twice and thus help guide the research program. No replacement has yet been found to fill the vacancy created by Dr. Natori's resignation.

Dr. Akira Tanaka resigned on March 31, 1966 and he was replaced by Dr. Shoichi Yoshida who came to the Institute from the National Institute of Agricultural Sciences in Tokyo.

No replacement has yet been made for the vacancy in Agricultural Economics created by the resignation in 1965 of Dr. Vernon W. Ruttan. However, Dr. Randolph Barker, who is now a Visiting Professor of Agricultural Economics at the College of Agriculture, is supervising our economics program on a half-time basis, and it is expected that he will join our staff in July 1967 on a full-time basis.

Trustees

In January 1966, the following new Members of the Board of Trustees were elected: Mr. Fernando Lopez, Vice President of the Philippines and Secretary of Agriculture; Dr. Glauco Viegas, Director General, Instituto Agronomico, Brazil; Dr. Sala Dasananda, Director General, Rice Department, Ministry of Agriculture, Thailand; Dr. N. Parthasarathy, Regional Rice Improvement Specialist, FAO, Bangkok; and Dr. Ralph W. Cummings, Field Director, Indian Agricultural Program, The Rockefeller Foundation, India.

Resignations were received from Dr. A. H. Moseman and Secretary Jose Feliciano, whose changed positions disqualified them as Members of the Board. The memberships of Dr. T. H. Shen and Mr. Ahsan-ud-Din terminated because their terms had expired.

Finances

As in 1965, the operating costs of the Institute were provided equally by the Ford Foundation and The Rockefeller Foundation. The amount received during 1966 from the two Foundations totalled $1,380,000.

Other funds received by the Institute during 1966 are as follows:

1. From the US National Science Foundation, for a project entitled "Preservation of the World's Rice Germplasm" US$13,800
2. From Plant Protection Ltd. of England, for studies of herbicides for minimum tillage experimentation .. .. US$ 5,000
3. From the International Potash Institute, for studies of plant breeding and use of potash on rice .. .. .. US$ 2,750
4. From various sources for the support of the rice production specialist training programs .. .. US$49,556.96
5. From the International Minerals and Chemicals Corporation, for studies on the response of rice to fertilizer and soil amendments in tropical Asia .. .. US$10,000

Plant Physiology

The remarkable yielding ability of IR8 has prompted the plant physiologists to examine its growth characteristics in comparison with other varieties. The general objective is to identify physiological features associated with high yield potential. Studies of rice plants growing as a crop—the effect of spacing, plant type, fertility level, and interactions between them—have continued. Photoperiodism investigations put special emphasis this year on the response of the new lines being developed by the Institute plant breeders. Results of mineral nutrition studies have stressed the modifying effect of nitrogen and silica nutrition on plant morphology. Work on the oxidizing power of rice roots has been initiated in the hope that the results will help to unravel the important but complex problems associated with physiological disorders.

Growth Analysis of Varieties

To collect information on the agronomic and physiological characters of the new high-yielding variety, IR8, its growth was analyzed in comparison with those of other varieties.

Five varieties differing markedly in plant type and other agronomic characters were grown in the Institute field in the 1966 wet season. To study the growth of these varieties, both under isolated conditions and in communities, plants were grown at 30 x 30 cm and 100 x 100 cm. Whenever there was danger of lodging, the plants were supported by bamboo sticks.

Grain yield, plasticity, and nitrogen response

As shown in Table 1, at 30 x 30 cm spacing IR8 gave the highest yield with 100 kg/ha N, whereas at 100 x 100 cm spacing Peta yielded the highest with 100 kg/ha N. The plasticity of varieties differs markedly in response to changes in spacing (Table 2). Plasticity index is here defined as the ratio of grain weight per hill at 100 x 100 cm to that at 30 x 30 cm spacing. As expected, the plasticity index is smallest for CP 231, a variety for direct sowing, and largest for Peta, a typical leafy tropical variety. The plasticity index is negatively correlated with nitrogen response (% increase) of varieties (Fig. 1). The larger the plasticity index, the smaller the nitrogen response. IR8 and 81B-25 have moderate plasticity indices. Since a large plasticity index insures that a rice variety is adapted to a wide range of environment, a moderate value is one of the requisites for consistent high yields under diverse cultural conditions.

Growth characters

Table 3 summarizes some characters of varieties pertinent to growth and yield. IR8 can be charac-

Table 1. Grain yield (ton/ha) and nitrogen response of five varieties, 1966 wet season.

Variety	30 x 30 cm spacing				100 x 100 cm spacing	
	Nitrogen level (kg/ha N)		Nitrogen response (kg/ha)*	Nitrogen response (% increase)†	Nitrogen level (kg/ha N)	
	0	100			0	100
IR8	5.26	6.10	0.84	16	2.20	2.31
81B-25	5.14	5.35	0.21	4	1.77	2.13
CP 231	3.58	4.43	0.85	24	0.67	0.83
Peta	4.93	4.52	—0.41	—8	3.00	3.50
Hung	3.38	3.13	—0.25	—7	1.48	1.68

* Grain yield at 100 kg/ha N—grain yield at 0 kg/ha N.

† $\frac{\text{Grain yield at 100 kg/ha N—grain yield at 0 kg/ha N}}{\text{grain yield at 0 kg/ha N}}$, x 100.

Table 2. The plasticity of rice varieties in response to spacing, 1966 wet season.

Variety	30 x 30 cm spacing			100 x 100 cm spacing			Plasticity index (B/A)
	Grain (g)/hill (A)	Height (cm)	No. of panicle/hill	Grain (g)/hill (B)	Height (cm)	No. of panicle/hill	
IR8	51.2	108	16.9	225	107	55.4	4.39
81B-25	47.2	144	16.9	195	146	54.0	4.13
CP 231	36.1	151	9.2	75	133	21.8	2.08
Peta	42.5	193	16.3	325	183	75.2	7.65
Hung	29.3	193	16.3	158	169	61.6	5.39

Note: Each figure is mean of 0 kg/ha N and 100 kg/ha N.

Table 3. Growth characters* of five varieties grown at 30 x 30 cm spacing, 1966 wet season.

Variety	Maturity (days)	Total dry weight (ton/ha)	Height (cm)	Maximum no. of tillers/hill	Effective tillers (%)	Panicle:straw ratio
IR8	121	12.0	108	20.0	85	0.96
81B-25	138	13.1	144	21.7	78	0.74
CP 231	108	7.8	151	10.8	85	0.99
Peta	138	12.5	193	21.5	76	0.68
Hung	107	8.5	193	18.0	91	0.61

* Mean of 0 kg/ha N and 100 kg/ha N.

terized as an early maturing, short-statured, moderate-tillering variety. It is resistant to lodging. Its total dry matter production is about the same as that of Peta but panicle: straw ratio is much higher.

Varietal traits related to photosynthetic activity

Leaf area index (LAI) and net assimilation rate (NAR). As shown in Fig. 2, IR8 can be considered as a moderate leafy variety in comparison with Peta. The flag leaf of IR8 was 16/o in the wet season.

Net assimilation rate is as important as leaf area in dry matter production. However, NAR as measured in a community is dependent on LAI because of mutual shading, which affects light conditions in a community. To eliminate its dependence on LAI, the NAR of rice varieties was calculated from the data obtained at 100 x 100 cm spacing. The NAR calculated in this way can be considered as a measure of photosynthesis per unit leaf area minus respiration of whole organs (Table 4). There is an apparent varietal difference in NAR. CP-231 has the highest value; IR8, 81B-25 and Hung, intermediate; and Peta, the lowest. However, it is possible that the high NAR of CP-231 is due to less mutual shading within a hill.

Crop growth rate (CGR). Although total dry matter production is not necessarily related to grain production, it has been well established that grain production largely depends on dry matter production after flowering. This is particularly the case when high yield is to be attained by liberal application of fertilizer. Dry matter production is an integral of crop growth rate (dry matter increase, g/sq m of land area per week) for a given period. It is thus important for a variety to maintain high CGR after flowering to attain high grain yield.

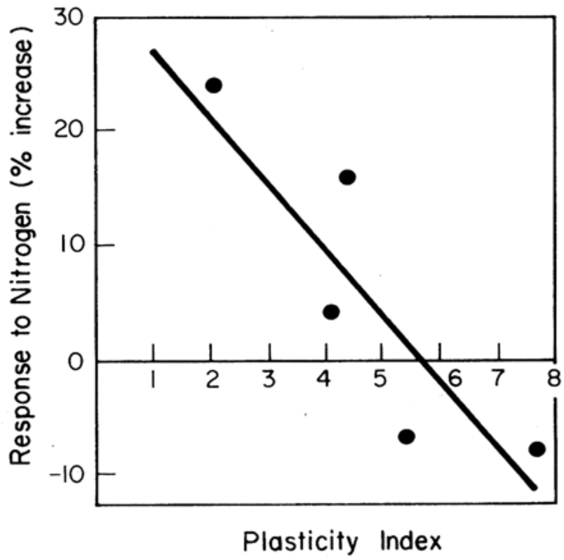


Fig. 1. Relation between plasticity index and nitrogen response.

Changes in CGR with time is a varietal characteristic. As shown in Fig. 3, at early stages of growth the CGR of Peta was slightly higher, reached a peak value well before flowering, levelled off until flowering, and then showed a sharp drop. On the other hand, IR8 kept a steady increase until flowering and then decreased. The peak CGR of IR8 is remarkably higher than that of Peta. The CGR of CP 231 was the lowest at any growth stage, probably due to smaller LAI.

Factors controlling the peak CGR are not exactly known. In addition to solar energy, they could include plant type, photosynthetic ability

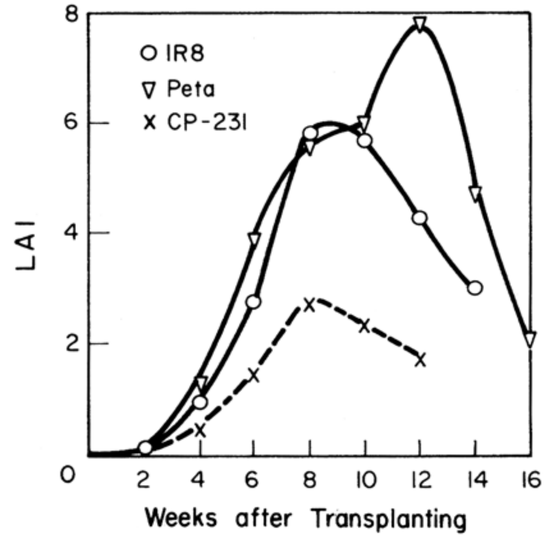


Fig. 2. Leaf area index at successive stages of growth of three varieties, grown at 30 x 30 cm spacing with 100 kg/ha N, 1966 wet season.

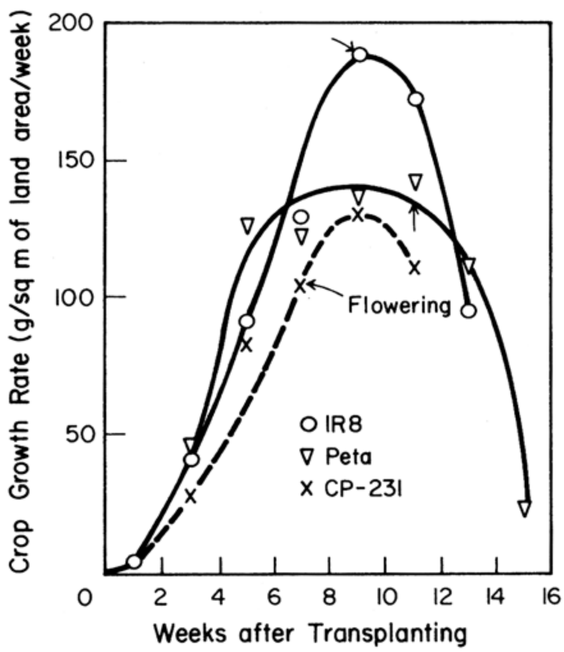


Fig. 3. Crop growth rate at successive stages of growth of three varieties, grown at 30 x 30 cm spacing with 100 kg/ha N, 1966 wet season.

per unit area, balance of photosynthesis against respiration, LAI, or a combination of all these factors.

The peak CGR is important because it gives a measure of possible maximum yield under given conditions. For instance, assuming that the peak CGR is continued for 5 weeks before and after flowering, and dry matter produced during this period becomes grain, IR8 should have yielded about 9.5 ton/ha even in the wet season. The difference between 9.5 tons and the 6.1 tons actually obtained (Table 1), is a measure of the improvement possible from improved cultural practices.

Ratio of photosynthetic organ to non-photosynthetic organ (P:N ratio). Ratio of photosynthetic organs to non-photosynthetic organs is important because it can be a measure of the photosynthesis-respiration balance. The higher the ratio, the more favorable the photosynthesis-respiration balance. As shown in Table 5, the P:N ratio is generally high at vegetative stage and becomes low after internode elongation. There are great varietal differences in the P:N ratio. IR8 maintains a favorable ratio, whereas that of Peta becomes unfavorable after internode elongation occurs.

Varietal traits related to light conditions in a community

Leaf erectness. As shown in Table 15, IR8 and 81B-25 have erect leaves both at tillering and flowering. On the other hand, Peta has erect leaves comparable to IR8 and 81-B-25 at tillering, but becomes droopy around flowering. Hung has the most droopy habit of the varieties studied.

Productive structure of IR8 and Peta. Spatial arrangement of photosynthetic and non-photosynthetic organs as a function of height above the ground is called "productive structure of a community." Figure 4 presents an example of productive structure of IR8 and Peta populations at flowering. From this figure, it is clear that IR8 has a better arrangement of leaf blades with respect to utilization of solar energy than Peta.

Nitrogen uptake

It has been frequently mentioned that indica varieties are more active in nitrogen uptake at early stages of growth than japonica varieties, and that this is inversely related to nitrogen responsiveness. However, during all growth stages, IR8, a high nitrogen-responsive indica variety,

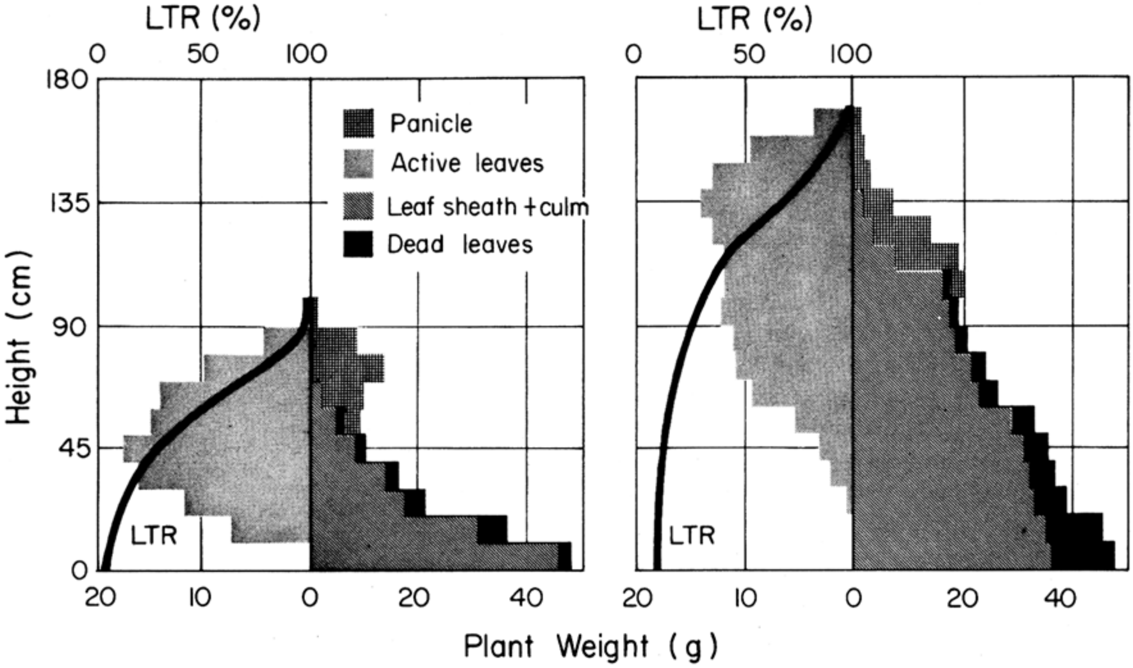


Fig. 4. Productive structure of IR8 (left) and Peta (right) populations at flowering.

showed as active a nitrogen uptake as did Peta, a low responsive indica variety (Fig. 5). This indicates that active nitrogen uptake *per se* at early stages of growth is not necessarily associated with low nitrogen responsiveness of a variety.

Ecological Adaptability of a Typical Tropical Variety

The tropical rice varieties commonly planted in the Philippines during the rainy season are usually tall, leafy, and photoperiod sensitive. These varieties grow very vigorously at the early stages, resulting in early mutual shading, lodging, and eventual low yields. In spite of low yields, the majority of farmers are still using these varieties.

Raminad Str. 3 (RS) is a typical tropical variety, which is popular in the northern part of the Philippines. Being a highly photoperiod-sensitive variety, the date of planting is flexible and the harvest date usually fixed. The growth duration is therefore quite variable. Farmers start planting this variety as soon as water is available and may continue planting until September. The growth duration of the crop is largely ignored as it probably has little effect on yield.

Table 4. Mean net assimilation rate* of five varieties before and after flowering grown at 100 x 100 cm spacing, 1966 wet season.

Variety	Before flowering	After flowering
IR8	63.0	59.0
81B-25	60.7	67.0
CP 231	93.3	94.9
Peta	56.2	52.0
Hung	66.3	66.9

* (a) Expressed as dry matter increase, g/sq m of leaf area/week.
(b) Mean of 0 kg/ha N and 100 kg/ha N.

Table 5. Ratio of photosynthetic to non-photosynthetic organs of five varieties grown at 30 x 30 cm spacing with 100 kg/ha N, 1966 wet season.

Variety	40 days after transplanting	At flowering
IR8	1.94	0.56
81B-25	1.59	0.50
CP 231	1.19	0.72
Peta	1.32	0.32
Hung	0.91	0.39

Under certain environmental conditions and cultural practices, an optimum growth duration for high grain yield has been reported. However, no optimum growth duration has been shown for varieties grown during the rainy season. Thus, by planting RS at different times during the rainy season, yield may not be affected even though different growth durations will be experienced.

The reasons for the preferences of farmers for this type of rice plant may be manifold; agricultural practices, climate, and economic and social aspects probably contribute, but ecological adaptability of the variety to different cultural practices and environmental conditions is probably the main reason for this preference. Ecological adaptability is defined here as the ability of the plant to yield consistently, although possibly at a low level, when subjected to

Table 6. Growth duration and grain yield of Raminad Str. 3 planted monthly.

Month planted	Growth duration* (days)	Grain yield (kg/ha)
January	346	1,930
February	315	760
March	287	1,940
April	256	1,250
May	226	1,880
June	202	3,390
July	181	3,220
August	150	2,830
September	130	2,960
October	125	—
November	142	4,800
December	186	1,570

* Sowing to harvest.

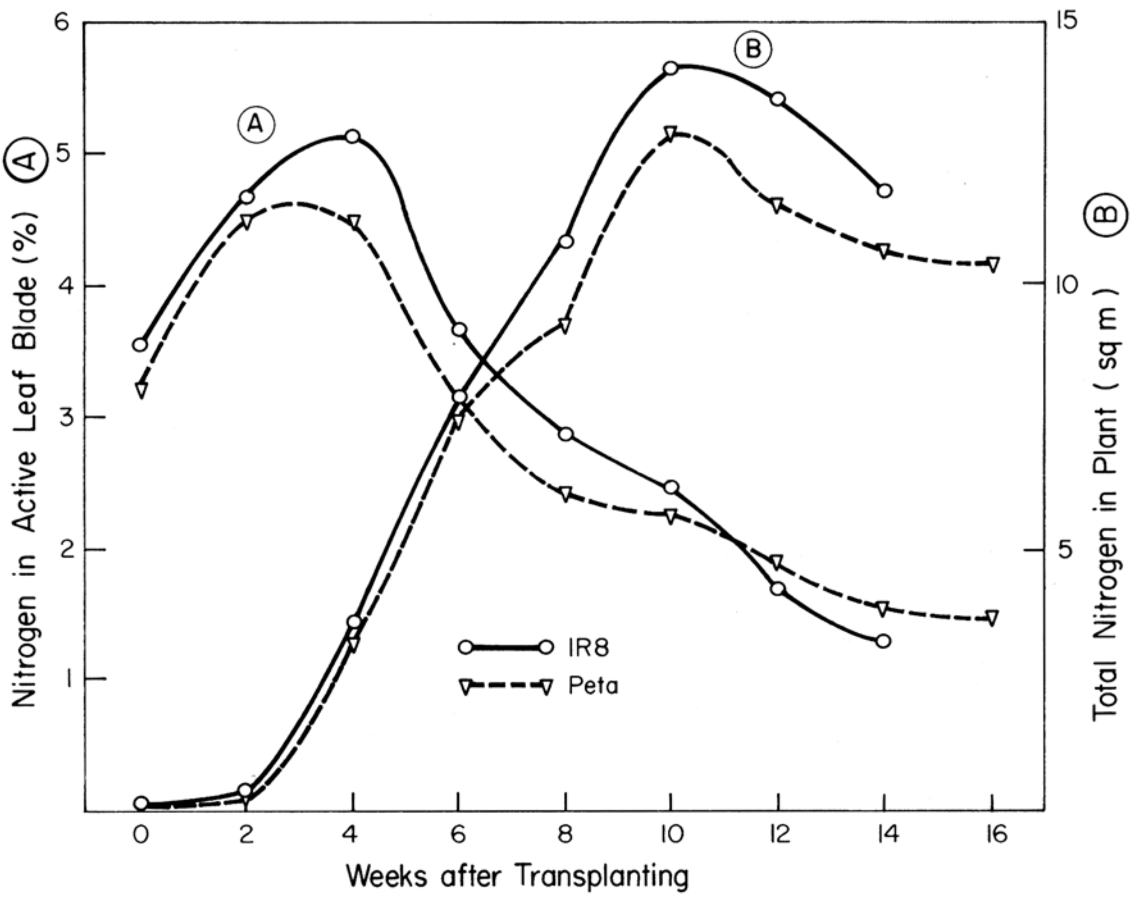


Fig. 5. Percentage and total amount of nitrogen at successive stages of growth in IR8 and Peta.

different cultural practices. It could be claimed that this is not adaptability but an inability of the plants to respond favorably in terms of increased grain yield to the cultural improvements. For lack of a better word, however, adaptability will be used here as defined above.

A series of experiments using RS was designed to study this adaptability in general and, in greater detail, the effect of growth duration on the yield of a tropical variety, the possibility of an optimum growth duration, and the factors affecting it. The experiments involved a variety of treatments such as spacing, nitrogen level, weeding, date of planting, and different locations.

The growth durations of RS planted at different months of the year varied from 125 to 346 days. The plantings from January to August flowered more or less at the same time (Fig. 6).

Since it is not practical to plant RS from January to May, the resulting growth duration being unusually long, the adaptability of the variety is limited in this case. However, RS is usually sown in the rainy season only or from June to September. Considering only the rainy season, there was no significant difference in grain yields per hectare between monthly plantings (Table 6).

Using this type of variety, the practice of fertilizer application, weeding, straight-row planting, specific spacing, and time of planting would have little effect on yield in the three localities where the experiment was performed (Tables 7 and 8). The results show the high ecological adaptability of RS to different cultural practices; that is, the grain yields were fairly consistent under different treatments when planted during the rainy season. With adequate water supply and control of plant pests, the farmers can rely on a consistent yield. This adaptability is probably the main reason for the preference of farmers for this type of variety.

The reason for this adaptability, or consistent but low yields of such varieties, may be traced to their growth patterns. RS is a leafy variety with a long growth duration (up to 346 days at Los Baños), grows up to 270 cm high, and tillers vigorously (a maximum of 500). RS grows very rapidly during the early stages of growth; the LAI and number of tillers reflect the rapid growth. This growth pattern results in early mutual shading and a large decrease in tiller number which continues until a "balance" in the population has been attained. At this stage the growth rate is slow. The balance may be attained earlier in early plantings, heavy nitrogen application, or closer spacing. However, by flowering stage the balance has already been attained in all treatments. Thus, at flowering, the different treatments (nitrogen, weeding, spacing, and date of planting) have more or less the same tiller number and LAI, accounting probably to a great extent for the small differences in grain yield (Figs. 7, 8, and 9).

Farmers sometimes resort to leaf pruning to minimize over-vegetation and to delay lodging. Present experiments show that leaf pruning had very little beneficial effect on yield. Although wide spacing could prevent early mutual shading, a heavy tillering variety with a long growth duration like RS could still eventually have the same number of tillers per square meter as a closely spaced planting. Little improvement can be expected by widening the spacing as the resulting high tillering produced will also lead to severe mutual shading.

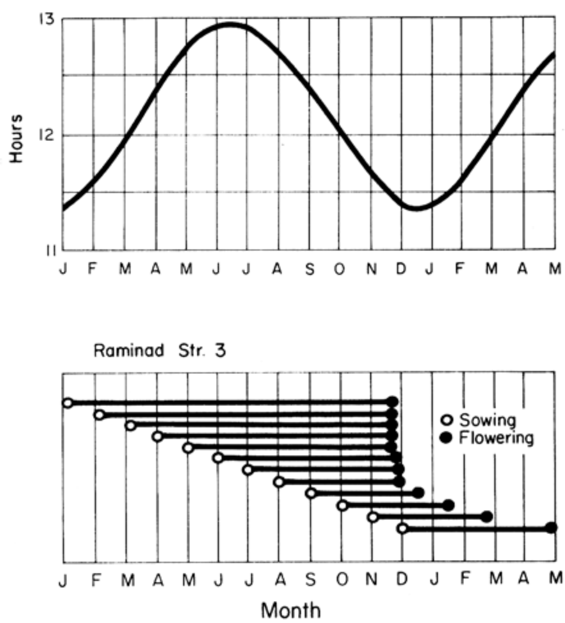


Fig. 6. Daylength changes at Los Baños and flowering of Raminad Str. 3.

Normally, the rapid and dense early growth of the RS plant suppresses weeds. Under some conditions, however, early growth of the variety is slowed down by weed competition. This suppression of early growth may, by delaying mutual shading, actually benefit the rice crop.

For farmers who do not normally weed, RS or a similar variety would be preferred for its high competitive ability. A short plant with a short growth duration would suffer more from weed competition.

Tropical rice soils which have been used for centuries are usually low in nitrogen and the farmer adds, if any, very little fertilizer. Water depth control is also often imperfect in the tropics. RS has a better chance of survival in relatively deep water and at low fertility levels than the short-statured improved varieties.

No optimum growth duration was noted although productivity (grain yield per hectare per day in the field) would naturally be lower from the early plantings with a long growth duration.

The varieties popular among farmers in the tropics are tall with excessive vegetative growth, resulting in serious mutual shading and low

Table 7. Yield of Raminad Str. 3 planted at three locations.

Month planted	Cagayan	Los Banos	Maligaya
		(kg/ha)	
May			
0 N—nonweeded	3550	3920	1530
0 N—weeded	3150	3880	2210
60 N—nonweeded	3280	4030	2580
60 N—weeded	3020	3220	3560
June			
0 N—nonweeded	3960	3870	3760
0 N—weeded	3870	4200	3270
60 N—nonweeded	—	3670	3770
60 N—weeded	—	3380	4010
July			
0 N—nonweeded	5030	4480	2970
0 N—weeded	4330	4530	3170
60 N—nonweeded	4420	4570	2910
60 N—weeded	3880	3670	3240
August			
0 N—nonweeded	3900	2580	3760
0 N—weeded	4780	2620	3180
60 N—nonweeded	3850	2600	3610
60 N—weeded	4250	2380	2610
Ave. 0 N	4070	3760	2980
60 N	3780	3440	—
Ave. nonweeded	4000	3720	—
weeded	3900	3490	—
Ave. May	3250	3760	2470
June	3920	3780	3650
July	4670	4310	3070
August	4200	2550	3290

LSD (Cagayan) = 535
LSD (Los Baños) = 586
LSD (Maligaya) = 433

Table 8. Raminad Str. 3 planted at Los Baños and given different treatments.

Month planted	Lodged	Supported	Pruned at	
			60 days*	90 days*
		(kg/ha)		
May				
0 N—nonweeded	3920	3920	3120	3450
0 N—weeded	3880	3900	3930	3920
60 N—nonweeded	4030	3480	3400	2770
60 N—weeded	3220	3970	3680	3830
June				
0 N—nonweeded	3870	4500	3450	3330
0 N—weeded	4200	5450	3200	3350
60 N—nonweeded	3670	5020	2680	2880
60 N—weeded	3380	5270	3080	2880
July				
0 N—nonweeded	4480	4380	4040	3280
0 N—weeded	4530	5070	2840	2630
60 N—nonweeded	4570	4220	3480	2400
60 N—weeded	3670	4610	3870	2820
August				
0 N—nonweeded	2580	2170	3080	—
0 N—weeded	2620	2630	2580	—
60 N—nonweeded	2600	3050	2050	—
60 N—weeded	2380	2550	2130	—

* After transplanting.
LSD (supported, lodged) = 345,586
LSD (pruning—May, June and July) = 437

yields. These types have persisted with very little direct human improvement, possibly because they are well adapted to their climatic and agronomic environment.

At the present level of rice farming in most Asian countries, RS and similar varieties still have their value. However, this type of adaptability and the accompanying cultural practices have to be changed if high yields are to be obtained. The experiments strongly suggest that, even with the best management, high yields cannot be expected with this type of variety.

Influence of Planting Pattern on Growth Process

Better understanding of the competition between rice plants in a community for light and nitrogen is one of the key requirements for achieving an ideal growth of the rice plant and maximum grain production.

A change in the planting pattern as well as planting density may result in a change in the time of competition for nitrogen and light becoming serious between rice plants.

To study the response of rice varieties to changes in planting pattern, two varieties, IR8 and Tainan 3, were grown with three different planting patterns. Three levels of planting density and two levels of nitrogen were superimposed on planting pattern. Nitrogen was applied only as a basal dressing.

Table 9. Design of planting pattern experiment.

Square (cm)	Single row (cm)	Double row (cm)	No. of hills/sq m
15 x 15	10 x 22.5	10 x 10 x 35	44.4
30 x 30	20 x 45.0	20 x 20 x 70	11.1
45 x 45	30 x 67.5	30 x 30 x 105	4.94

Table 10. Grain yields at different planting pattern x plant density x nitrogen level (ton/ha).

Density	IR8			Tainan 3		
	Square	Single row	Double row	Square	One-lane	Two-lane
			0 N			
44.4	5.04	5.72	5.06	3.81	3.40	3.56
11.1	5.39	5.10	4.11	3.51	3.00	3.08
	5.02	4.33	3.21	2.99	2.53	2.95
			100 N			
44.4	6.20	7.09	7.35	5.23	5.13	4.94
11.1	6.48	6.53	6.05	4.44	4.32	4.29
4.94	5.23	5.16	4.14	4.03	3.56	3.26

Table 9 shows the design of the experiment and Table 10, the yield data obtained.

From Table 10, the following statements can be made: (1) When planting density was low, grain yield was as follows: square > single-row > double-row; that is, a more uniform distribution of plants in the field favored an increase in grain yields. (2) When planting density was high, IR8 yielded the most in the single-row treatment with 0 kg/ha N and in the double-row treatment with 100 kg/ha N, respectively. With Tainan 3, there was little difference in grain yields between different planting patterns. (3) Variation in grain yields due to density was rather small for square planting but fairly large for single-row and double-row plantings.

These results show that when planting density and nitrogen level are low, and LAI is not excessive, uniform distribution of plant hills enhances yields; but when planting density and nitrogen level are high, and LAI becomes rather excessive, non-uniform distribution of plant hills results in increased grain yields.

To illustrate the above statements, changes in LAI and light transmission ratio (LTR) with time are shown in Figs. 10a and 10b.

As shown in Fig. 10a, when planting density and nitrogen level were low, LAI was much larger in the square planting during the whole growth stage than in the double-row planting. Since even the maximum LAI was below the optimum for dry matter production, the bigger the LAI the higher the grain yield. On the other hand, when planting density and nitrogen level were high, early growth of the square planting

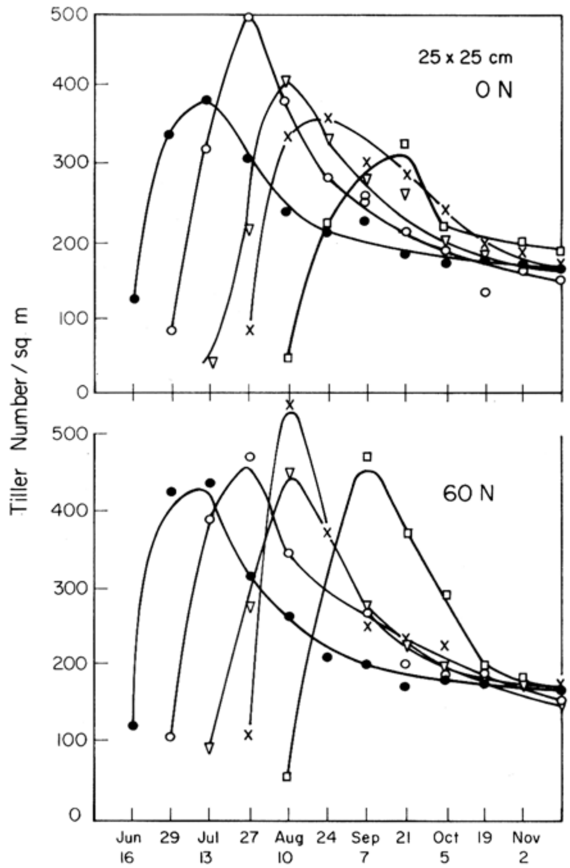


Fig. 7. Tillering patterns of plants sown at different months and nitrogen levels (25 x 25 cm spacing).

was very vigorous and the LAI reached its maximum long before flowering. However, with the double-row planting, early growth was reduced and the LAI reached its maximum around flowering time. After flowering, however, the

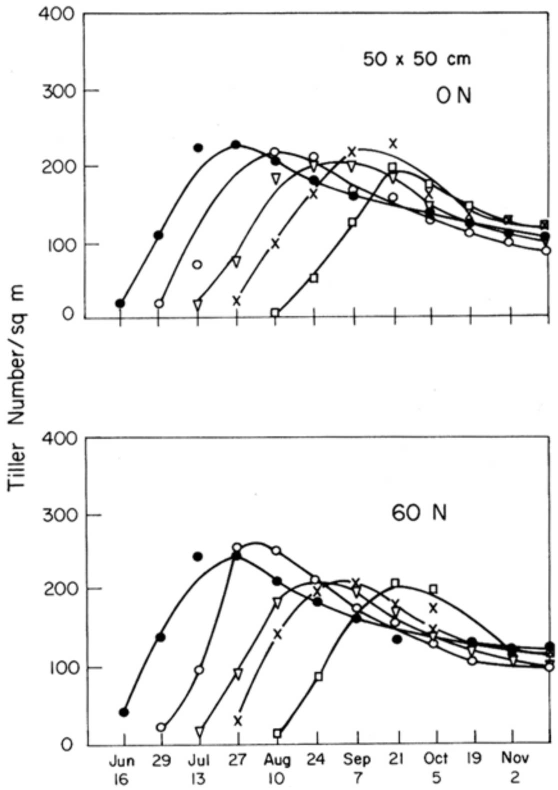


Fig. 8. Tillering patterns of plants sown at different months and nitrogen levels (50 x 50 cm spacing).

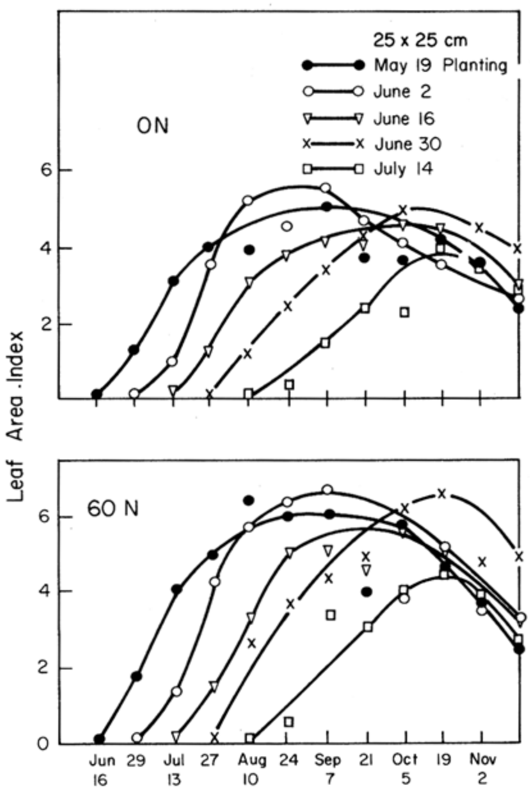


Fig. 9. Leaf area index curves (at flowering) of Raminad Str. 3 planted at different months and nitrogen levels.

LAI was remarkably higher in the double-row planting than in the square planting. Since grain yield is a function of dry matter production after flowering, and adequate LAI is one of the requisites for dry matter production, the high LAI of the double-row planting after flowering may explain its high yield.

A delayed early growth of the double-row planting can be explained in terms of competition for nitrogen. In the double-row planting, each hill has narrower spacings in three directions and a wider spacing in one direction than in the square planting. Consequently, competition for nitrogen starts earlier in the double-row planting than in the square planting, resulting in a rather limited early growth.

LTR of the rice community planted in double rows was measured in the wider spacing. Consequently, data of LTR measurement indicate that at least part of the leaf area in the double-row planting was receiving more sunlight than in the square planting (Fig. 10b).

The above data clearly demonstrate that the non-uniform planting pattern has highly favorable effects upon LAI, LTR and grain yield at high-planting density and at high-nitrogen level.

Response to Photoperiod

Promising IR lines

The photoperiod response of varieties and new lines is especially important if they are introduced to latitudes outside their native habitat or place of origin. At the Institute, the plant breeders have developed a number of new lines and recommended several for field trials in different parts of Southeast Asia. The photoperiod responses of some of these lines are shown in Table 11.

IR3-66, IR4-2, IR8, IR8-36, and IR11-222-4 are practically photoperiod nonsensitive and should have a constant growth duration at all latitudes in the tropics and sub-tropical areas. IR6-53-2, IR11-452-1-1, and IR52-18-2 are more sensitive than the above lines and would show greater variations in growth duration when planted at higher latitudes or different months of the year. The effect of temperature on the growth duration of the lines tested is, however, not known.

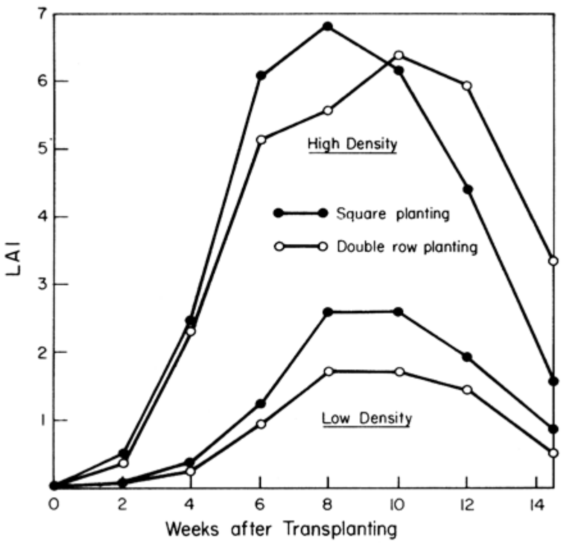


Fig. 10a. Leaf area index as affected by planting pattern. Variety: IR8, high density: 44.4 hill/sq m with 100 kg/ha N; low density: 4.94 hill/sq m with 0 kg/ha N.

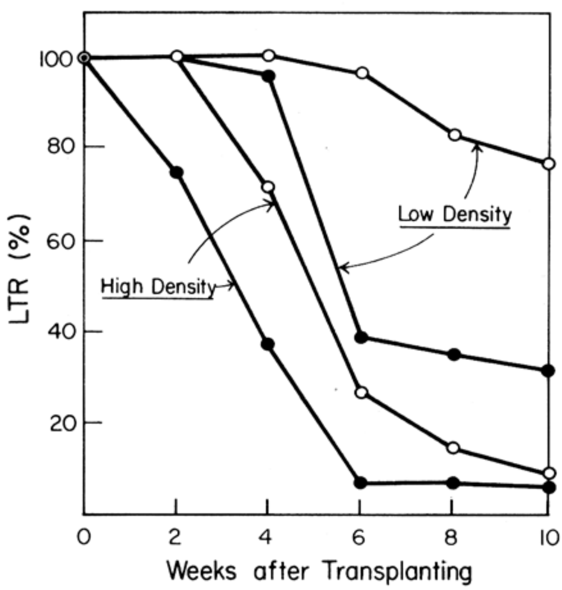


Fig. 10b. Light transmission ratio as affected by planting pattern.

IR3-36, IR4-93-2, IR5-47-2, and IR8-172-3 will react as photoperiod nonsensitive in latitudes similar to Los Baños (14° 10 ′ N) but flowering will be delayed by daylengths longer than 14 hours. Reports on the delay of IR5-47-2 at latitudes higher than Los Baños can be accounted for by such a response to photoperiod.

IR14-149-3 shows an unusually long basic vegetative phase. The long growth duration of this line will make it less adaptable at higher latitudes.

Critical photoperiod

Previous studies on the inheritance of photoperiod sensitivity by the geneticists and plant physiologists at the Institute showed that the basic vegetative phase and the photoperiod-sensitive phase can be analyzed independently as they are inherited separately. This type of analysis should eliminate most of the variability in studying the inheritance of photoperiod sensitivity. However, from the studies it was also apparent that factors like temperature, turning point or optimum photoperiod, and critical photoperiod can affect the response of a variety to photoperiod. The optimum photoperiod and the critical photoperiod affect the length of the photoperiod-sensitive phase. The optimum photoperiod is the daylength at which the number of days from sowing to harvest is minimum, while the critical photoperiod is the daylength beyond which no flowering occurs.

An experiment was initiated to test a procedure for differentiating the turning point and the critical photoperiod of F_2 plants and to seek information on the possible inheritance of these two factors.

The seeds were sown in a tray of soil. After 10 days, the seedlings were planted in clay pots, four plants per pot. All the plants were grown under 24-hour photoperiod until the time of treatment. About 50 days after transplanting, or when the seedlings had developed 6 to 8 tillers, each plant was divided into six parts of one or more tillers per part. Each part was planted in a separate pot. To reduce the number of pots required, parts of four distinct F_2 lines were planted in each pot. Finally, there were six groups of pots with a plant part of each F_2 line in each group. After 35 days of growth the

Table 11. Photoperiod response of promising lines developed at IRRI. Data show the number of days from sowing to flowering.

Line number	Cross	Photoperiod (hours)			
		8	12	14	16
IR3-36-3	BPI-76 x Dgwg*	81	82	125	140
IR3-66	BPI-76 x Dgwg	83	90	106	112
IR4-2	H-105 x Dgwg	85	83	93	102
IR4-93-2	H-105 x Dgwg	88	99	135	150
IR5-47-2	Peta x Dgwg	86	92	137	144
IR6-53-2	Siam 29 x Dgwg	85	91	108	126
IR8-36	Peta x Dgwg	89	91	102	111
IR8-172-3	Peta x Dgwg	87	95	149	157
IR8	Peta x Dgwg	88	90	105	117
IR11-222-4	FB-24 x Dgwg	83	80	97	110
IR11-452-1-1	FB-24 x Dgwg	90	89	112	123
IR14-149-3	BPI-76 x Kh.68	115	102	112	130
IR52-18-2	BPI-76/2 x Kh.68	83	89	106	119

* Dee-geo-woo-gen.

following photoperiod treatments were imposed: 8, 10, 12, 12½, 13, and 13½ hours.

Raminad Str. 3 (RS) and BPI-76, the two parents used, are indica types. As determined earlier, both are photoperiod sensitive and can be prevented from flowering if grown at a 24-hour photoperiod. One hundred and sixty-three F_2 plants were used. Both parents and the F_1 plants were also included. The experiment was terminated 160 days after the start of the treatment.

The critical photoperiod of the parents and F_1 plants are shown in Fig. 11a. RS has a critical photoperiod at about 12 hours and 30 minutes, BPI-76 at 13 hours, and the F_1 plants at 12 hours and 30 minutes.

An attempt was made to classify the F_2 plants. The longest photoperiod at which flowering occurred was considered the critical photoperiod of the particular plant. However, there were some plants for which the difference in days to flower between two successive photoperiods was greater than 50 days. In such cases, the shorter photoperiod was considered as the critical photoperiod. Classified this way, the shorter critical photoperiod was found to be dominant to the long photoperiod (Table 12). Between the two parents, RS had the shorter critical photoperiod. Figure 11b shows the four types of critical photoperiod in the F_2 plants, varying from 12 to 13½ hours.

To study this aspect in detail, photoperiods of smaller graduations should be used. The critical photoperiod should also be considered in studying the inheritance of the photoperiod response as it can change the response pattern of the F_2 population as shown in Table 13. Among treatments ranging from 10 to 13 hours, the F_2 plants flowered in a manner similar to that of the BPI-76 plants. However, at 13½ hours the response was similar to RS, that is, most of the plants did not flower. This appears to be the result of the critical photoperiod. The difference in the photoperiod-sensitive phase of sensitive plants is affected by both the critical as well as the optimum photoperiods.

Optimum photoperiod or turning point

The optimum photoperiod as defined by Chandraratna in the International Rice Commission Newsletter (Spec. No.) 1963, is the daylength at which the number of days from sowing to harvest is minimum. The optimum photoperiod of BPI-76 as determined in an earlier study is around 10 hours, and that of RS, 9 hours.

The optimum photoperiod of individual plants was calculated by using Chandraratna's formula. The photoperiods used in the present experiment to calculate the optimum photoperiod were 8, 10, 12 hours, and the successively longer treatments (half-hour intervals) up to the critical photoperiod of the particular plant.

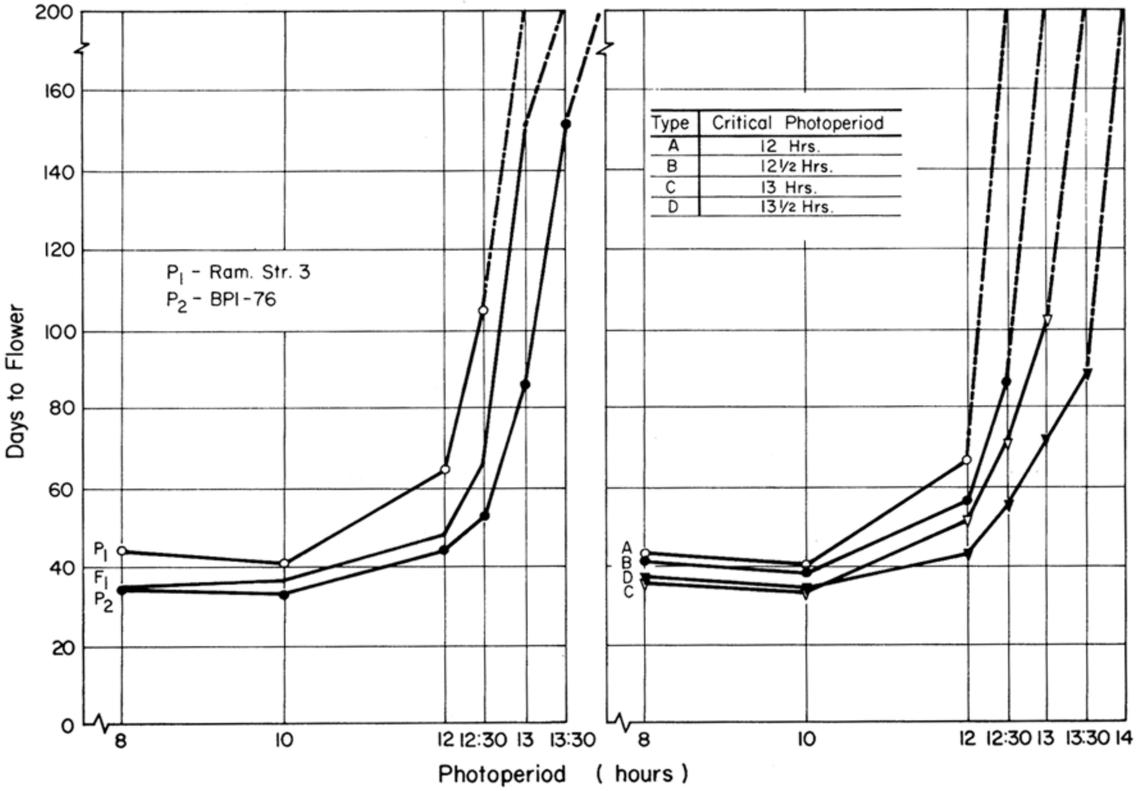


Fig. 11a. Response curve of Raminad Str. 3, BPI-76 and F_1 plants to different photoperiods.

Fig. 11b. Four types of critical photoperiod in F_2 plants.

Table 12 shows that, in the F_2 population, short optimum photoperiod is dominant to long optimum photoperiod. The high P value (.98-.95) is in good agreement with 3 short optimum:1 long optimum photoperiod.

The polynomial equation of Chandraratna shows that the optimum photoperiod is affected by the critical photoperiod. Many F_2 plants with a long critical photoperiod had also a long optimum photoperiod. There is also evidence for a linkage between these two segregating factors as indicated by the high X^2 value of 127.7026 (Table 12). The long optimum photoperiod is associated with a long critical photoperiod, and the short optimum photoperiod with a short critical photoperiod.

Transgressive segregates for critical photoperiod and optimum photoperiod, were detected in this cross (Fig. 12).

The photoperiod-sensitive phase (p.s.p.) is essentially the measure of the photoperiod response, and the above data show that it can be affected by the optimum as well as the critical photoperiods. The shorter the optimum and critical photoperiods, the longer would be the p.s.p. under a long-day treatment.

Days from photoinduction to flowering

To obtain the number of days from sowing to panicle initiation without actually dissecting the plants, 35 days is subtracted from the number of days from sowing to flowering. This was the method used in the previous experiments, a method based on the common practice and from experiments using BPI-76.

The present data support this method although it can be seen that there is a wide range in the number of days from treatment to flowering (Fig. 13). The means of the F_1 and F_2 plants are around 35 days. However, the range of the F_2 plants is from 30 to 44 days. RS took a longer time to fully develop a panicle than BPI-76.

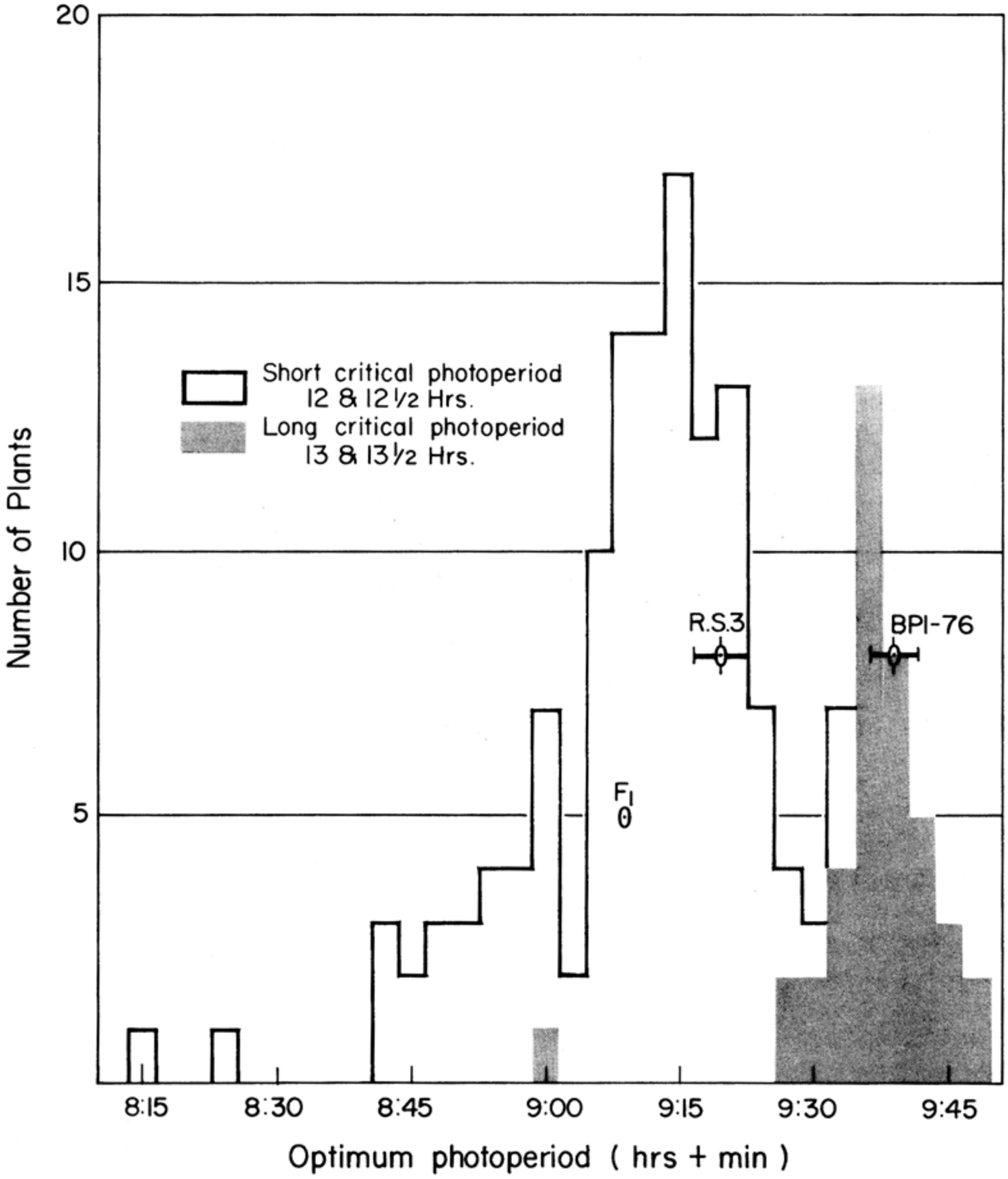


Fig. 12. Distribution and mean of parents, F_1 and F_2 plants by the length of the optimum photoperiod (hours and minutes) and critical photoperiod in the cross of Raminad Str. 3 x BPI-76.

Table 12. Two-way classification of F_2 plants with respect to critical photoperiod and optimum photoperiod.

Critical photoperiod	Optimum photoperiod (days)		
	Short	Long	Total
Short	119	5	124
Long	3	36	39
Total	122	41	163

Critical photoperiod	x^2=.1023	P=.80—.70 (3:1)
Optimum photoperiod	x^2=.0020	P=.98—.95 (3:1)
Independent test	x^2=127.9938	P=<.01 (linkage)

Table 13. Number of F_2 plants flowering at different photoperiods.

Photoperiod	Number of plants		Parent	
	Flowering	Not flowering	RS	BPI-76
10	163	0	FLW	FLW
12	163	0	FLW	FLW
$12\frac{1}{2}$	163	0	FLW	FLW
13	116	47	NOT	FLW
$13\frac{1}{2}$	29	134	NOT	FLW

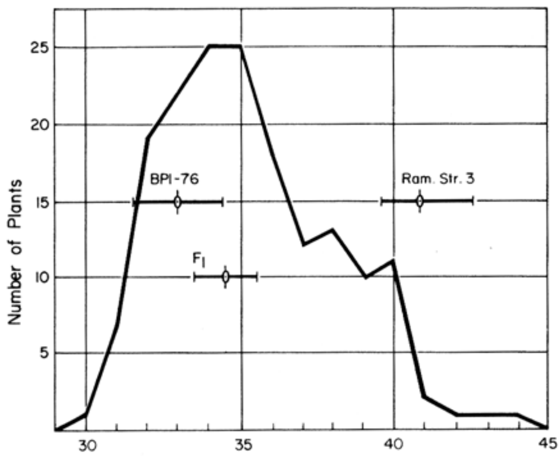


Fig. 13. Days from treatment to flowering at optimum photoperiod.

This can be the result of either a delay in panicle initiation or a slower panicle development or both.

Although these differences in the number of days from treatment to flowering are relatively minor, they can nevertheless affect the measurement of the p.s.p. and especially the basic vegetative phase (b.v.p.). In studying the inheritance of b.v.p., one should perhaps consider only those materials with large differences in b.v.p.

Mineral Nutrition

Effect of silica and nitrogen supplies on leaf erectness

Leaf erectness is one of the important leaf characters that affect light conditions in a rice community. While the leaf erectness is characteristic of each variety, it is also affected by nutritional conditions of the rice plant. For instance, a nitrogen- or phosphorus-deficient plant has more erect leaves than the normal. Of course, this is meaningless when high yield is to be attained by liberal application of fertilizers.

Previous experience indicates that silica supply can affect leaf erectness of the rice plant to a great extent. In view of the relationship between dry matter production of a rice community and the utilization of solar energy, one of the important roles of silica in the rice plant may be related to its function in the maintenance of more erect leaves. To get quantitative information about the effect of silica on leaf erectness of rice varieties, a water culture experiment was conducted in the wet season of 1966. Five varieties with different degrees of leaf erectness were compared at different levels of silica and nitrogen supply. Leaf openness was used as a measure of leaf erectness. Leaf openness is defined as the angle between the line of culm and the line connecting the collar and the tip of a leaf blade; mean leaf openness is the mean value of leaf openness of all leaves on the main culm except the leaf at the top.

Table 14 summarizes the effect of silica and nitrogen supply on mean openness of each variety at flowering. In general, increased nitrogen results in higher leaf openness values, and increased silica decreases leaf openness markedly. IR8 and 81B-25 are considered to have erect leaves under ordinary field conditions. However, the leaves of these varieties became droopy when the plants were cultured in the absence of silica and with high nitrogen supply (Fig. 14). These results clearly indicate that leaf erectness of the rice plant is controlled not only by the varietal characters but by silica and nitrogen nutrition.

It is frequently mentioned, though not quantitatively, that leaf erectness of a variety differs according to stages of growth. Furthermore, the water-cultured and the field-grown plants of the same variety may differ in their response to nutritional conditions due to differences in environmental conditions. To study the above possibilities, the same varieties used in the greenhouse study were grown in the field. The leaf openness of these plants was measured

Table 14. Effect of silica and nitrogen on the mean leaf openness* of five varieties (at flowering stage).

N (ppm)	SiO_2 (ppm)			
	0	40	200	Mean
		81B-25		
5	16.2	9.5	10.3	12.0
20	27.5	31.0	20.6	26.4
200	49.1	30.3	25.8	35.1
Mean	30.9	23.6	18.9	24.5
		IR8		
5	22.9	16.3	11.2	16.8
20	53.1	39.8	18.9	37.3
200	76.6	68.5	22.4	55.8
Mean	50.9	41.5	17.5	36.6
		CP 231		
5	43.3	35.9	33.7	37.6
20	77.4	62.6	57.9	66.0
200	100.3	76.1	79.3	85.2
Mean	73.7	58.2	56.9	62.9
		Peta		
5	24.6	19.7	13.2	19.2
20	67.2	57.3	34.7	53.1
200	78.5	70.3	48.7	65.8
Mean	56.8	39.1	32.2	46.0
		Hung		
5	109.4	40.9	65.1	71.8
20	101.9	105.9	78.3	95.4
200	135.1	137.6	149.2	140.6
Mean	115.5	94.8	97.5	102.6

* Mean value on three main culms.

at tillering and flowering, and was compared with that of the water-cultured plants (Table 15).

In general, observed values of leaf openness were much smaller in the field-grown than in the water-cultured plants. However, the order of leaf openness of the varieties used remains the

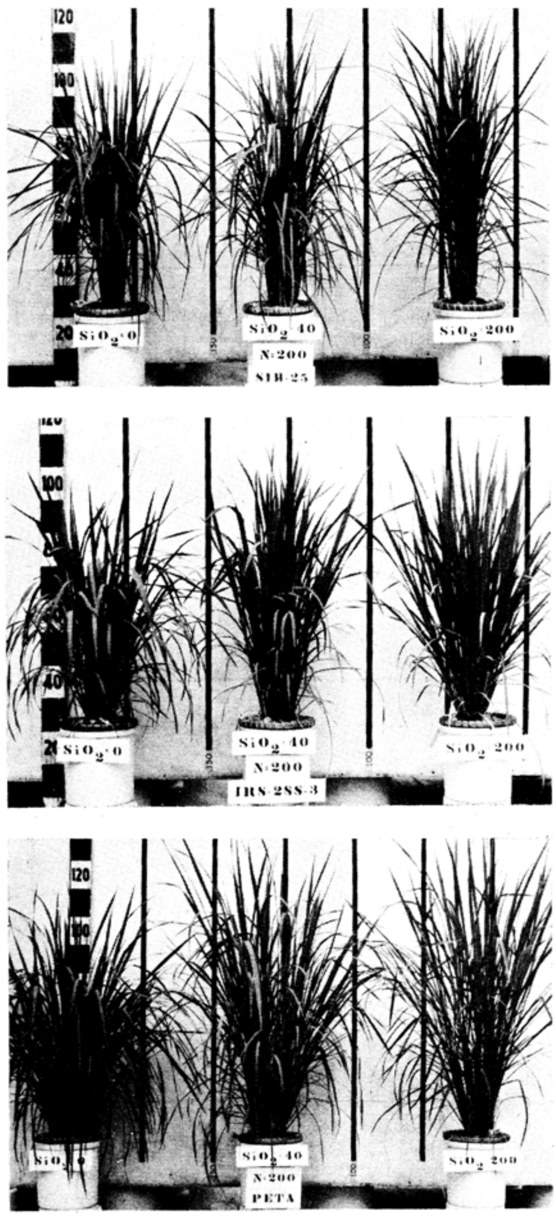


Fig. 14. Effect of silica on leaf erectness of rice varieties (60 days after sowing).

same. Changes in leaf openness between different growth stages differ among varieties. 81B-25 and IR8 maintained about the same leaf openness at flowering as at tillering, whereas Peta and Hung showed remarkably greater leaf openness at flowering than at tillering. Mean leaf openness is well correlated with the light extinction coefficient (K) of a rice community, which is defined by the well-established formula: $I = I_0 \exp(-K.LAI)$ (Fig. 15).

Table 16 shows that the silica content of rice leaves grown at low levels of silica in the nutrient solution was below 10 percent. Leaf concentrations of this order or less have frequently been observed in samples taken from farmers' fields in Southeast Asia, and, from the morphological changes in response to silica demonstrated in these experiments, it seems that there may be many instances in which the light conditions in the rice crop will be improved by application of siliceous materials, leading to increased grain yields.

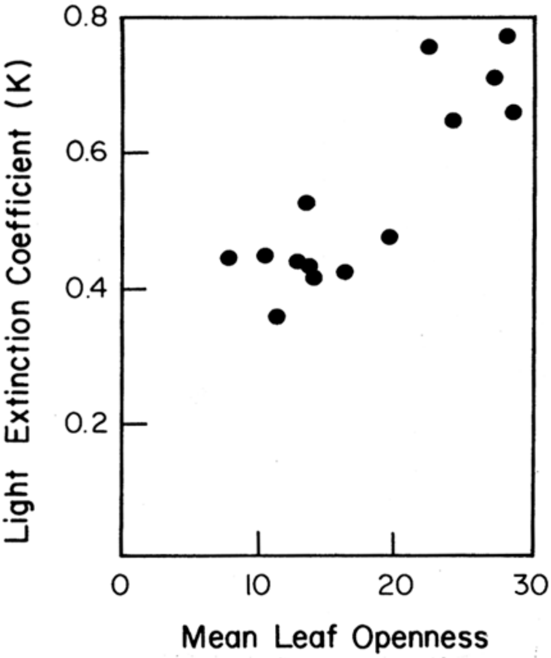


Fig. 15. Relation between mean openness and light extinction coefficient (8 weeks after transplanting).

The above experiments demonstrate that while leaf erectness of the rice plant is characteristic of each variety, it can be changed greatly by silica and nitrogen nutrition. The role of silica in the maintenance of leaf erectness will become important when rice is to be grown with liberal application of nitrogenous fertilizer in paddy fields in which the silica-supplying power is low.

Oxidizing power of rice roots

Rice roots have power to oxidize their rhizosphere. It is this facility that enables the rice plant to grow under flooded conditions. There are many cases in which harmful substances such as ferrous iron, hydrogen sulfide, and some organic acids produced under highly reductive conditions retard rice growth. This kind of disorder is often called physiological disease.

For the rice plant to grow normally under highly reductive conditions, rice roots should maintain a reasonably high oxidizing power. In a preliminary attempt to study oxidizing power of rice roots, some factors affecting the root oxidizing power were studied by the α-Naphthylamine method.

Effect of age of seedlings on root oxidizing power. The root oxidizing power of Peta seedlings was determined at different physiological ages from 2- to 5-leaf stage. Both intact and detached roots were used. As shown in Fig. 16, the root oxidizing power was very high at the 2-leaf stage and decreased continuously as the

Table 15. Comparison of mean leaf openness between the water-cultured and field-grown plants at tillering and flowering.

Variety	Water-cultured*	Field-grown†
	Tillering	
81B-25	19.7	12.9
IR8	20.0	13.9
CP 231	53.8	25.5
Peta	24.8	13.8
Hung	52.9	35.2
	Flowering	
81B-25	18.9	18.3
IR8	17.5	15.4
CP 231	56.9	37.1
Peta	32.2	32.7
Hung	97.5	79.5

* Mean values of 0, 20, and 200 ppm N at 200 ppm SiO_2.
† Mean values of 0, 50, and 100 kg/ha N.

Table 16. Silica content* of leaves of five varieties grown at different silica treatments (SiO_2%, at harvest).

Variety	Silica supply (ppm)		
	0	40	200
81B-25	0.70	4.34	15.4
IR8	0.64	5.83	18.0
CP 231	0.72	5.21	15.4
Peta	0.49	3.33	12.2
Hung	0.58	4.48	15.2

* Mean values of 0, 20, and 200 ppm N.

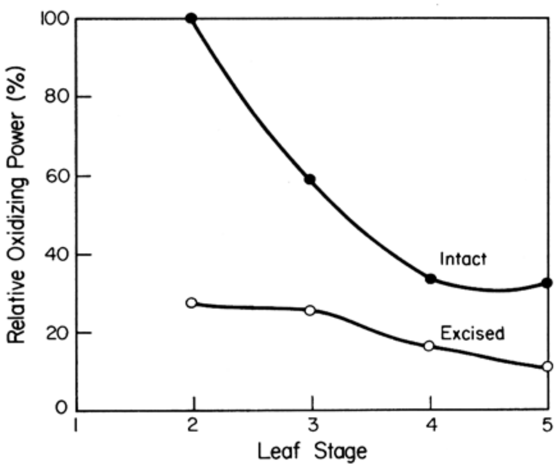


Fig. 16. The relationship between age of seedlings and oxidizing power of roots.

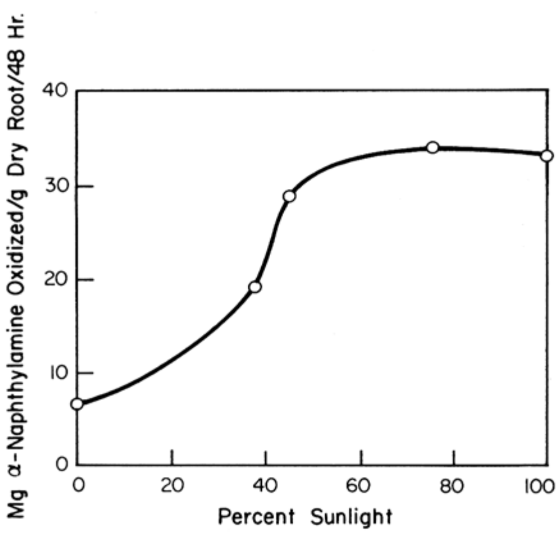


Fig. 17. Effect of light intensity on oxidizing power of Peta seedlings.

seedling grew older. This tendency was more noticeable when intact root was used. Higher oxidizing power of rice roots of younger seedlings may be related to frequent observations that the rice plant is easily subjected to iron chlorosis at the young seedling stage.

Effect of light intensity on root oxidizing power. Peta seedlings at the 4th leaf stage were grown for 1 week in complete culture solutions under varying light intensities by using abaca cloth. One set was placed in the greenhouse under full sunlight for the same period of time. A separate set of seedlings was placed in a dark room for 2 days. The intact roots were treated with α-Naphthylamine on the same day at the completion of the experiment.

Apparently, light intensity has a strong effect on the oxidizing power of rice roots (Fig. 17). The seedlings grown at increasing light intensities showed successively increasing root oxidizing power. Those grown in the dark even for only 2 days exhibited a markedly reduced root oxidizing power.

Table 17. Effect of nutrient deficiencies on the oxidizing power of rice roots.

No. of hours of α-Naphthylamine treatment	Nutrient treatment	mg α-Naphthylamine oxidized/g dry root
	Complete	7.2
	—N	5.4
	—P	4.2
5	—K	3.3
	—Ca	6.9
	—Mg	5.1
	—Si	7.3
	Complete	32.4
	—N	18.0
	—P	19.8
48	—K	15.6
	—Ca	24.0
	—Mg	28.2
	—Si	32.4

Effect of nutrient deficiency on root oxidizing power. Peta seedlings at the 2-leaf stage were transferred to the following culture solutions: complete, -N, -P, -K, -Ca, -Mg, -Si. The seedlings were allowed to grow in these solutions for 12 days, at which time the deficiency symptoms for each element were very apparent. The root oxidizing power was measured after 5 and 48 hours, using intact roots.

As shown in Table 17, nutrient deficiency of any element, except silica, reduced the oxidizing power of rice roots. Deficiencies in nitrogen, phosphorus, and potassium greatly lowered the oxidizing power; lack of calcium and magnesium likewise lessened the oxidizing power, although to a small extent. Silica, on the other hand, had no effect on the oxidizing power of rice roots.

The above data indicate that the oxidizing power of rice roots is affected more by nutrients

Table 18. Root oxidizing power and dry weight of 1,000 seeds of some rice varieties.

Variety	mg α-Naphthylamine oxidized/g dry root/48 hours	Dry weight of seeds (g/1,000 seeds)
Tainan 3	36.5	23.39
CP-SLO-17	30.4	29.65
Peta	29.6	25.11
IR8	25.5	28.82
Taichung (Native) 1	25.4	24.10
Hung	25.3	24.41
Milfor-6(2)	27.0	28.50
81B-25	19.9	25.80
CP 231	19.5	18.83
H-4	13.9	26.80
Murungakayan 302	11.0	24.90
BPI-76	8.2	17.80

of greater metabolic significance than by nutrients of less metabolic significance.

Varietal differences in root oxidizing power. In a preliminary attempt to screen rice varieties for their root oxidizing power, seeds of 12 varieties differing in seedling vigor were sown in culture solution and grown until the 3rd leaf had started to emerge. The dry weight of the seeds was recorded to see if there was any correlation between oxidizing power and the reserved food materials in the seeds.

Table 18 shows the oxidizing power of the seedlings of the different varieties tested and the dry weight of 1,000 seeds. Obviously, oxidizing power is not directly related to the food reserve in the seeds. It is apparent, however, that varietal differences in root oxidizing power do prevail.

Murungakayan 302 and H-4 are Ceylonese rice varieties. The former variety had previously been observed to be susceptible to "bronzing", while the latter was found resistant to the same physiological disease. From the result of this experiment, Murungakayan 302 showed a slightly lower oxidizing power than H-4, although that of the latter was not as high as the other varieties tested. Further studies along this line will be made to identify varieties resistant to physiological diseases.

Biochemistry

Water culture studies established that, where histidine was the only nitrogen source, rice plants developed normally to the panicle initiation stage but failed to form grain. During the reproductive growth phase in such plants there was a decrease in carbohydrate production, chlorophyll content, total nitrogen, soluble protein, and ability to fix CO_2. *Microscopic examination showed that the pollen tubes failed to elongate; fertilization, therefore, did not occur. In plants depending on histidine for their nitrogen supply there was a decrease after panicle initiation in enzymatic activity associated with photosynthesis, caused by an insufficient supply of nitrogen, and there seemed to be abnormalities in protein metabolism. Since the key enzyme concerned with histidine metabolism is histidase, the activity of this enzyme was studied. It was found that histidase is inducible by its substrate, histidine, but that its activity in the roots dropped sharply at panicle initiation. The low level of histidase activity, leading to diminished histidine catabolism, may be responsible for the insufficient nitrogen supply to the plant if histidine is the sole source of nitrogen during the reproductive stage. These studies throw light on the biochemical bases of the transition from the vegetative to the reproductive phases of growth. The fact that histidase is inducible rather than constitutive suggests that different modes of genetic expression are involved in the vegetative and reproductive stages.*

Biochemical Approaches to *L*-Histidine-induced Sterility in the Rice Plant

Use of various amino acids as sole nitrogen source for water-cultured rice plants

Although ammonia and, to a lesser extent, nitrate form the major inorganic nitrogen compounds utilized for the growth of higher plants, it has become recognized that some organic nitrogen compounds, like urea, can be utilized as a direct nitrogen source without prior decomposition to inorganic nitrogen. Since the most immediate pathway of assimilation of inorganic nitrogen is its incorporation into amino acids, the supply of amino acids as the sole nitrogen source should support the growth of higher plants.

Thus, the ability of various amino acids to serve as the sole nitrogen source was compared with the effectiveness of the equivalent amount of inorganic nitrogen (ammonium ion) in water-culturing the rice plant. Taichung (Native) 1 was used throughout the present study. The composition of the culture medium is given in Table 1. After 2 days of soaking, seeds were sown on a wet seedbed with no fertilizer. Twenty-one days after sowing, two seedlings were transplanted to culture pots to make one hill per pot. The culture medium was changed every 3 days, and the pH was maintained at 5.0 to 5.5. The result of growth pattern analysis at the time of harvest is presented in Table 2, and panicle details are shown in Table 3. As can be seen from these tables, rice plants use most of the amino-acid nitrogen as efficiently as inorganic nitrogen, with the outstanding exception of histidine. It was observed that the ability of histidine to support the vegetative growth of rice plants compared favorably with that of ammonia. Histidine, however, failed to induce the accumulation of starch grains in the spikelets at the stage of reproductive growth. Histidine acts, therefore, as a specific inhibitor of the developmental transition between vegetative and reproductive growth phases. To further investigate the biochemical events responsible for this phenomenon, the growth of rice plants under histidine water-culturing was analyzed in detail.

Table 1. Composition of culture medium adjusted to pH 5.0-5.5 daily.

Element	Concentration (mg/l)
N*	40
P	9
K	16
Ca	4
Mg	6
Fe	2

* When amino acids were used as nitrogen source, all the nitrogen atoms in the molecule were considered to be equally available. One mole of histidine, for instance, was considered to be 3 atom-equivalents of nitrogen.

Effects of histidine on the growth of rice plants

The total dry weight of the plant at various growth stages is shown in Fig. 1, and the number of days taken to reach those stages is in Table 4. The duration of each growth phase was almost the same for both ammonium sulfate- and

Table 2. Growth pattern analysis at harvest of rice plants water-cultured with various amino acids as sole nitrogen source.

Nitrogen source	Dry weight (g/hill)			Plant height (cm)	Root length (cm)	Panicle number
	Panicle	Straw	Root			
No nitrogen	19.0	17.8	9.7	44.8	45.5	15
Ammonium sulfate	49.0	43.5	17.0	51.5	40.9	35
Arginine	41.8	40.0	16.9	52.7	42.4	33
Histidine	8.8	62.3	18.2	50.6	42.4	30
Lysine	39.5	35.5	16.5	50.0	41.8	30
Aspartic acid	37.0	30.0	13.3	48.5	36.4	27
Glutamic acid	28.5	24.5	8.5	43.3	31.8	24
Phenylalanine	24.8	22.8	11.8	43.9	40.9	21
Tyrosine	23.3	27.3	13.3	45.5	43.3	19

Table 3. **Analysis of panicles at harvest or rice plants water-cultured with various amino acids as sole nitrogen source.**

Nitrogen source	Panicle weight (g)	Panicle length (cm)	Spikelets/ panicle	Fertile spikelets/ panicle	Fertility percentage
Ammonium sulfate	1.40	4.4	51	40	78
Arginine	1.27	4.6	55	41	75
Histidine	0.29	3.6	40	0	0
Lysine	1.32	4.9	59	44	75
Aspartic acid	1.37	5.0	57	44	77
Glutamic acid	1.19	4.9	59	46	78
Phenylalanine	1.18	4.8	54	42	78
Tyrosine	1.23	5.5	51	31	61

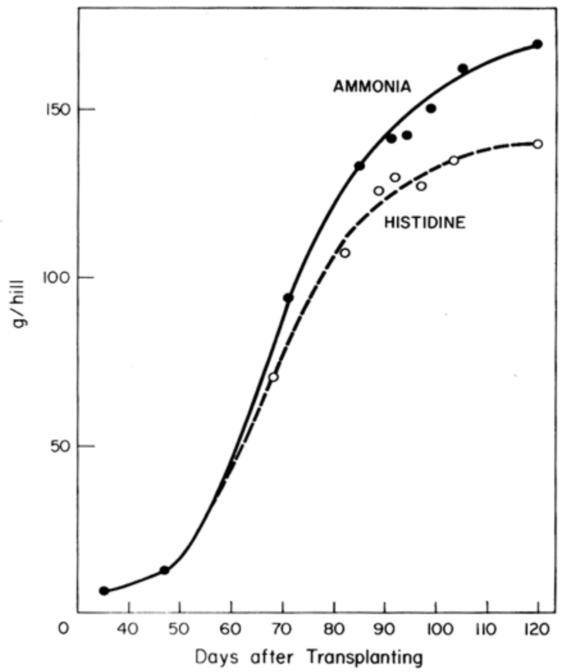


Fig. 1. Total dry weight at various growth stages of rice plants grown in cultures containing either ammonia or histidine as the nitrogen source.

histidine-cultured plants. The growth rate was approximately the same for the first 60 days, then the rate of dry matter production of the histidine plants started to lag behind that of the ammonium ones. At harvest, the dry weight of the histidine plants was 80 percent of the ammonium plants. That this difference of about 20 percent was due to a lack of grain formation is shown in Fig. 2. It should be noticed that in the histidine plants, the decrease in panicle weight seems to be compensated for by the corresponding increase in culm weight. A typical difference in the morphology of the two differently cultured plants at the milky stage is illustrated in Fig. 3.

A remarkable difference in total carbohydrate production between ammonium- and histidine-cultured plants is evident in Fig. 4. Practically, no starch was formed in the panicles of the histidine plants. As shown in Fig. 5, comparatively greater amounts of carbohydrates were accumulated in the culms of the histidine plants. The analysis of the culm at harvest (Table 5) indicates that the greater amount of carbohydrate in histidine plants can be accounted for by a significant accumulation of starch in the culm.

From the foregoing results, it appears that the failure of grain maturation in histidine plants is not due to their inability to synthesize starch in the plant as a whole, but rather to some hindrance in translocating photosynthetic products to the panicle after the flowering stage. To elucidate the picture of carbohydrate translocation in detail, the levels of carbohydrates and amylase activities were determined in various organs through various growth stages of the rice plant (Fig. 6). It is generally believed that the primary products of photosynthesis in the leaf blade are translocated to leaf sheath and culm, where they are stored until reproductive growth is initiated. The function of amylase in carbohydrate translocation has been problematic. The sharp rise of the amylase activity in the leaf sheath at flowering stage, coinciding with the rise of starch content in that organ (Fig. 6 (a)), suggests that amylase is playing an important role in carbo-

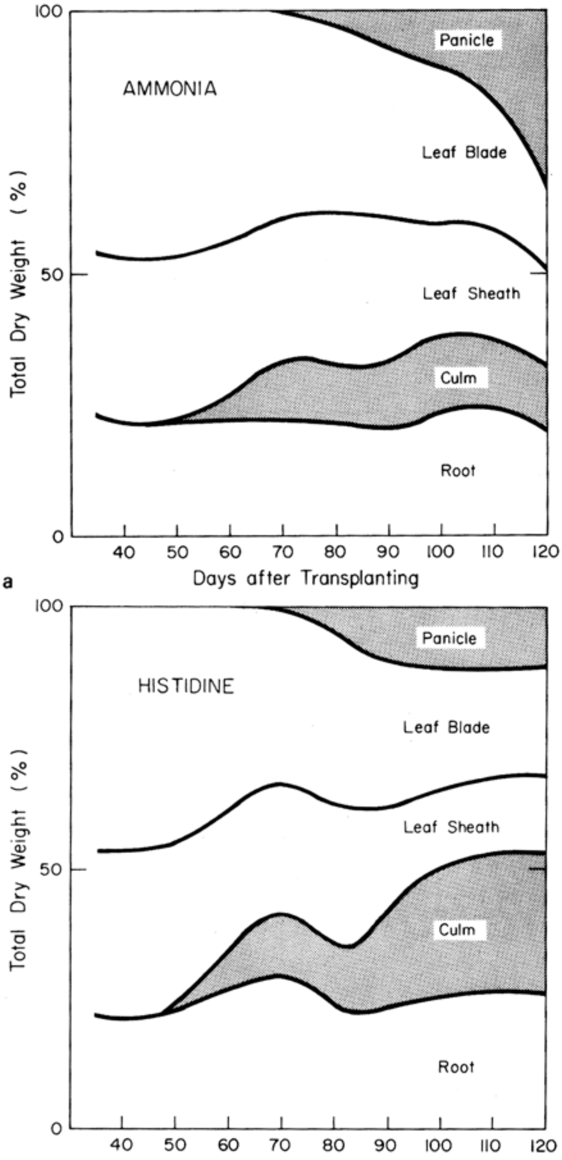


Fig. 2. Dry weight percentage of organs at various growth stages of ammonium sulfate-cultured (a) and histidine-cultured (b) rice plants.

hydrate translocation in the leaf sheath, particularly at the transition from the vegetative to the reproductive growth stage. There appears to be a specific mechanism, possibly hormonal, to induce the amylase activity in the leaf sheath at this growth stage. The fact that the sharp rise in amylase activity was not observed in the histidine plants (Fig. 6 (b)) supports this view. It is also noteworthy that the amylase activity in the culm is very low throughout, which partially accounts for the accumulation of starch in the culm of the histidine plants. In the case of the ammonium plants after flowering stage, the panicle is presumably ready to accept the translocated carbohydrates from the culm, and hence there is no accumulation of carbohydrates in the culm.

To sum up the studies on carbohydrate metabolism: water-culturing of rice plants with histidine as the sole nitrogen source brings about an overall decrease in carbohydrate production after the ear-initiation stage, resulting eventually in complete inhibition of starch formation in the panicle.

Fig. 3. Typical appearance of rice plants at milky stage, water-cultured with ammonium sulfate or histidine as nitrogen source.

Effects of histidine on nitrogen metabolism

The total nitrogen and soluble protein contents were determined at various growth stages. As shown in Fig. 7, the rate of increase in total nitrogen and soluble protein was the same for both culture conditions until the ear-initiation stage, but thenceforth that of the histidine plants

Table 4. Growth stages of rice plants water-cultured with ammonium sulfate or histidine.

Growth stages	Nitrogen source	
	Ammonium sulfate (days after transplanting)	Histidine
Tillering (T)	35	35
Maximum tiller number (Tm)	47	47
Ear-initiation (E)	71	68
Booting (B)	85	82
Heading (H)	91	89
Flowering (F)	94	92
Milky (M)	99	97
Late milky (Ml)	105	103
Harvest (Ha)	120	120

Table 5. Composition of carbon compounds in culm at harvest.

Nitrogen source	Starch	Total sugar (% of total dry weight)	Cellulose
Ammonium sulfate	1.3	6.1	35.0
Histidine	8.3	9.3	41.3

Table 6. CO_2-fixation to ribose-5-phosphate by soluble enzyme of leaf blade.

Nitrogen source	Tillering stage	Heading stage (μmoles CO_2 fixed/g fresh weight)	Milky stage
Ammonium sulfate (A)	4.1	4.1	2.7
Histidine (B)	3.0	1.6	0.8
B/A X 100	73	39	30

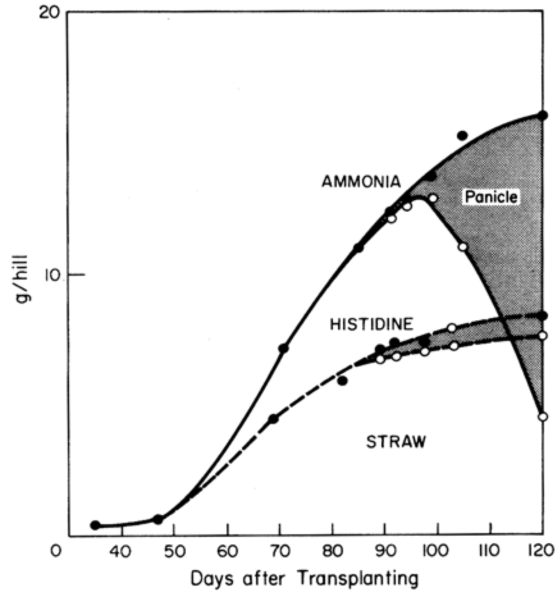


Fig. 4. Total carbohydrates at various growth stages of rice plants grown in cultures containing either ammonia or histidine as the nitrogen source.

leveled off. This observation suggests that the activities of some, if not all, enzymes in histidine plants may become lower than those of ammonium plants after the ear-initiation stage. That this is in fact the case was demonstrated by the determination of the level of the enzymes associated with photosynthesis in the leaf blade. As shown in Table 6, the ability of the extract from the histidine plants to catalyze the fixation of CO_2 to ribose-5-phosphate, one of the primary processes of photosynthesis, was decreased to 40 percent of that of the ammonium plants at the heading stage and remained low throughout the reproductive stage. It was also observed that the chlorophyll content of histidine plants was decreased more or less in parallel with the photosynthetic activity (Table 7). These results are consistent with the studies on carbohydrate metabolism, in that over-all decrease in carbohydrate production in histidine plants may be explained, at least in part, by the decrease in enzymatic activities associated with photosynthesis, which is caused by an insufficient supply of nitrogen after the ear-initiation stage.

Since protein metabolism is intimately related to the metabolism of nucleic acid, particularly that of RNA, the level of RNA at various growth stages was investigated. Figure 8 shows the RNA content of the leaf blade and panicle at various growth stages. There is no significant difference in RNA content between ammonium and histidine plants, except at the booting stage. The fact that the leaf blades and panicles of histidine plants contain less than 60 percent of the RNA found in ammonium plants is indicative of some abnormalities in protein metabolism at this particular growth stage. The nucleotide composition of RNA isolated from the two organs at booting and milky stages was determined. There was no significant difference in composition between ammonium and histidine plants (Table 8).

Table 7. Chlorophyll content of leaf blade at various growth stages.

Nitrogen source	Tillering stage	Heading stage	Milky stage
	(mg chlorophyll/g fresh weight)		
Ammonium sulfate (A)	3.3	2.8	2.3
Histidine (B)	2.8	2.3	1.5
B/A X 100	85	82	65

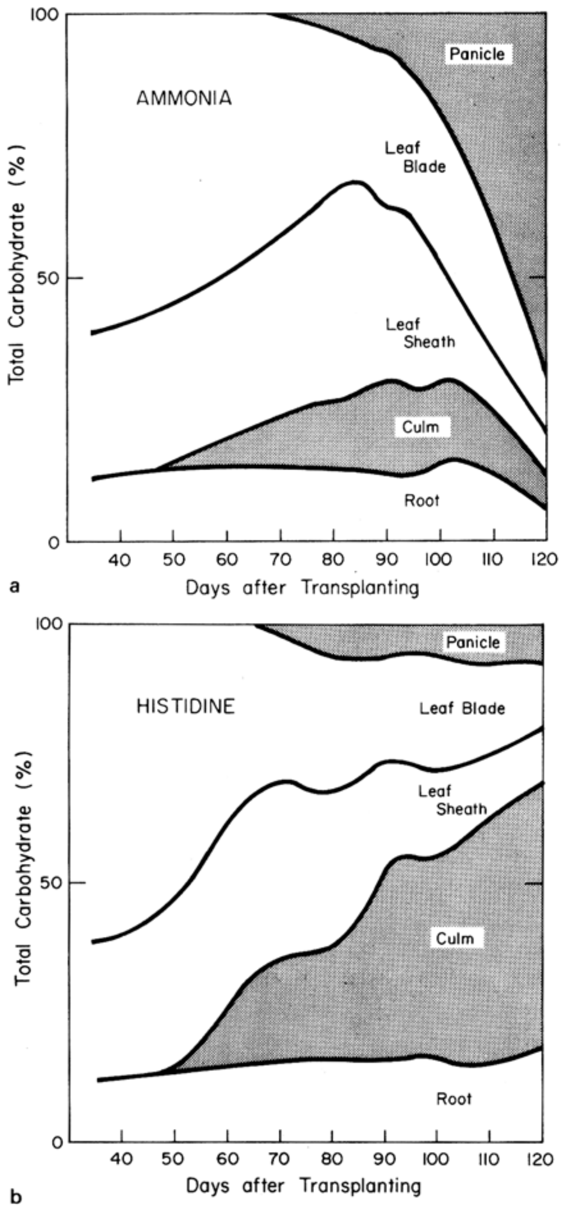


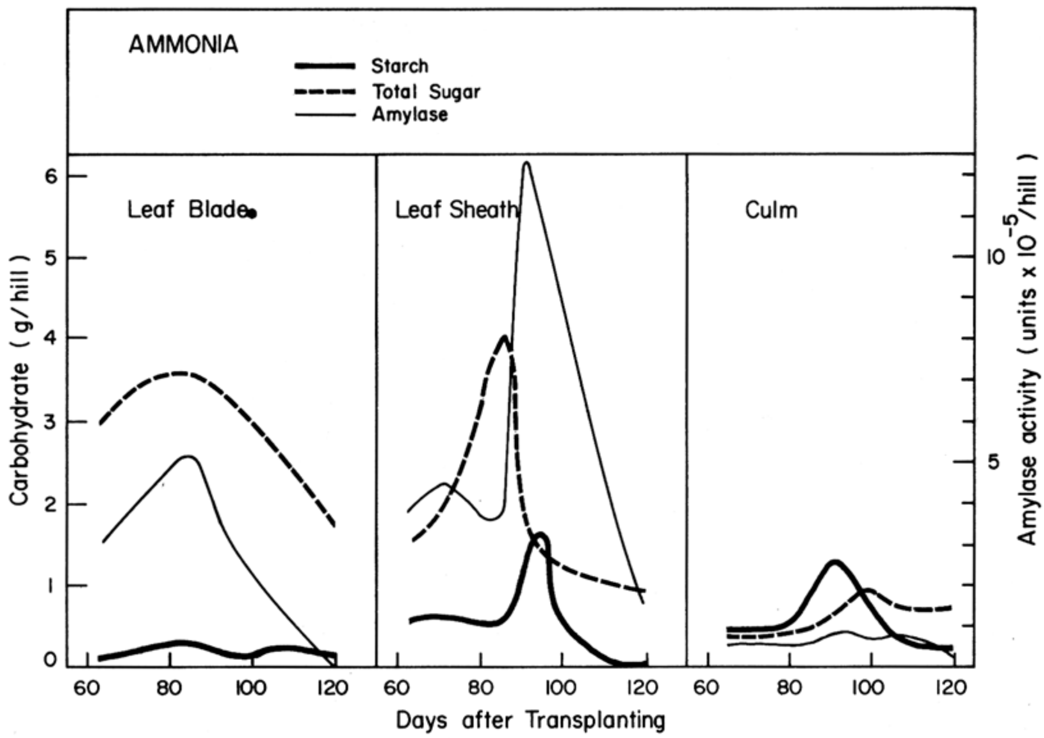
Fig. 5. Percentage of total carbohydrate in organs at various growth stages of ammonium sulfate-cultured (a) and histidine-cultured (b) rice plants.

Enzymatic basis of histidine-induced nitrogen deficiency

It has so far been assumed that the effects of histidine-culturing on rice plants are caused by histidine itself and not by decomposition products of histidine in the culturing pot. To check if histidine undergoes any significant bacterial decomposition in the pot, uniformly-labeled *L*-histidine-^{14}C was mixed with non-radioactive histidine to make the final concentration of histidine equal to the standard culture. The samples were withdrawn from the pot every day for paper-chromatography analysis. An autoradiogram was prepared on x-ray film from the chromatogram. As shown in Fig. 9, no new radioactive spots, other than the original histidine spot, were observed during 3 days under the standard culturing condition, indicating that there is no significant decomposition of histidine in the pot and that histidine is probably absorbed as such by the rice plant.

At least two of the three nitrogen atoms of the histidine molecule have to be converted to inorganic ammonia before the nitrogens in histidine can be utilized for general nitrogen metabolism in plants (Fig. 10). The first and the most important enzyme of histidine catabolism, therefore, is histidase. Histidase activity was found to be very low in ammonium-cultured plants and increased appreciably in the root upon transfer of the plant to histidine culture (Fig. 11). Thus, histidase is an inducible enzyme by its substrate, histidine. The time course of histidase induction after the transfer of the rice plant to histidine culture is shown in Fig. 12. It should be noted that histidase activity reaches its maximum level after 2 days of exposure to the histidine culture.

Since histidase is the key enzyme in histidine metabolism, the activity of this enzyme in the roots of histidine-cultured plants was determined at various growth stages (Fig. 13). The change of histidase activity was found to be biphasic. The enzyme activity was high until the tillering stage and dropped precipitously at ear-initiation to about 10 percent of that at tillering stage. The activity went up a little and then dropped again at the milky stage, remaining rather low until harvest. Since histidase activity can be considered to be the rate-limiting step of the



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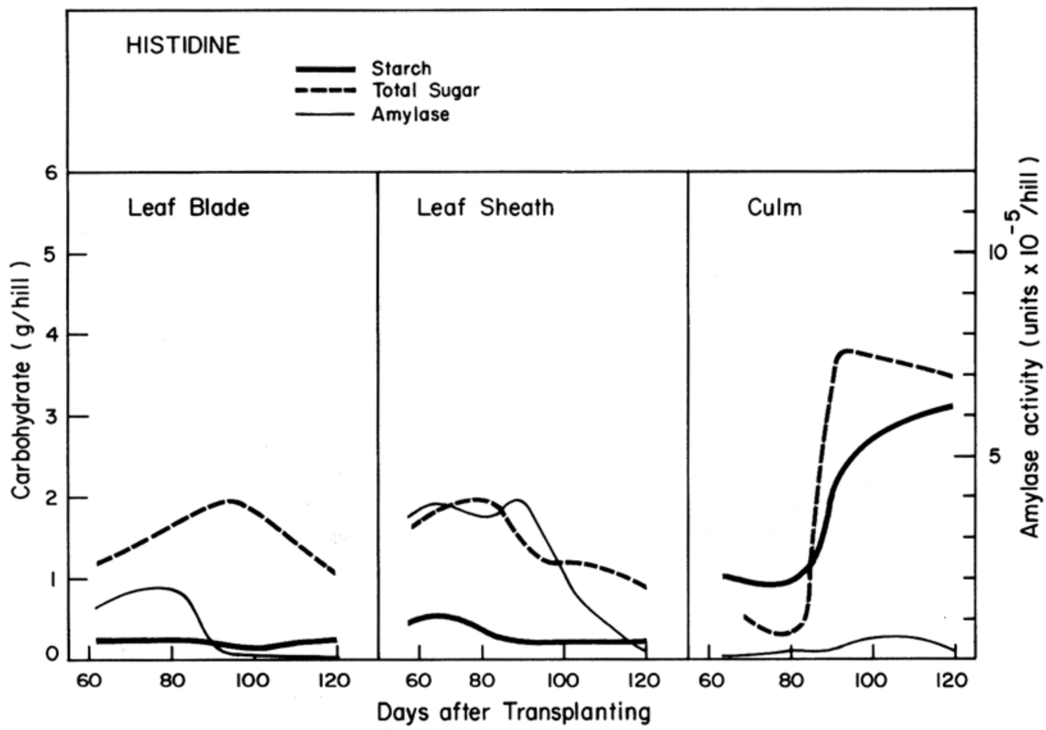

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Fig. 6. Changes in carbohydrate contents and amylase activities in organs of ammonium sulfate-cultured (a) and histidine-cultured (b) rice plants.

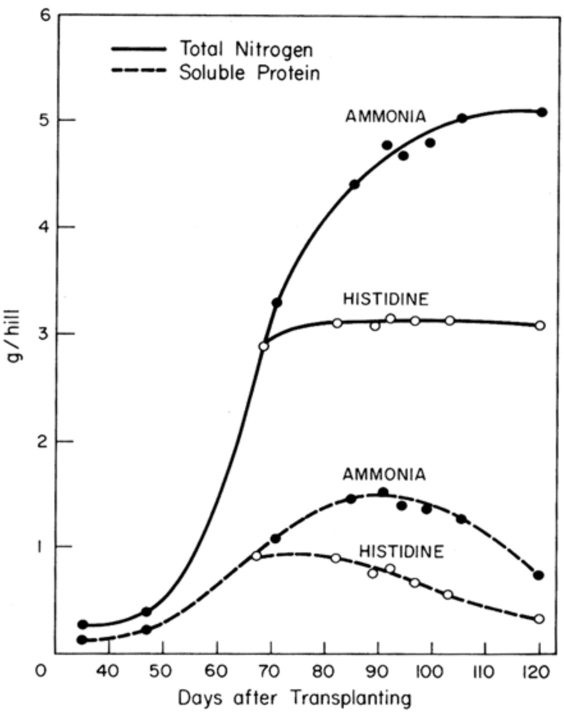


Fig. 7. Total nitrogen and soluble protein at various growth stages of rice plants.

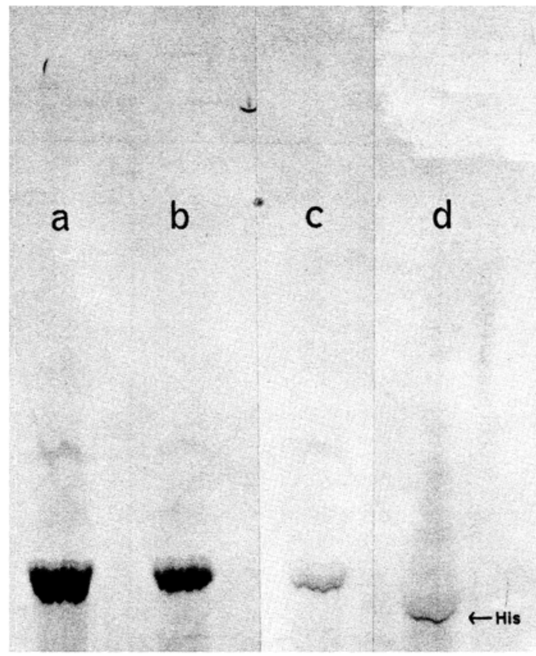


Fig. 9. Autoradiograms of histidine culture medium 0(A), 1(B), 2(C), and 3(D) days after addition of *L*-Histidine-U-^{14}C.

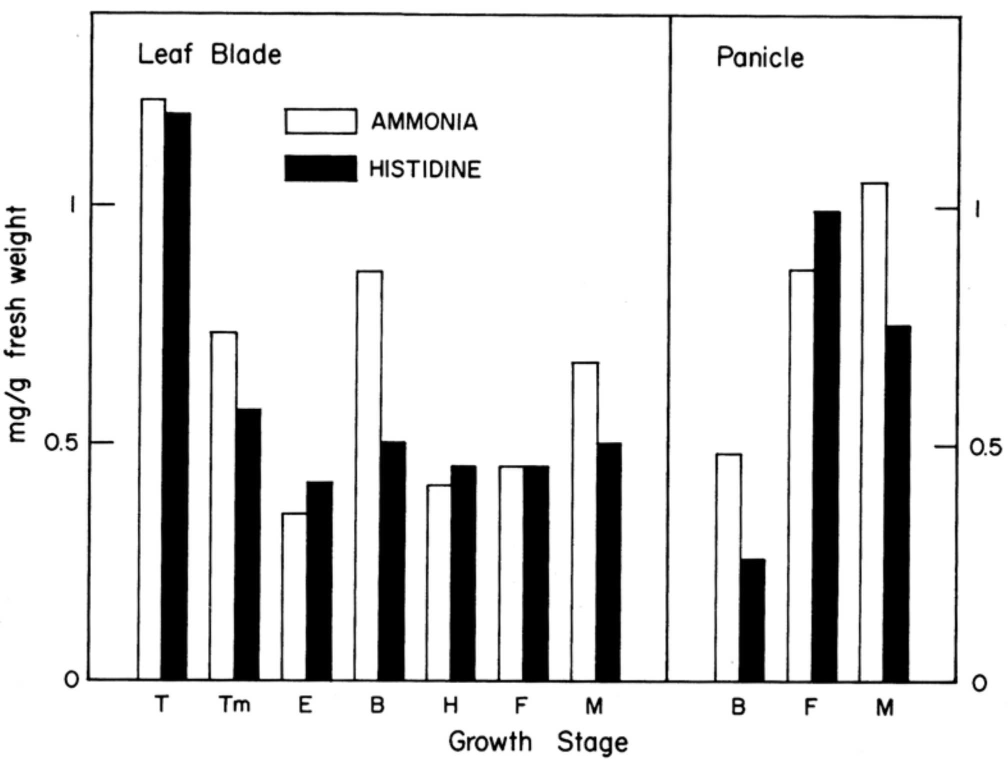


Fig. 8. RNA content of rice plants grown in cultures containing either ammonia or histidine as the nitrogen source. See Table 4 for explanation of growth stages.

Table 8. Nucleotide composition of RNA isolated from rice plant.

Growth stage	Organ	Nitrogen source	Adenylic	Guanylic (mole percent)	Cytidylic	Uridylic
Booting	Leaf blade	Ammonium sulfate	21.3	31.6	23.2	23.9
		Histidine	21.8	31.4	19.8	27.0
	Panicle	Ammonium sulfate	24.1	33.4	22.1	20.4
		Histidine	21.3	32.3	25.3	21.1
Milky	Leaf blade	Ammonium sulfate	20.7	33.2	21.6	24.5
		Histidine	19.3	28.2	22.8	29.7
	Panicle	Ammonium sulfate	19.8	29.8	23.2	27.2
		Histidine	21.3	31.7	24.6	22.4

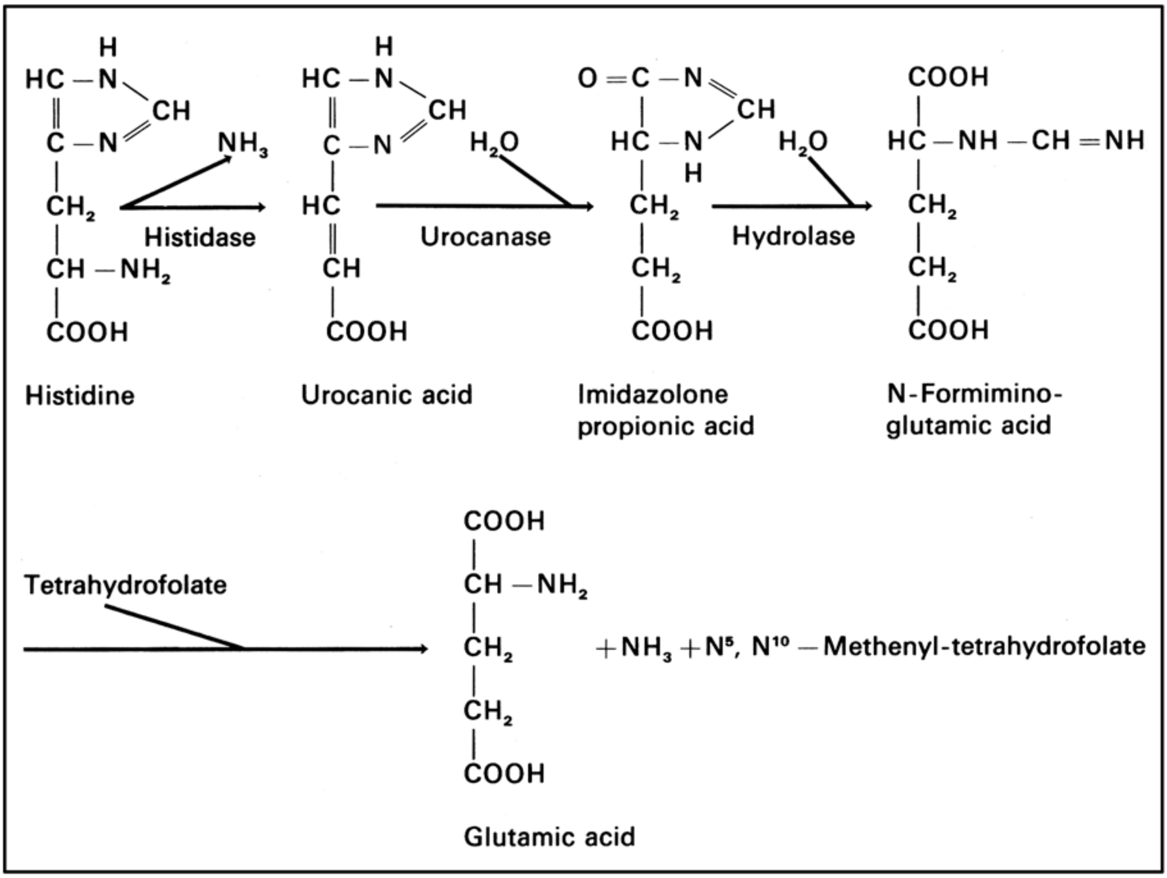


Fig. 10. Catabolism of histidine.

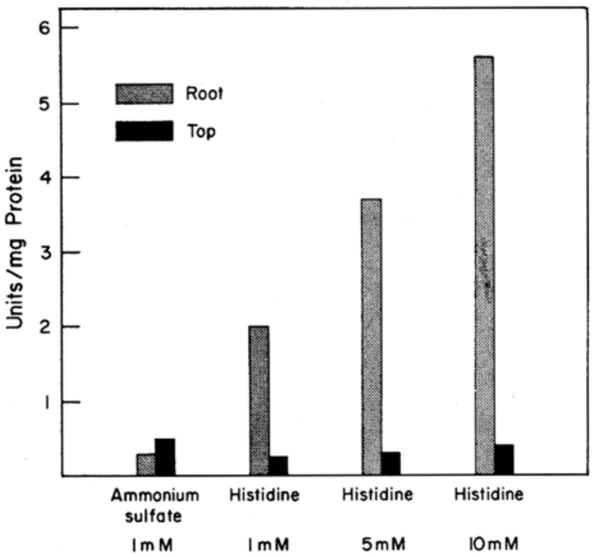


Fig. 11. Induction of histidase activity measured 32 hours after transferring ammonium sulfate-cultured plants at maximum tiller number stage to histidine cultures of various concentrations.

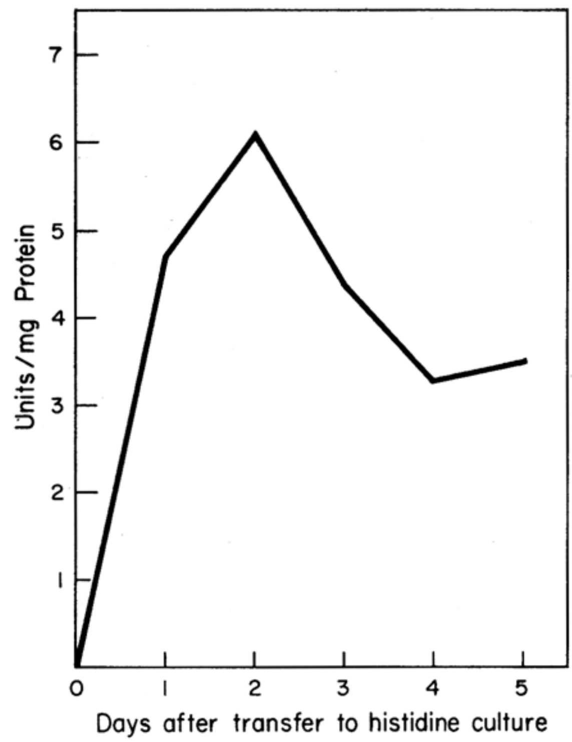


Fig. 12. Time course of histidase induction measured after ammonium sulfate-cultured plants at tillering stage were transferred to histidine culture (5mM).

nitrogen liberation from the histidine molecule, it is conceivable that a remarkable decrease in histidase activity at the ear-initiation stage will cause an insufficiency of available nitrogen to the plant. It should be recalled that the difference in carbohydrate and nitrogen metabolism between ammonium and histidine plants starts to appear at the ear-initiation stage. It should also be pointed out that this is the critical stage of transition from the vegetative to the reproductive phase in the life of the plant. It is tempting to suggest that the decrease in histidase activity at the transition from vegetative to reproductive phase provides the enzymatic basis for the subsequent abnormalities of histidine-cultured plants in terms of both nitrogen and carbohydrate metabolism. The mechanism of the decrease in histidase activity at this particular stage of the development of the plant remains to be elucidated.

Morphological study on histidine-induced sterility

A histidine-cultured rice plant is highly sterile in the sense that practically no starch is found in the panicles at harvest. To study the morphological basis of the sterility, the pollen germination on the stigma was examined microscopically (Fig. 14). While pollen tube elongation was clearly observed in the ammonium plants, no such elongation was seen in the histidine plant. It appears, therefore, that fertilization does not take place in histidine plants.

The absence of pollen tube elongation on histidine plants is not understood, nor is it known whether pollen or stigma, or both, is defective in such plants. But it is possible that the drastic decrease in histidase activity, leading to severe nitrogen deficiency, at the ear-initiation stage causes inhibition of the developmental transition from the vegetative to the reproductive phase. This contention is supported by the observation that histidine-cultured plants that were transferred to ammonium sulfate culture at the ear-initiation stage grew normally to produce starch in the panicle.

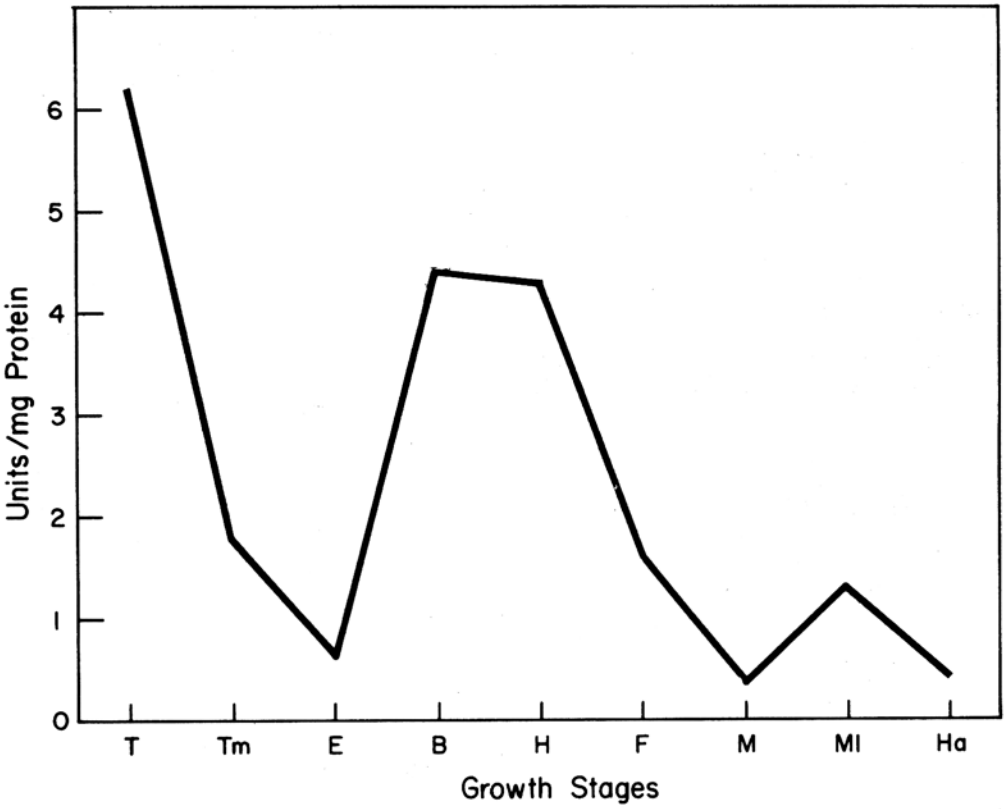


Fig. 13. Histidase activity in roots of histidine-cultured plants at various growth stages. Samplings were made 2 days after transference from ammonium sulfate to histidine culture. See Table 4 for explanation of growth stages.

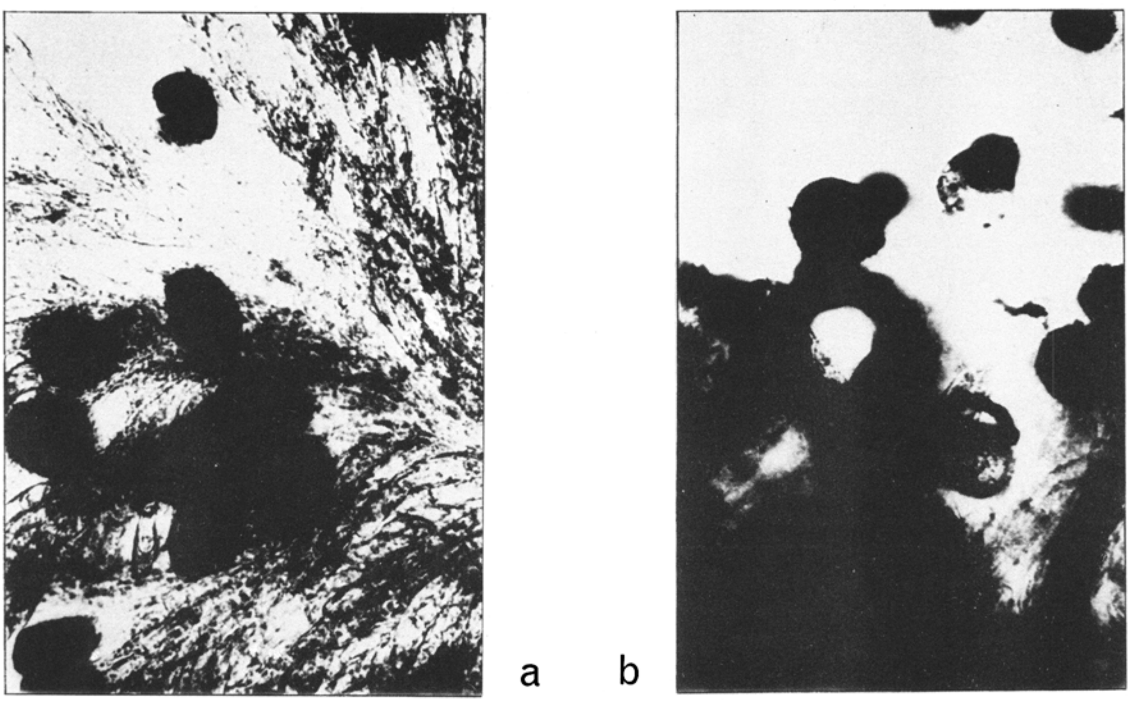


Fig. 14. Pollen germination on stigma of ammonium sulfate-cultured (a) and histidine-cultured (b) plant.

Cereal Chemistry

In continuing the study of the relationship between physicochemical properties of the rice endosperm and its eating, processing, and nutritive qualities, emphasis was on: (a) the influence of cooking variables, such as pre-soaking, water level, age of sample, and the physical properties of starch granule on the eating quality of rice, (b) the nature of endosperm opacity, (c) the physicochemical nature of rice protein, and (d) the screening for varietal differences in protein and lysine contents.

1966 ANNUAL REPORT, The International Rice Research Institute *Mailing Address:* Manila Hotel, Manila, Philippines

Cooking and Eating Quality Studies

Amylose content has been shown to be the main factor affecting the eating quality preference for milled rice. Other factors are protein content and gelatinization temperature of the starch. Amylose is the linear fraction of starch in nonwaxy rices; the main and branched fraction is called amylopectin. The varieties that are generally preferred in the Philippines for the tenderness of cold, cooked rice have amylose contents below 25 percent. (Least significant difference for amylose content is 1.7 percent.) Consumer surveys, however, indicate preference for the variety Wagwag, which has about 28 percent amylose. To resolve these conflicting results, 1-year-old BPI-76 (26% amylose) and Wagwag milled rices were evaluated by a taste panel at the Home Technology Department, University of the Philippines College of Agriculture (UPCA).

When prepared in automatic electric cookers with the same amount of water, BPI-76 was more tender, cohesive, and glossy than Wagwag and was generally the preferred sample. When the cooking water of Wagwag was increased to attain a cooked rice texture comparable to that of BPI-76, the latter was still the slightly preferred sample. Wagwag cooked rice was still duller in appearance and expanded more on cooking than BPI-76. BPI-76 and Wagwag have similar grain size and shape, but Wagwag has the more translucent grain. Because of their similar grain dimensions, BPI-76 is being used to adulterate Wagwag in the market. Presumably, the preference for Wagwag recorded by consumer surveys is due to factors other than eating quality.

Pakistani rice breeders consider 370 Basmati to be a superior quality variety on the bases of its elongation on pre-soaking and cooking, its tenderness, and its characteristic aroma. Varietal differences in volume expansion during cooking is evident from the photograph of raw and cooked rice samples of four Pakistani varieties (Fig. 1). Analysis of their physicochemical properties indicated that the Basmati samples had lower amylose contents and gelatinization temperatures (and were more readily digested with alkali) than the two poorer quality varieties (Table 1). However, it is not clear to what extent this mode of expansion is dependent on physicochemical properties. Leuang Awn 29, a low-gelatinization-temperature, high-amylose Thai variety, also elongated to the same extent as Basmati on cooking, despite its greater girth size. Cooking tests at the UPCA Home Technology Department indicated that pre-soaking alone does not result in elongated grain of 370 Basmati. Excess cooking water is the other requisite. Tenderness of the cooked Basmati in comparison with the poorer quality samples may be explained in terms of the lower amylose content of the former.

Rice samples from Burma, Egypt, Laos, and Nigeria were received during the year and were analyzed for physicochemical properties. The samples from Burma ranged in amylose content from 20.6 to 30.5 percent (Fig. 2), but all had intermediate gelatinization temperatures. They contrasted with Thai varieties which were generally of low gelatinization temperature. The samples from Egypt and the waxy Laotian samples were all of low gelatinization temperature. However, the nonwaxy Laotian rices had

Table 1. Some physiochemical properties of Pakistani milled rice.

Variety	Cooking quality (Pakistan)	Dimensions Length (mm)	Dimensions Width (mm)	Protein (%)	Amylose (%)	Gelatinization temp. (C)	Alkali spreading clearing values
6129 Basmati	very good	7.2	1.8	9.27	20.9	70	5.5, 4.6
370 Basmati	good	6.8	1.9	7.90	22.2	70	5.9, 5.1
246 Palman	medium	6.7	1.6	8.51	27.5	76	3.0, 1.9
349 Jhona	poor	6.4	2.2	7.84	26.8	74	4.4, 3.2

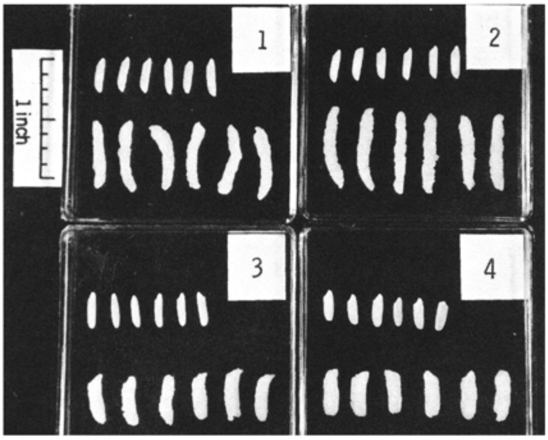


Fig. 1. Four Pakistani varieties differed in the extent of elongation during cooking. (1) 6129 Basmati; (2) 370 Basmati; (3) 246 Palman; (4) 369 Jhona.

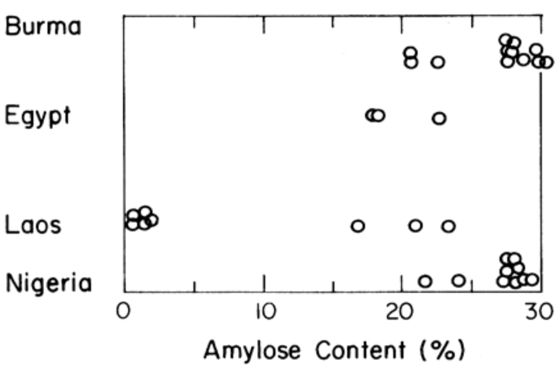


Fig. 2. Scattergram of amylose content of milled rice from four countries.

intermediate to high gelatinization temperature. The Nigerian rices were all of intermediate gelatinization temperature.

Out of nine waxy Philippine varieties studied, only Malagkit Sungsong and Malagkit Sungsong Puti had gelatinization temperatures below 70 C and high digestibility values in alkali. These two differ mainly in the color of the hull. The rest had high gelatinization temperatures ranging from 74 to 78 C and low digestibility in alkali. Malagkit Sungsong is the only waxy variety included among the Philippine Seedboard varieties. In a preliminary study in cooperation with UPCA of the alkali digestibility values of UPCA waxy lines from nonwaxy x waxy crosses, the alkali values only ranged from intermediate to high for crosses involving Malagkit Sungsong. The other lines involving other waxy parents had only low and intermediate alkali values. The nonwaxy parents were all of intermediate alkali digestibility values. Promising lines from these crosses are undergoing yield trials at the UPCA. The 1966 wet-season crop of these waxy lines will be used in studying the still uncertain implication of gelatinization temperature on the physical characteristics of the rice grain.

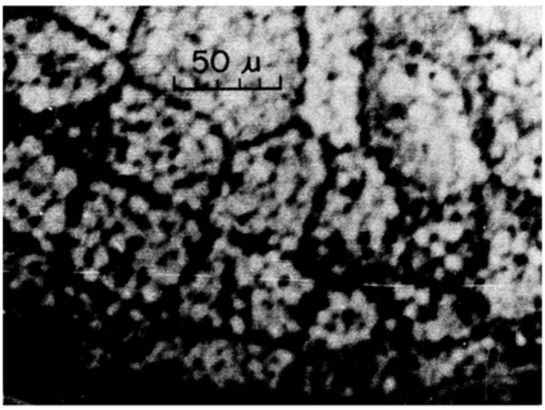
Changes in Physicochemical Properties During Development and Aging

Cooking and eating characteristics of milled rice are affected by the age of the sample. Old rice is relatively more flaky than freshly harvested rice. Conflicting information exists in the literature on the changes of properties of rice starch during storage. To help resolve this problem, studies have been initiated into the changes in physicochemical properties of starch and protein during grain development of the variety IR8 and the changes occurring during storage. It was considered pertinent to the problem of storage changes also to study the ripening grain, since storage changes may well be the continuation of processes that started in the field during grain dehydration.

Changes in the cooking and eating characteristics of rice on aging have been attributed by Indian investigators to: (a) changes in the colloidal state of the starch from sol to gel, and (b) reduction in amylase activities in the grain. Samples of freshly harvested and dried IR8 rough rice was stored at ambient temperature as rough rice, milled rice, and purified starch, and their properties assessed monthly. During a storage period of 4 months, water absorption ratio of rice at ambient temperature and on cooking decreased progressively. Birefringence end-point temperature and alkali digestibility showed little change. Milled rice amylogram showed a general increase in peak viscosity, final viscosity at 94 C, and that on cooling to 50 C. The iodine binding capacity of the samples was still unchanged.

Taste panel evaluation of freshly harvested and 2-month-old IR8 rice, together with 1-year-old BPI-76 that was cooked with the same water level, revealed higher tenderness and cohesiveness scores and greater preference for BPI-76 than for IR8 samples. Freshly harvested IR8 rice, however, was preferred over the aged sample and the former had higher tenderness, cohesiveness and gloss scores than the latter.

Samples of IR8 grain from the 1966 dry season were obtained at 3-, 4- or 7-day intervals during grain development and analyzed. The caryopsis attained optimum length within 4 days, optimum width in 2 weeks, and optimum thickness in 3 weeks after flowering. The caryopsis started becoming translucent from the core 1 week after flowering. Translucency was almost complete, except for the outermost layer of the grain, 11 days after flowering, with the opaque layer being thickest at the ventral (belly) area. Two weeks after flowering, the whole endosperm was already translucent except for the opaque belly.



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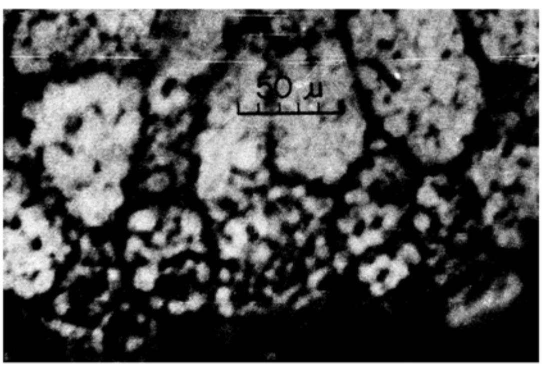

b

Fig. 3. Radially flattened cells with loose arrangement of starch granules were more abundant in the ventral area: (a) than in the dorsal area, and (b) of the developing endosperm. This ventral area corresponds to the white belly. Stain: hematoxylin.

Histological changes of the endosperm cross section in the developing grain were similarly studied. Microscopic examination showed that the aleurone layer was two to three cells thick at the dorsal area and only one cell thick in the others. These cells were still nucleated in the 4-day samples, but the aleurone nucleus could not be detected in the 1-week sample. Compound starch granules were already detected in the 4-day-old sample, but they were loosely packed in the peripheral cells, especially in the ventral area. Cells were isodiametric along the lateral axis but were elongated along the dorsiventral line.

Three to four layers of radially flattened cells with loose packing of starch granules were adjacent to the elongated cells along the dorsiventral line at the ventral end, whereas only one to two layers were evident at the dorsal end. All these cells were nucleated in the 4-day-old sample, and staining with hematoxylin or bromphenol blue indicated the presence of only few discrete protein particles. Staining was minimal at the center of the endosperm. In the 1-week-old samples, protein bodies were distinctly observed. In all samples, the ventral portion showed a greater protein staining area and a smaller starch-staining area than the dorsal portion.

In the 3-week-old sample, the three layers of radially flat cells in the ventral portion were still observed, in contrast to not more than one layer at the dorsal end (Fig. 3). On iodine staining, these were seen to correspond to areas of loose packing of the starch (Fig. 4). Many simple granules were observed embedded in the proteinaceous "matrix". The same phenomenon was observed in the mature grain, where the loosely packed ventral section corresponds to the white belly.

Changes in gross composition of the rice grain during development were similar to those of other cereals. Moisture content per grain was highest 1 week after flowering but decreased steadily with grain development (Fig. 5). Dry matter, starch, and protein increased as the grain developed but leveled off 4 weeks after flowering.

The starch granules progressively increased in size during ripening and reached a mean granule size of 6.3 microns in the mature caryopsis (Fig.

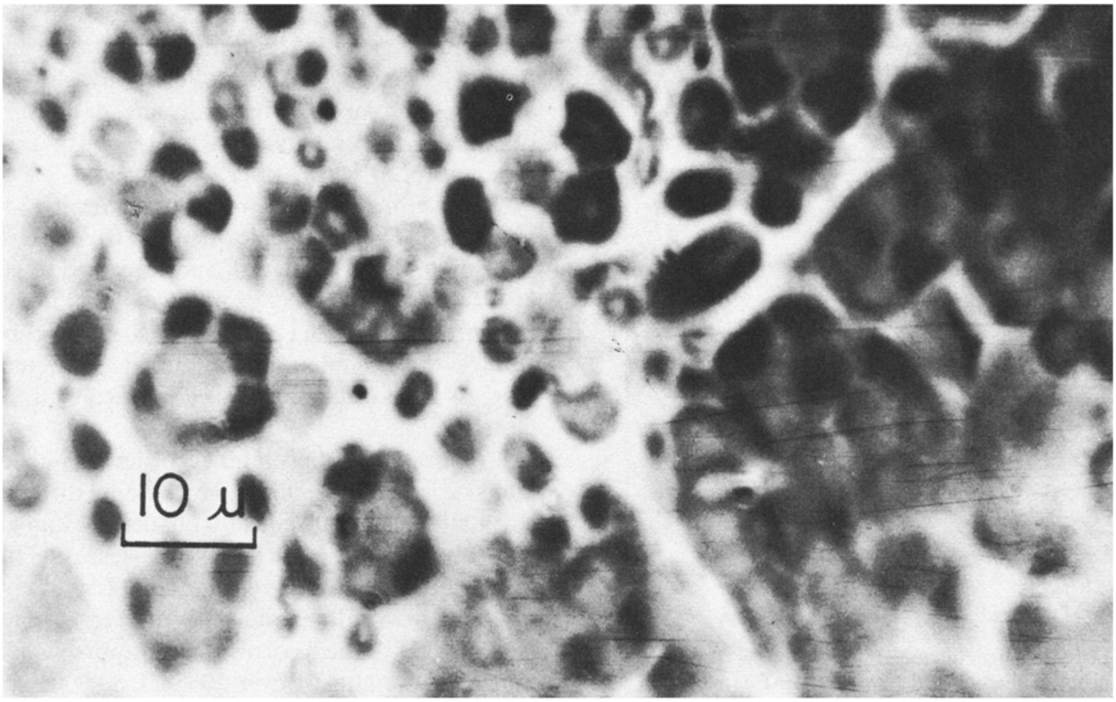

Fig. 4. Iodine staining reveals the loose packing of starch granules in the white belly portion of IR8 endosperm in contrast with the compact granule arrangement of the adjacent translucent portion.

5). In contrast, final gelatinization temperature decreased from 65 to 63 C during development. Similar negative correlations between granule size and gelatinization temperature have been reported for developing starch granules of other plant species. Increases in the iodine binding capacity (denoting increases in amylose content) and the relative viscosity of 0.2 percent starch solution in dimethyl sulfoxide were also noted during ripening. No change was observed in the swelling power and the solubility of the starch sample at 85 C.

Amylose and amylopectin fractions were isolated from starch samples obtained from 4- and 21-day-old, and fully mature grains. Starch was pre-treated with three volumes of dimethyl sulfoxide with heating up to 70 to 75 C. The gelatinized starch was precipitated and washed with methanol, and dissolved in boiling water. 1-Butanol:Pentasol 27 (1:1 v/v) was added to the hot starch solutions as precipitant for amylose. These fractions are being characterized.

Protein fractions were extracted by percolation from acetone powders of the grain using 5 percent sodium chloride, 60 percent ethanol, and 0.4 percent sodium hydroxide. The sodium chloride extract was dialyzed against distilled water to separate the non-protein nitrogen fraction from albumin-globulin. The second and third extracts are prolamin and glutelin, respectively. In terms of micrograms per grain, very slight variation in non-protein nitrogen was noted (Fig. 6). A progressive increase in glutelin was observed. A similar increase was noted for prolamin. Albumin-globulin reached a maximum concentration 2 to 3 weeks after ripening but decreased slightly afterwards. It is interesting to note that the quantity of glutelin in the grain paralleled the abundance of protein bodies in the endosperm cells.

Acetone powders of 4- and 14-day-old, and mature grains were dialyzed against distilled water, hydrolyzed, and analyzed for amino acid content by standard ion-exchange chromatography. The lysine content of the 14-day-old and mature samples was lower than that of the 4-day-old sample. These data may be explained on the basis of the relative proportion and lysine con-

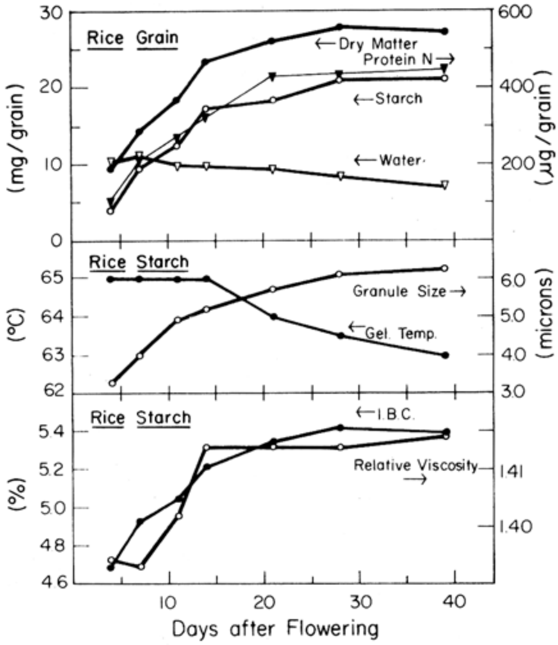

Fig. 5. Changes in the composition of the IR8 rice grain and in the properties of rice starch during development.

tent of the protein fractions present in the developing grain. Albumin-globulin has the highest content of lysine, followed by glutelin and then prolamin. Similar lysine data were obtained with undialyzed acetone powders of these samples.

The acetone powders were extracted with 3*M* urea—0.5*M* sodium chloride in 0.01*M* pH 7 phosphate buffer, dialyzed, and subjected to gel filtration. The relative absorbance of 280 mμ of this urea-salt extract showed a sharp decline toward the completion of grain development (Fig. 6). Urea-salt solution is a poor solvent for glutelin.

Fractionation of proteins according to molecular size is readily facilitated by passing through a cross-linked dextran gel (Sephadex) of known constant pore size, which acts as a sieve. Gel filtration on Sephadex G-100 columns (2.5 x 32 cm) of these urea-salt extracts gave three distinct peaks (Fig. 7), which correspond to approximate molecular weights of over 200,000, 80,000, and

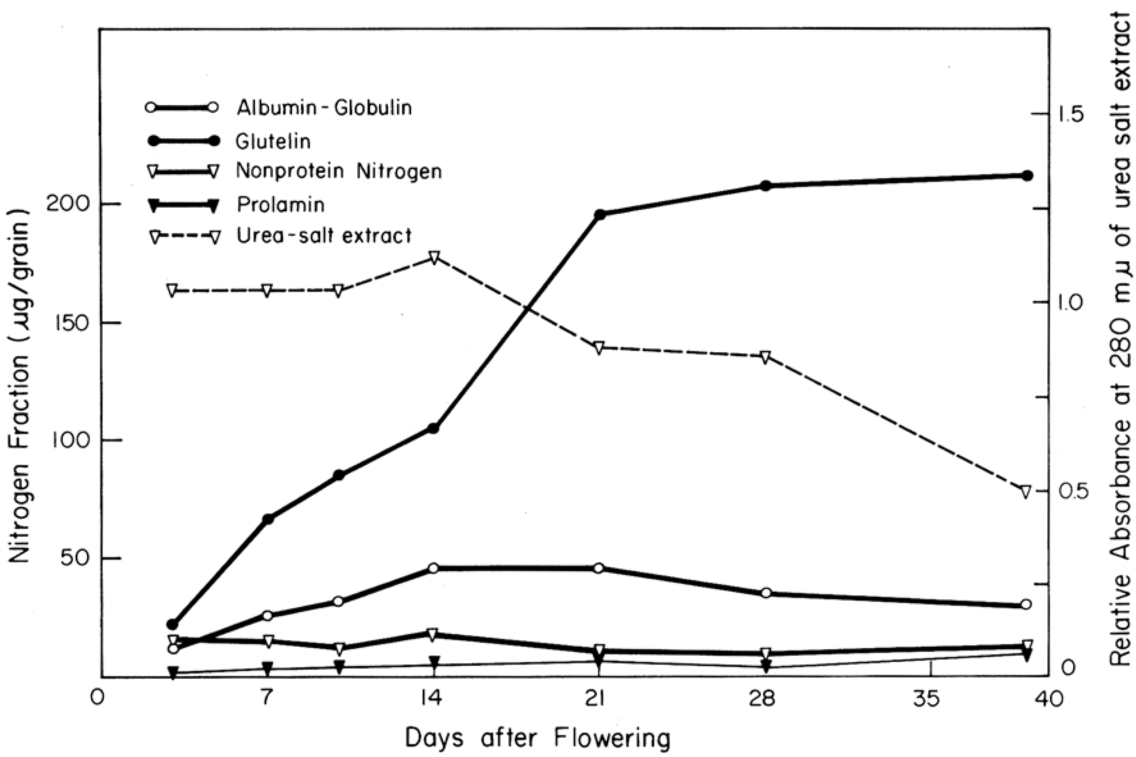

Fig. 6. Changes in the extractable nitrogen fractions and in the urea-salt extract of IR8 rice-grain acetone powder during development.

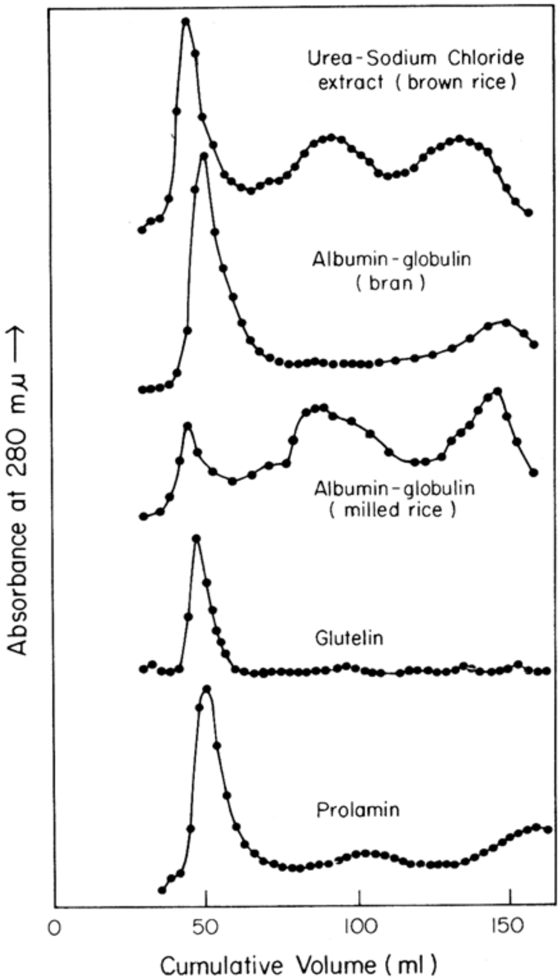

Fig. 7. Elution curves in Sephadex G-100 (2.5 x 32 cm) of rice protein extracts. Solvent: 3.0*M* urea to 0.5*M* sodium chloride in 0.01*M* pH 7.0 phosphate buffer.

30,000, respectively. The relative quantity of all the peaks decreased during grain development. This may reflect the increase in molecular weight and cross-linking of rice during ripening, resulting in decreased solubility even in this already strongly dissociating solvent.

Physicochemical Studies of Rice Proteins

To determine the nature of the peaks in the gel filtration of proteins in developing grain in relation to the solubility fractions, preparations of albumin-globulin, glutelin, and prolamin were also subjected to gel filtration. The albumin-globulin extract from bran showed mainly the first and third peaks, but only a trace of the intermediate peak (Fig. 7). A similar extract of milled rice gave all three peaks, with the first peak less pronounced than the others. This indicates a difference, at least in molecular weight distribution, of the albumin-globulin extract of the bran (aleurone layer) and that of the starchy endosperm.

Glutelin gave mainly the first peak which corresponds to high molecular weight protein. Subsequent gel filtration on Sephadex G-200 showed that it has molecular weight of at least 260,000. Prolamin gave the first and third peaks. Previous work indicated that prolamin and albumin usually contaminate each other. In fact, all these protein solubility fractions are highly complex and not mutually exclusive.

Other protein preparations were studied by gel filtration. Methanol-chloroform (2:1 v/v) extract had the third peak as the main component with a subdued first peak. Hence, this extract has a lower molecular weight than the conventional prolamin fraction. The 4-percent lactic acid extract showed a greater proportion of low molecular weight proteins than albumin-globulin. Hence, these two fractions are not identical in molecular weight distribution.

Gel electrophoresis and ion-exchange cellulose chromatography also indicated the heterogeneity of these protein fractions. In electrophoresis, proteins are placed in a supporting medium (gel) to which an electric field is applied, resulting in their fractionation into discrete zones, depending on their net ionic charges at the pH of the solvent. Starch-gel electrophoresis in pH 3.1 aluminum lactate buffer with urea in the gel gave results similar to those of wheat proteins. The albumin-globulin bands were the fastest migrating fractions. Prolamin bands were slower and closer to the sample slot. Although glutelin remained essentially in the sample slot, faint bands corresponding in mobility to prolamin and albumin-globulin were also observed. These faint bands may either be real minor glutelin constituents or contaminant proteins. The nonmigration of glutelin in the starch gel may reflect its high molecular weight compared with the other rice proteins that migrated, since molecular sieving is known to occur in the starch gel. Similar results were obtained with polyacrylamide gel using the same buffer. The extracts using 4 percent aqueous lactic acid and methanol: chloroform (2:1 v/v) showed similar but not identical electrophoretic mobilities to albumin-globulin and prolamin, respectively.

Proteins may also be characterized in terms of the composition of constituent amino acids. In terms of amino acid composition, prolamin exhibited a low proline content of 5 percent, which is lower than that of other cereal prolamins. Prolamins are characteristically of high proline content. The ammonia content of glutelin amounted to only 60 mole percent of that of aspartic and glutamic acids combined, indicating that these two acids are not entirely in amide form (asparagine and glutamine) in the native protein. Albumin-globulin had a lysine content of 4.8 percent which is higher than that of 3.1 percent for glutelin and 0.3 percent for prolamin.

Rice protein has been shown to be present in the endosperm as discrete bodies. Isolation of protein bodies of IR8 developing grain and milled rice in aqueous medium is being undertaken. Milled rice was homogenized in 0.2*M* pH 7.2 phosphate buffer containing 1 percent sodium deoxycholate and 0.002*M* magnesium chloride, and centrifuged in a sucrose-density gradient. Three zones were formed. The opaque upper layer and the clear middle zone had discrete protein bodies, but there were less impurities present in the latter. The lowest zone was rich in starch granules. The collected fractions were dialyzed and freeze-dried for characterization.

Physicochemical Studies of Rice Starch

The absence of amylose in waxy starch makes it more suitable than nonwaxy starch to study the relationship of properties of amylopectin with physical properties of the starch granule, such as gelatinization temperature. Amylopectin was prepared by ethanol precipitation from clarified pentanol-saturated autoclaved starch.

The intrinsic viscosity [η] of waxy amylopectin was positively correlated with gelatinization temperature but only for samples with gelatinization temperature of 69 C or lower (Fig. 8). Other waxy samples, with gelatinization temperature between 74 to 78 C, did not gelatinize completely on autoclaving and the amylopectin obtained from them may have been a subfraction. Since the amylopectins have similar degrees of branching, as reflected from periodate oxidation data, their molecular weight reflected in their [η] may be a more important factor than their shape in influencing their physical properties. Pre-treatment of Pilit Morado waxy starch with dimethyl sulfoxide or liquid ammonia

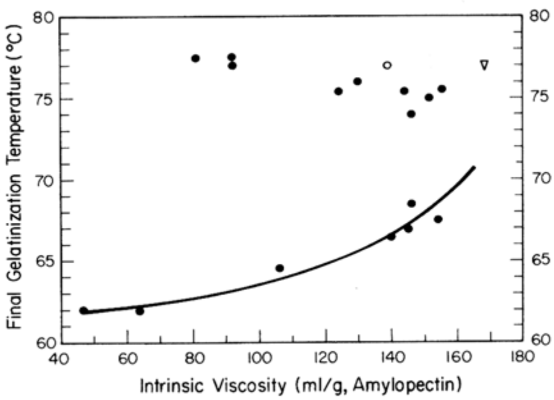

Fig. 8. Relation between intrinsic viscosity of amylopectin and the gelatinization temperature of waxy starch. • = Autoclaved; o = Pre-treated with ammonia and autoclaved; Δ = Pre-treated with dimethyl sulfoxide and boiled.

resulted in the recovery of amylopectins of higher [η] than obtained by autoclaving for 2 hours at 125 C. Higher values were obtained with the milder pre-gelatinization with dimethyl sulfoxide followed by dissolving in boiling water than by liquid ammonia pre-treatment followed by autoclaving: 163 as against 139. With the standard autoclaving method, the [η] of the amylopectin obtained was 92.

The swelling power and solubility of starch granules at 85 C were determined for selected waxy and nonwaxy starches. Swelling power and solubility of six samples of waxy starch were inversely related to gelatinization temperature. In fact, the waxy sample with the lowest gelatinization temperature dissolved completely at 85 C. The data for nonwaxy starches were more complicated. The wide range of blue values of the solubilized starch from the nonwaxy samples indicated a composition of the leached starch ranging from almost pure amylopectin to pure

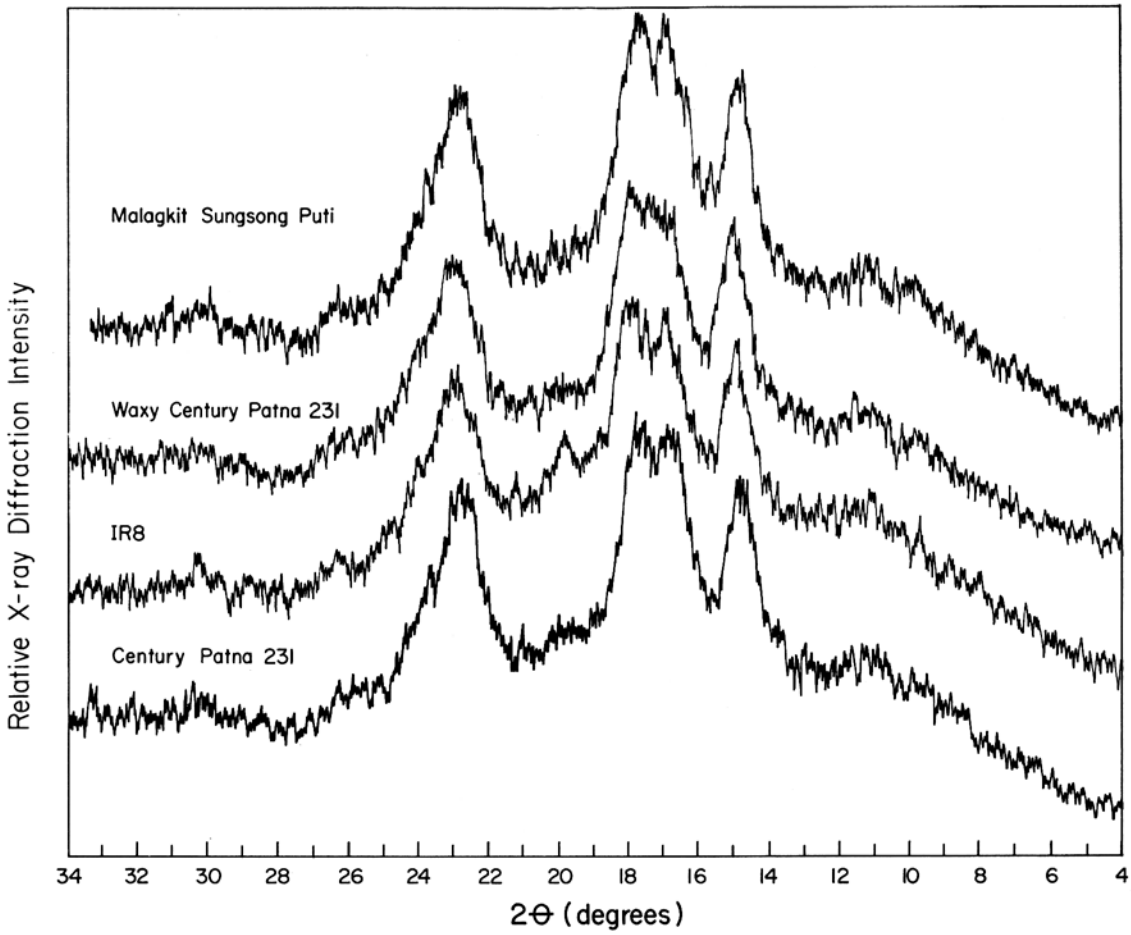

Fig. 9. X-ray diffractograms of waxy and nonwaxy rice starches of low and high gelatinization temperature show differences in degree of crystallinity.

amylose. Such blue values were not simply related to gelatinization temperature of the nonwaxy starch.

In recent work on starch, samples of isogenic lines have been selected to reduce variation due to environment. For three pairs of isogenic lines differing in the *waxy* gene, the nonwaxy amylopectin had a higher [η] than the waxy amylopectin (Table 2). The isogenic pair had similar gelatinization temperatures. However, the [η] values of the fractions were different from those of samples from the same varieties in a previous study. This indicates the environment may affect the [η] of the fractions of starch and may explain the poor relationship among properties previously observed for starches obtained from different varieties grown in different environments.

Further x-ray diffraction studies in cooperation with the Institute of Scientific and Industrial Research, Osaka University, Japan, showed varietal differences in degree of crystallinity (Fig. 9). Of two waxy samples, Malagkit Sungsong Puti was more crystalline than Waxy Century Patna 231. Their gelatinization temperature and [η] were 58.5 to 61 C and 67.7 ml/g, and 67 to 75.5 C and 124 ml/g, respectively. The degree of crystallinity was greater for the lower-molecular-weight Malagkit Sungsong Puti amylopectin (although it was still more water-soluble) than the higher-molecular-weight Waxy Century Patna 231. Presumably, degree of crystallinity of waxy rice is a less important factor influencing gelatinization temperature than molecular weight of the amylopectin.

With two nonwaxy starches, Century Patna 231 was more crystalline than IR8. Their gelatinization temperatures and amylose contents were 67 to 75.5 C and 14.4 percent, and 56.5 to 63 C and 28.4 percent, respectively. Other high-

Table 2. Physicochemical properties of starch from brown rice of three isogenic pairs.

Variety	Gelatinization temperature (C)	Amylose content (%)	Intrinsic viscosity*	
			Amylopectin (ml/g)	Amylose (ml/g)
Taichung 65	58–66	15.8	154	186
Glutinous Taichung 65	59–66	Waxy	140	–
Caloro	61–69	17.2	177	150
Cal 5563A1	61–68	Waxy	146	–
Century Patna 231	67–75	14.4	160	202
Waxy Century Patna 231	67–75	Waxy	124	–

* LSD (0.05, amylopectin)= 6.5 ml/g; LSD (0.05, amylose) = 5.2 ml/g.

amylose varieties with low gelatinization temperature, such as Taichung (Native) 1 and Nahng Mon S-4, also had poor crystallinity in their x-ray diffractograms. Degree of crystallinity may be an important factor affecting the gelatinization temperature of nonwaxy starch. Century Patna 231 and Waxy Century Patna 231 are isogenic and their samples were grown under identical conditions. They have similar degrees of crystallinity. Thus, degree of crystallinity of rice starch is not dependent on the presence or absence of amylose *per se*.

The absence of peak 1 in the 2θ region of 4 to 7° verified that the x-ray diffraction pattern of all the rice starches was of the A type and not C_A type, in accordance with the classification scheme of Katz. No trace of the V pattern was noted even with the high-amylose samples of low gelatinization temperature, such as IR8, although a small peak at $2\theta = 19.8°$ was present (Fig. 9).

Endosperm Opacity

Studies were continued on the nature of opacity of some nonwaxy caryopses, since those opaque portions tend to reduce endosperm hardness, thus contributing to grain breakage during milling. Waxy rice was observed to have a compact arrangement of compound starch granules in the endosperm cells (Fig. 10). Presumably the cause of opacity of waxy rice is different from that of nonwaxy rice. A few waxy starch granules were even noted in the aleurone cells.

In nonwaxy rices, the loose arrangement of starch granules is the cause of opaque portions. In a strain of crumbly rice (No. 7154) from the United States, the presence of air spaces between the starch granules was evident throughout the cross section of the endosperm (Fig. 11). In contrast to the white belly, not all but only a small portion of the spaces between the starch granules of crumbly rice stained with hematoxylin. Many of the starch granules were simple and spherical.

To further characterize the opaque portion, the white belly of IR8 was collected by hand dissection from milled rice and is being analyzed in comparison with the rest of the endosperm. Protein content and amino acid composition of the two portions (opaque and translucent) were

Fig. 10. Photomicrograph of the immature endosperm of the waxy variety, Malagkit Sungsong. Stain: hematoxylin.

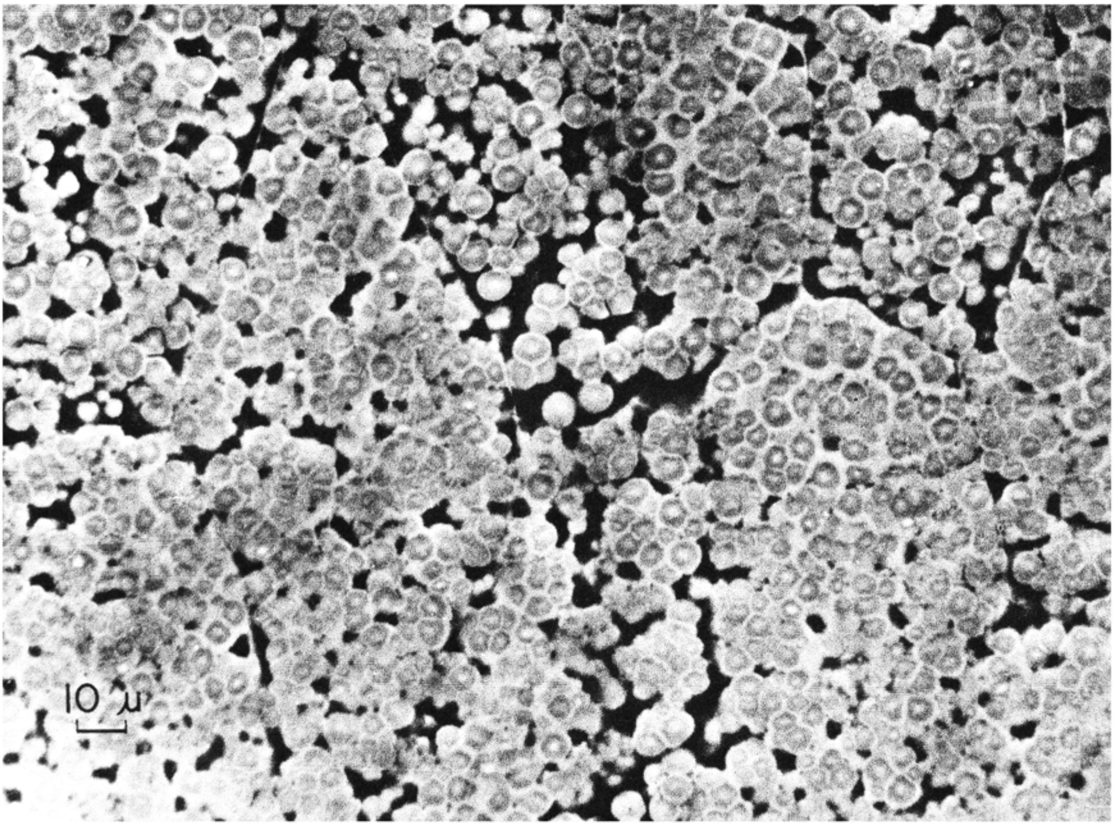

Fig. 11. Photomicrograph of the endosperm of crumbly rice No. 7154, showing the air spaces between starch granules. Stain: hematoxylin.

almost identical. Rice chemists in the United States also found little difference in the amino acid composition of the over-milling fractions of milled rice. This indicates that only the aleurone proteins differ in composition from starchy-endosperm proteins. Starch of the white-belly portion had a 2 C higher gelatinization temperature than the rest of the endosperm. In contrast, starch of the white-core portion of Taichung (Native) 1 was previously noted to have a lower gelatinization temperature and larger granule size than that of the rest of the endosperm.

Nutritive Quality of Rice

Screening of the Institute's rice germ plasm bank of 8,500 entries for protein content was initiated in connection with a cooperative project with the Varietal Improvement Department to breed rice of improved nutritive value. Samples were dehulled and the resulting brown rice was ground and analyzed for Kjeldahl nitrogen and lysine content.

Initial work was centered on methodology of protein and lysine assays. The assays must be rapid but fairly accurate and reproducible. Automatic analysis using the AutoAnalyzer system was given priority. In the Kjeldahl analysis, the method being used is macro-Kjeldahl digestion and distillation. Upon receipt of the AutoAnalyzer, nitrogen determination will be by manual micro-Kjeldahl digestion followed by colorimetric assay of the ammonia content of the digests with the Analyzer. Protein content of brown rice for 4,023 samples ranged from 5.6 to 18.2 percent wet basis (Fig. 12). The mean protein content was 9.9 $\pm$ 1.8 percent. The wide range of protein content may reflect both varietal and environmental factors.

More steps are required for lysine determination. Exploratory work was geared toward reducing to a minimum the technician time

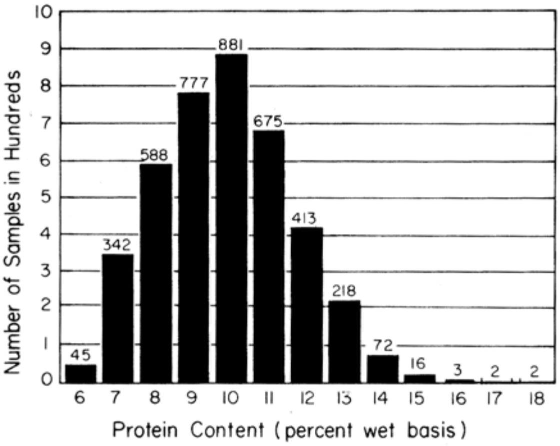

Fig. 12. Brown rice samples from the world collection had a wide range of protein content.

required per sample. Brown rice flour was hydrolyzed in a sealed tube with hydrochloric acid, and the hydrolyzate neutralized. Preliminary experiments indicated that the presence of air inside the sealed tube does not affect lysine recovery during hydrochloric acid hydrolysis. Hence, freezing the solution and evacuating the test tube prior to sealing were deleted. Preparing the hydrolyzate by filtering the humin formed and concentrating in a rotary evaporator to remove the excess hydrochloric acid requires much attention. Since the hydrolyzate must have a pH of 6.0 for the assay using lysine decarboxylase, trials were made to dry the hydrolyzates in vacuum desiccators over sodium hydroxide pellets and titrating with sodium hydroxide solution in the presence of appropriate indicator. However, the humin present was found to adsorb the indicator dye. Hence, the humin had to be removed by filtration before the hydrolyzate was neutralized to pH 6.0.

With the Warburg manometric assay with lysine decarboxylase, carbon dioxide recovery of lysine standard ranged from 85 to 90 percent. The enzyme suspension was prepared daily from commercially available acetone powder. In this method, a 400-mg sample of brown rice was used per analysis. With the AutoAnalyzer unit on order, smaller samples may be used which may also reduce the quantity of humin formed during hydrolysis. Starting samples for this analysis are the hydrolyzates neutralized to pH 6.0.

Samples of 11 other *Oryza* species were analyzed for amino acid content of brown rice using the amino acid analyzer. No major differences in amino acid composition were noted among the species, including *Oryza sativa* L.

Preliminary results of the animal feeding study to determine the comparative nutritive value of low and high protein content rice at the United States Naval Research Unit No. 2 (NAMRU-2), Taipei, Taiwan, indicated that the nutritive values of two rice varieties paralleled their protein contents. In this cooperative project, two Philippine rice varieties were studied: BPI-76, with 11.7 percent (dry weight) protein, and Intan, 7.0 percent. The lysine contents of BPI-76 and Intan were 3.57 and 3.90 g/16.8 g N. Three cooked milled rice diets and one standard casein diet were fed. The respective total protein contents of the Intan and the BPI-76 rice diets were 5.6 and 9.3 percent. The third rice diet contained smaller amounts of the BPI-76 rice to reduce the diet protein level to 5.6 percent. The standard casein contained 20.1 percent protein.

Growth characteristics of rats in each diet group were distinctive. As expected, animals consuming the standard diet exhibited normal growth. Animals fed the BPI-76 rice diet, 9.3 percent protein, initially grew more slowly than the standard-diet group but continued to grow at a nearly constant rate for a longer period of time until their body weights approached those of the standard group. Rats fed the Intan rice diet grew at a slightly faster rate than those fed the diluted BPI-76 diet but considerably slower than the group fed the higher BPI-76 rice diet.

Varietal Improvement

Seed of IR8, a newly named variety, has been distributed by the Institute to more than 60 countries in Asia, Africa and the Americas for further testing and multiplication. Because of its sterling performance throughout tropical Asia, IR8 has been used as a parent in 70 of the 270 new crosses made during the year. Particular effort is being directed toward incorporating the desired maturity range, higher levels of disease resistance, improved grain appearance and milling quality, and a range of cooking characteristics into the plant type exemplified by IR8. In the meantime, efforts to develop additional improved varieties have continued. Over 25,000 pedigree rows were sown in four separate plantings. Yield trials, both at the Institute and in other countries, have revealed a number of promising lines.

Studies on the competitive ability of different plant types have demonstrated an inverse relationship between competitive ability and yield, a fact of great significance to rice breeders, and at least a partial explanation of past failures with bulk population breeding in the tropics.

Genetic studies were continued to elucidate the inheritance of plant height, panicle length, panicle number, and grain number on a quantitative basis. Cooperative research with plant physiologists has demonstrated the feasibility of dividing and reconstituting the two principal components of the vegetative growth period on both a physiologic and genetic basis. The genetic information obtained by the component-analysis approach will lead to a fuller understanding of the inheritance of flowering date. The cytologic examination of F_2 plants of indica-japonica crosses provided additional evidence on the complex cytogenetic nature of hybrid sterility. Genetic and statistical analysis of plant characters associated with lodging resistance indicated the importance of plant height and leaf sheath protection in affecting the lodging resistance of different genotypes.

Varietal Testing and Development

World collection

The description and preservation of rice germ plasm has been assisted by a 4-year grant of $55,200 from the United States National Science Foundation. The collection of cultivated varieties consists of 10,323 accessions, and apart from 410 received during the year, a complete morphologic-agronomic description has been recorded for all of them. These data have been coded for over 8,000 accessions for preparation of a varietal catalogue.

During the year, 1,052 cultivated varieties were sent upon request to 41 countries. Another 233 seed samples and 24 plant samples of wild taxa in the genus *Oryza* were sent to nine institutions in five countries.

Breeding program

Regional yield tests conducted in the Philippines and other countries in South and Southeast Asia show conclusively that IR8 has produced consistently higher grain yields than Taichung (Native) 1 or other short, stiff-strawed nitrogen-responsive strains developed in the breeding program. Consequently IR8 has been used extensively as a parent in the breeding program. Of the 270 crosses made in 1966, over 70 involved IR8 as one of the parents. The main breeding objectives of these crosses were to incorporate into the IR8 plant type the following desired traits:

1. a range of maturity from 100 to 145 days (seeding to maturity);
2. improved resistance to blast, tungro, bacterial leaf blight and bacterial streak;
3. improved grain size and shape, and milled rice appearance; and
4. a range of amylose content of grain from below 20 to above 30 percent.

Maturity. An early-maturing line from the cross of Peta/5 x Belle Patna was crossed with IR8, and the F_1 plants backcrossed to IR8. Early-maturing F_1 backcross plants were again backcrossed to IR8. From this series of backcrosses, early-maturing lines similar to IR8 should be available in the near future.

TKM-6 from India, Yukara from Japan, CP 231 x SLO-17 from the U.S.A., and other early-maturing varieties were crossed with IR8. Late-maturing hybrid lines from the backcross of Peta/2 x Taichung (Native) 1 were selected from pedigree rows. Lines as late as 147 days were tested in the observational yield trial and are being considered as parental sources of medium-late maturity.

Blast resistance. Blast-resistant varieties used in the breeding program include Dawn, H-105, Sigadis, and several japonica varieties from Taiwan. Blast-resistant hybrid lines, selected from crosses involving the above-mentioned varieties, and which possess other desirable traits, were used as parents in the crosses with IR8. Peta/3 x Dawn, Dawn/3 x Sigadis, Sigadis/3 x Taichung (Native) 1, H-105 x Dee-geo-woo-gen, and BPI-76 x Taiwan japonica are examples of hybrid lines used as sources of blast resistance in IR8 and other crosses.

Bacterial leaf blight. Bacterial leaf blight resistance has been combined with blast resistance in a number of hybrid lines. Selection for desirable plant-type lines possessing resistance to both diseases is underway. Important sources of bacterial leaf blight resistance are Sigadis, Taiwan japonica varieties, Dawn, CP 231 x SLO-17, B581A6-545 and B589A4-18.

Bacterial streak. Bacterial leaf streak resistance is present in many varieties including Taichung (Native) 1. Pedigree rows and yield trial plots occasionally become heavily infected with bacterial streak. During such periods excellent field notes on the reaction of hybrid lines are obtained. Streak-resistant hybrid lines combining many other desirable features are now available for use in the breeding program.

Tungro virus. Peta, Sigadis and Mas were the original sources of tungro resistance. Tungro-resistant hybrid lines selected from several Peta, Sigadis, and Mas crosses were used as parents in crosses with IR8.

The Pankhari 203 variety from India, which the Institute plant pathologists found to be highly resistant to tungro, was used as a parent in several crosses with IR8 and other varieties. The F_1 plants of the cross, Dawn x Pankhari 203, were crossed with IR8. Tungro-resistant and blast-resistant F_1 plants from this three-way cross were backcrossed to IR8. This was possible since resistance to both diseases behaved as a dominant trait in the F_1 hybrids. The blast resistance of Dawn and the tungro resistance of Pankhari 203 are being transferred to IR8 by repeated backcrossing of resistant F_1 backcross plants to IR8.

Grain characteristics. Hybrid lines selected from crosses involving U.S.A. and Thailand varieties were used as sources of long grain, clear endosperm texture, and intermediate amylose content. The principal U.S.A. varieties used were Dawn and CP 231 x SLO-17. The Thailand varieties were Nahng Mon S-4 and Leuang Yai 34. Several BPI-76 x Taiwan japonica varieties may be useful as parental sources of low amylose content. TKM-6 and Pankhari 203 crosses involving IR8 and similar dwarf lines may also give promising grain characteristics, with the improved grain characteristics coming from TKM-6 and Pankhari 203.

Other sources of improved plant type. Promising plant-type lines have been selected from a number of crosses in which reduced plant height is the result of multiple gene action rather than of a single major gene, as in the case of the Taiwan semi-dwarf varieties. In crosses involving CP 231 x SLO-17, hybrid lines as short as IR8 and Taichung (Native) 1 were selected.

In the cross of Peta x Tangkai Rotan, a number of lines of intermediate height, such as IR5-47-2, have been selected. In some production areas the IR5 lines may have advantages over IR8 due to a more vigorous vegetative growth, a slightly taller stature, medium-late maturity, and higher tungro resistance than IR8.

Pedigree nurseries

A total of 25,234 pedigree rows were grown in four nurseries sown in October and December 1965, and in May and June 1966. By seeding at two dates in the fall and two dates in the late spring, the workload is spread over longer periods.

Blast readings in the seedling stage were obtained on over 70 percent of the pedigree lines by growing them in a special blast nursery (Annual Report, 1963, pp. 35-38).

Flag leaf inoculations for determining bacterial leaf blight reactions were made on several thousand pedigree rows from selected crosses. Over 1,000 plant-lines were evaluated for reaction to tungro virus by Institute virologists.

Grain dormancy tests were obtained on most of the plant selections harvested from the nurseries.

A portion of the grain harvested from individual plants taken from F_2 populations, bulked hybrid populations, or pedigree rows were milled and visually classified for grain size, shape and appearance (Annual Report, 1965, p. 84). Alkali digestion and amylose content were determined on a large number of the plant lines harvested.

Yield trials

Advanced test. Yield trials in replicated 8-row plots, 5-m long, were planted in December 1965 and June 1966. A total of 92 entries were grown in the December trial and 89 in the June trial, of which 57 and 72, respectively, were Institute-developed lines. The average yields of 29 Institute lines that were included in both trials were 6,670 and 4,248 kg/ha, respectively, compared with average yields of 5,880 and 3,491 kg/ha for 11 varieties and lines selected from the world collection.

Agronomic, disease, and grain quality data recorded on 31 varieties and lines grown in the December and June trials are shown in Table 1. A number of lines produced reasonably high yields in the December trial where no serious disease problems were encountered. This would indicate that there are a number of promising plant types capable of producing high yields when diseases are not a limiting factor. In the June trial, grassy stunt and tungro virus diseases caused severe damage to many lines and resulted in marked yield reductions. Lodging also resulted in yield reductions, particularly with such varieties as Peta, Sigadis, and BPI-76. The rather low yields reported for IR5-47-2 and sister lines in the June trial can be attributed to lodging.

Blast, bacterial leaf blight, and tungro data were made possible through cooperation with the Institute plant pathologists.

Observational yield trial. A total of 764 varieties and lines were grown in non-replicated observational yield trial plots. Most of the strains were hybrid lines selected from pedigree rows. In addition to yield data, information was recorded on time of maturity, plant height,

Table 1. Agronomic, disease, and quality data on selected varieties and lines grown in replicated yield trials at two planting dates (December 1965 and June 1966), IRRI.

IRRI Acc. No.	Variety or selection	Grain yield (kg/ha)		Maturity (days seeding-harvest)		Mean pl. ht.	Mean no. pan-icles/ plant	Mean lodging (%)		Disease				Seed dor-mancy	Milled rice yields (%)		Gelat. temp.	Amylose
		Dec.	June	Dec.	June	(cm)		Dec.	June	Tungro virus	Bact. leaf blight	Bact. streak	Blast	(%)	Head	Total		(%)
35	Peta	3004	821	132	147	166	17	100	100	R	S	S	S	93	44.3	67.6	I	29.8
39	BPI-76	5170	1795	146	147	146	12	0	100	S	S	MS	S	86	54.1	68.0	HI	24.8
4095	Sigadis	3434	2236	132	147	167	16	100	100	R	MR	S	MR	97	39.0	70.7	I	29.4
9915	BPI-76-1 (Bicol Sel.)	6171	3619	126	129	148	11	100	100	S	S	MS	S	65	64.2	70.3	HI	28.5
87	Chianung 242	5795	3778	121	123	135	12	70	25	S	R	MS	S	60	57.3	73.9	L	19.0
6918	Takao (Kh.) 21	6682	4354	121	116	125	14	45	0	S	R	MR	MR	6	62.2	76.0	L	23.6
146	PI 215936	6414	3976	121	119	126	13	50	0	S	R	MS	MS	7	58.7	74.1	L	20.6
6993	CP 231 x SLO-17	6773	4036	118	114	105	14	0	0	S	R	R	S	46	53.7	66.9	H	20.4
6973	A6-545, (CP 231/3 x Bbt)/2 x PI 215936	6075	4179	123	119	112	11	0	0	S	R	R	MR	5	61.2	71.2	H/I	28.1
105	Taichung (Native) 1	7525	4361	122	119	105	18	0	0	S	S	MR	S	3	49.4	72.2	L	31.6
10319	MIFB 322-1 Sel.	6988	3936	139	135	113	16	0	0	S	MR	R	MS	98	60.9	70.5	HI	25.8
	IR4-90-2, H-105 x Dgwg	7591	4866	124	129	112	13	0	0	S	MS	S	R	13	52.0	71.6	L	32.8
	IR4-93-2, H-105 x Dgwg	6172	5016	139	133	121	14	0	0	S	MS	MS	R	24	59.5	70.6	L	33.2
10321	IR5-47-2, Peta x Tangkai Rotan	7068	4308	139	140	132	16	85	60	MR	MR	MS	S	95	53.9	70.7	I	33.9
	IR5-198-1-1, Peta x Tangkai Rotan	6491	3706	139	140	128	15	45	60	MR	MR	S	S	99	52.6	71.0	I	33.0
	IR8-172-3-1, Peta x Dgwg	7259	4040	139	140	111	17	0	48	S	MS	MS	S	65	36.3	70.9	I	30.8
	IR8-185-1-1, Peta x Dgwg	7292	4193	132	135	102	15	0	15	MS	S	S	S	55	53.9	70.8	I	30.9
	IR8-190-1-1, Peta x Dgwg	7051	4506	129	130	98	14	0	0	S	MS	MS	S	24	56.2	70.7	L	30.4
10320	IR8, Peta x Dgwg	8236	5377	129	129	103	15	0	0	MS	S	MS	S	21	51.9	72.4	L	32.6
10322	IR9-60, Peta x Igt	6263	5335	126	126	102	14	0	40	S	S	MR	S	55	46.2	74.0	I	32.0
	IR11-452-1-1, FB-24 x Dgwg	7178	4045	132	130	106	14	0	0	MR	S	MS	S	50	50.2	72.5	I	30.9
	IR11-460-1, FB-24 x Dgwg	7459	4499	121	118	112	14	7	20	S	S	MS	S	12	49.2	72.5	L	31.7
	IR14-149-3, BPI-76 x Kh. 68	6174	3898	126	119	127	16	45	0	S	MR	MR	MS	46	54.2	72.2	L	22.0
10323	IR52-18-2, BPI-76/2 x Kh. 68	6666	4574	126	119	121	12	0	0	S	MR	MR	MS	80	61.8	70.8	L	24.2
	IR60-12-4-1, BPI-76/2 x Ch. 8	7341	4365	129	130	137	11	0	0	MS	MR	R	MR	70	63.7	72.7	L	22.8
	IR67-124-5, CP 231 x Ch. 242	7031	3669	115	106	111	15	0	50	MS	S	MR	S	7	54.4	69.4	L	17.4
	IR68-141-3, CP 231 x PI 215936	6087	3897	122	117	121	15	0	0	S	MR	MR	S	60	64.4	72.9	L	20.3
	IR76-45-1, BPI-76 x T. 176	7056	4839	132	140	142	14	0	30	S	MR	MR	MS	59	65.8	73.8	L	18.2
	IR154-61-1-1, (CP 231 x SLO-17) x T(N)1		5392		115	98	16		0	S	MR	R	MS	13	65.4	73.0	H	17.0
	IR262-43-8-11, Peta/3 x T(N)1	7858	4806	122	122	93	17	0	45	MR	MS	MS	MS	65	34.2	71.9	I/L	31.2
	IR262-43-8-33, Peta/3 x T(N)1	4790	4107	132	131	103	17	0	50	S	MS	MS	S	81	40.3	72.5	I	31.3

NOTE: 1. Plant height, panicle number, and milled rice yields are mean values from the two trials.
2. Data on tungro reaction were largely based on field observation made at Los Baños and Bangkhen (Thailand) over several seasons and supplemented with seedling inoculation tests by the plant pathologists.
3. Disease data on blast were obtained from seedling tests made with the cooperation of the plant pathologists; bacterial leaf blight and streak data were obtained in the June-seeded trial on inoculated and naturally infected plants, respectively.
4. Dormancy data were obtained from plants grown in the June-seeded trial.
5. Amylose content and gelatinization temperature data were mean values of plants grown in the two yield trials.

lodging, reaction to diseases, and grain quality.

Over 300 of the lines were sent to other countries where they were grown in cooperative nurseries for further selection under local conditions.

International cooperative variety testing

Nursery-sized seedlots of Institute breeding lines were distributed to various cooperating agencies in the tropics for the purpose of collecting information on the performance of early-generation (F_5 to F_7) lines under a variety of environmental conditions. The breeding lines provide a working basis for cooperative breeding programs in India, Malaysia, Pakistan, and Thailand where a liaison scientist is stationed in each country on the staff of the Ford or The Rockefeller Foundation.

In addition to the four countries, a set of each of 300 breeding lines was sent during the year to Colombia, Costa Rica, Dominican Republic, Mexico, Taiwan and the U.S.A. Smaller sets of breeding material were distributed upon request to agricultural experiment stations in Australia, Brazil, Cambodia, Ceylon, Central African Republic, Dahomey, El Salvador, Fiji, Gambia, Ghana, Guatemala, Guyana, Honduras, Indonesia, Iran, Japan, Laos, Nepal, Nicaragua, Nigeria, Panama, Peru, Philippines, Republic of the Congo, Republic of Korea, Saudi Arabia, Senegal, Spain, Sudan, Timor Islands, and U.A.R.

During the year, about 6,000 seed packages of Institute breeding lines were air-mailed in response to more than 250 requests originating from over 50 countries outside the Philippines. The geographic distribution of the recipients covers latitudes between 43° N (northern Japan) and 36° S (southern Australia).

In the Philippines, three Institute lines (IR8-288-3 (IR8), IR9-60 and IR6-52-3) were entered in the dry-season general tests of the Seedboard at several sites and two nitrogen levels each. The medium fertility level varied from 45 to 90 kg/ha added N; and high fertility from 60 to 120 kg/ha. The test sites were located between 15° 43′ N (Muñoz) and 7° 14′ N (Midsayap).

Available yield data from four Philippine stations are partly given in Table 2. At the lower fertility level, IR8 was the leading entry among 18 selections at two sites and ranked third and fifth at the other two. At the higher nitrogen level, IR8 was the highest yielder at the University of the Philippines College of Agriculture (Los Baños), Bicol Station (Pili) and Mindanao Station (Midsayap). IR8 ranked second at the Maligaya Station (Muñoz), where the yield level of all varieties in the test was low. The grain yield of IR8 ranged from 3,467 kg/ha to 8,197 kg/ha and ranked first over all with a grand mean of 5,506 kg/ha. Peta, the check variety, averaged 3,351 kg/ha at four sites. IR6-52-3 and IR9-60 gave a wide variation in yield and averaged 4,340 kg/ha and 4,282 kg/ha, respectively, over the four locations; IR6-52-3 and IR9-60 ranked third and fourth in this series of tests and were higher yielders than Peta which ranked last among the 18 entries.

Five additional IR lines were entered in the wet-season general tests of the Philippine Seedboard. Partial data showed that IR5-47-2 was the leading entry at the University of the Philippines College of Agriculture and Maligaya Station.

During the dry season, IR8 and its pedigreed selections were the top yielders in the 303-line nursery at the Central Rice Research Institute (India), Tanjong Karang (Malaysia), and the Institute. In the aus crop of East Pakistan, the IR8 lines were also among the top-ranking ones at the Savar Farm of the Agricultural Research Institute, the Comilla Rural Academy and the Comilla Government Farm. IR8 was also one of the high yielders in trials at the Dokri Rice Research Station, West Pakistan, during the kharif season. Other high-yielding lines in the diverse group of 303 tested over a number of locations and seasons were all early-maturing, short-statured, nitrogen-responsive selections. The great majority of these lines are progenies from the cross of a tall tropical indica variety with a semi-dwarf indica from Taiwan (Dee-geo-woo-gen or I-geo-tze). A number of these semi-dwarf lines have excellent vegetative vigor at the early growth stages and a high grain : straw ratio. Other promising lines came either from crosses involving Taiwan's ponlai types and a U.S. selection, or the Peta x Tangkai Rotan cross (IR5 lines).

Table 2. Grain yield (kg/ha) of leading entries in the Philippine Seedboard general tests, 1966 dry season.

Entry	Station								Mean		
	Maligaya		UPCA		Bicol		Mindanao				
	MF*	HF†	MF	HF	MF	HF	MF	HF	MF	HF	Grand
Peta (ck)	3388	2614	3841	3621	4299	4726	1910	2394	3360	3339	3351
Milbuen 19	3269	3670	5817	6222	3216	3634	4113	4183	4104	4427	4266
BPI-76-1 (Bicol)	2948	2627	4888	5174	3344	3920	—	—	3727	3907	3817
BPI-76 (Maligaya)	3511	3010	6318	6138	3538	4536	—	—	4456	4561	4509
C-13	2869	2640	7044	5887	3546	4633	3806	3084	4316	4061	4189
IR8	3467	3582	7682	8197	3533	6041	5764	5777	5112	5899	5506
IR9-60	2446	2407	5192	5399	3995	4796	5482	4532	4279	4284	4282
IR6-52-3	2380	2504	5548	5698	4048	4712	4910	4919	4222	4458	4340
TPBSK-16-1	3588	3274	5707	5661	3375	4041	—	—	4223	4325	4274

* MF = medium fertility level.
† HF = high fertilizer level.

The above test results support the Institute's breeding objectives of developing early-maturing, photoperiod-insensitive, short-statured, nonlodging, nitrogen-responsive strains with short, erect, dark-green leaves. Many of the promising lines have moderate grain dormancy, relatively firm threshability, a moderate level of resistance to the blast and virus diseases, and acceptable grain shape and cooking quality. The wide adaptability indicated by these lines may be attributed to early maturity, photoperiod insensitivity, thermo-insensitivity, and the physiologically efficient, short-statured plant type.

International performance of IR8

Yield data obtained outside the Philippines were provided by cooperating agencies and individuals in various countries. They are summarized with the appropriate consent in order to provide a more complete evaluation of the variety.

During the rabi (dry) season in India, IR8 was grown on the farm of the All-India Coordinated Rice Improvement Project (Hyderabad) and at the Central Rice Research Institute (Cuttack). In a preliminary yield trial at Hyderabad, IR8 yielded 7,753 kg/ha; Taichung (Native) 1, 5,471 kg/ha; and IJ 52 (check), 4,952 kg/ha. In an unreplicated yield trial at Cuttack fertilized at 120 kg/ha N, Taichung 65 x Taichung (Native) 1 and IR8 topped a group of 13 strains, yielding 7,044 and 7,034 kg/ha, respectively. The highest yield of traditional check varieties obtained in the same season was about 4,500 kg/ha each.

During the kharif (monsoon) season, IR8 was entered in the All-India uniform variety trials and preliminary variety trials at a number of locations. The fertilizer levels were 50 and 100 kg/ha N. The grain yield of IR8 ranged from 1,937 to 7,559 kg/ha in 11 trials at eight locations; Taichung (Native) 1 yielded between 2,132 and 6,025 kg/ha in the same series of trials; and some of the local standard varieties produced around 3,000 kg/ha. IR8 averaged 4,888 kg/ha, a 27-percent increase over the 3,835 kg/ha mean of Taichung (Native) 1. In a farmer's demonstration field near New Dèlhi, IR8 yielded about 8,650 kg/ha.

The Union Ministry of Food and Agriculture of India has identified IR8 for large-scale seed multiplication during 1967.

In Malaysia, field-sized demonstration plots of IR8 were planted in Province Wellesley during April and May by the field staff of the Department of Agriculture, States of Malaya. The yield levels obtained at Permatang Manggis and announced at the field day were about 3,600 kg/ha for Mashuri fertilized with 67 kg/ha N, and 4,600 to 6,600 kg/ha for IR8 at fertilizer levels ranging from 67 to 202 kg/ha added N. A plan for seed increase was announced by government officials during the field day on August 12, and IR8 was named "Padi Ria". The Institute later provided 3 tons of seed to the Department to accelerate the seed increase program.

A fall-planted crop of IR8 in Sinaloa State on the Pacific coast of Mexico gave a yield of 8 ton/ha.

In East Pakistan, in a yield trial planted during the boro (dry) season at the East Pakistan Academy for Rural Development (Comilla), IR8 yielded 6,908 kg/ha and ranked third among 28 entries which were mostly Institute material. In another trial at the Abhoy Ashram Government Farm (Comilla), IR8 yielded about 6,710 kg/ha in the boro crop, ranking fourth among 28 entries. During the aus season, in three separate unreplicated trials IR8 gave estimated yields ranging between 6,700 and 8,200 kg/ha.

During the kharif season in West Pakistan, in a varietal trial at the Dokri Rice Research Station, IR8 yielded 8,441 kg/ha whereas the local check variety produced 3,471 kg/ha. In a variety-fertilizer trial at the same station, IR8 produced 10,248 kg/ha at 134 kg/ha N; the check variety gave 6,589 kg/ha at the same fertilizer level. Over a range of six fertilizer levels, IR8 averaged 8,272 kg/ha, a 43-percent increase over the mean of the check variety (5,783 kg/ha).

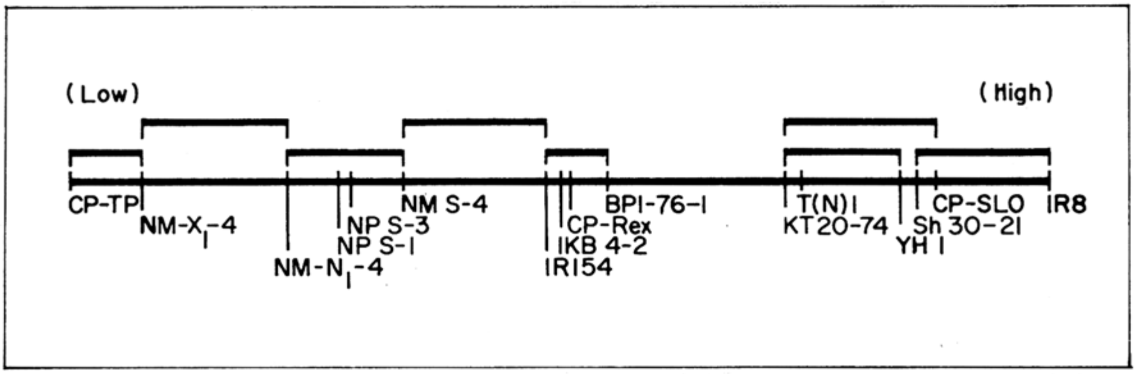

Fig. 1. Graphical array of grain yield of 16 entries in the IAEA uniform yield trial of indica types, 1966 wet season. The means within a bracket are considered homogeneous, and those not bracketed together are considered different.

At the Bangkhen Station in Thailand, IR8 yield figures ranged from 4,973 to 6,031 kg/ha over eight fertilizer levels in the one-monsoon season experiment in which it escaped serious virus infection. In another experiment where the incidence of tungro was severe, IR8 yielded about 3,800 kg/ha, which was below the yields of tungro-resistant varieties such as Peta, Sigadis, FK 135 and IR5-47-2. However, the yield of IR8 was about the same as that of the local variety.

Seed multiplication, distribution and naming of IR8

Between February and April, about 13 hectares of the Institute Farm were planted to IR8, as described in the Experimental Farm section of this Report. A seed harvest of approximately 75 tons was distributed for international multiplication and testing. About 58 tons were provided for multiplication on large, selected farms in seven provinces of central and southern Luzon, Philippines. Approximately 4.2 tons were planted for extensive testing purposes by governmental and private agencies in several hundred locations throughout the Philippines. About 2,400 Filipino farmers each received 2-kg samples for additional testing and multiplication. The total harvest from these wet-season plantings was approximately 9,000 tons.

Eight other countries were provided with a total of 5.2 tons for large-scale plantings. They were Burma, Colombia, India, Laos, Malaysia, Mexico, Pakistan and South Vietnam. In addition, hundreds of individuals and agencies in some 60 countries received smaller shipments for performance trials.

On the basis of its outstanding performance in tropical Asia, IR8 was officially recognized on November 28 as the first variety to be named and released by the Institute. Among the names associated with the variety in the Philippines have been 'the miracle rice', 'Magsaysay variety', 'San Luis variety', and 'Rizal No. 1'.

IR8 has strong seedling vigor, high tillering ability, short stature (90-105 cm), lodging resistance, positive response in terms of grain yield to high levels of nitrogen, moderately early maturity (120-130 days from seeding to harvest), moderate seed dormancy, and moderate field resistance to the tungro virus. The grain has a high amylose content and a low gelatinization temperature, indicating that the cooking quality is acceptable for most of the Asian market (Table 1).

One distinct drawback is that the selection is susceptible to bacterial leaf blight and highly susceptible to a few races of the rice blast fungus that are prevalent at Los Baños and elsewhere in the Philippines. Under field conditions, however, IR8 has shown greater tolerance to both these diseases than Taichung (Native) 1.

The grain is of medium size, chalky, and prone to breakage, and the head rice milling recovery therefore relatively low.

Despite its shortcomings, IR8 is a significant improvement on the rice varieties at present being grown commercially in tropical Asia. For this reason seed has been made available for further multiplication, even though later strains with better grain quality and more disease resistance may soon supersede it. The development of such strains, using IR8 as one of the parents, is in progress.

Yield trial of irradiated mutants and hybrid selections

A series of uniform yield trials covering eight locations in tropical Asia was initiated at the meetings sponsored by the International Atomic Energy Agency in Manila during February. The purpose of the coordinated trials was to evaluate on a regional basis those mutant progenies which have been reported to possess superior features, and to compare them with promising selections from hybridization programs. During the wet season, a yield trial for 16 indica types and an observation plot for 13 japonica types were planted at the Institute. The yield trial was transplanted in mid-August and fertilized with 90 kg of added nitrogen. The trial included seven mutant selections from four sources (India, Taiwan, Thailand, U.S.A.), three mutant- x variety-selections, one pure-line variety, and five hybrid selections from four sources (IRRI, Philippines, Taiwan and U.S.A.).

The 16 entries differed significantly in yield at the 1-percent level of significance. The ranking of grain yield of 16 entries and their division into yield-groups are shown in Fig. 1. IR8 led the group with a mean yield of 4,732 kg/ha, followed by CP 231 x SLO-17 (4,266 kg/ha), and Sh 30-21 mutant (4,222 kg/ha) in the same high-yielding group. In the second group, YH 1 selection (3,986 kg/ha), which originated from T(N)1 x Sh 30-21, ranked first and was followed by Taichung (Native) 1 (3,754 kg/ha) and KT 20-74 mutant (3,752 kg/ha). The check variety, BPI-76-1 (3,065 kg/ha), Irrad. CP 231 dwarf x Rexoro selection, IKB 4-2 mutant, and IR154-77-2 selection (CP-SLO x T(N)1) were the four members of the third yield-group. Nahng Mon S-4 variety, NP131-S3 mutant, NP131-S1 mutant, and Nahng Mon-N_1-4 mutant formed the fourth group. Nahng Mon-X_1-4 mutant and Irrad. CP 231 dwarf x TP selection belonged to the fifth group. Multiple range test also shows that CP 231 x SLO-17, Sh 30-21, YH 1, Taichung (Native) 1, and KT 20-74 actually belong to one homogeneous yield-group at the 5-percent significance level.

Studies on Competition

A 4-year series of studies on the causes, effects, significance and association of competitive ability with yield was concluded. Preliminary observations were given in the 1965 Annual Report.

In long-term mixtures of different varietal types, two tropical varieties, BJ and MTU, rapidly dominated Taichung (Native) 1, Chianung 242, and Milfor-6(2). After three cycles of bulking, the latter varieties were eliminated from

Table 3. Expected and observed frequencies of dwarf segregates in the cross Peta x Taichung (Native) 1.

Generation	Expected frequency without competition (%)	Observed frequency (%)	
		O N	High N
F_2	25.0	24.9	24.9
F_3	37.5	31.2	22.4
F_4	43.8	33.5	18.9
F_5	46.9	28.3	14.2
F_6	48.5	23.7	8.8

the mixtures. Competitive ability was inversely proportional to yielding ability.

The competitive ability of dwarf segregates was measured from F_2 to F_6 in the cross Peta x Taichung (Native) 1 (Table 3). The undesirable tall segregates had a strong competitive advantage over the dwarf segregates. Nitrogen application, close spacing, and rainy season plantings increased the competitive advantage of the tall segregates. It was demonstrated that in pure stands the weakly competitive dwarfs yielded more than the tall plants.

Weekly observations were made of the components of growth in contrasting plant types grown in mixtures and in pure stand. In the early growth stages the competitive plant types in pure stands were taller and had greater tillering, leaf number, leaf size, LAI and dry weight. Growth was initially rapid and then declined toward flowering. The weakly competitive varieties showed slow initial growth but by flowering they exceeded the competitive types in some growth characters.

In mixtures, however, growth of the poor competitors was dominated by the vegetatively vigorous types. Competition, first observed from 32 to 39 days after transplanting, was shown to be for light. The competitive types received more light in mixtures, at the expense of the smaller, less vigorous varieties, than in pure stands.

It was concluded that competitive ability is conditioned by early vigor and greater size of vegetative organs in the first weeks after transplanting. Characters observed at flowering or maturity should not be associated with competitive ability. Therefore, it is often observed that at maturity one variety may be taller or have more tillers but is less competitive than another variety.

The prominent negative correlation of competition and yield is intimately associated with the concept of plant type. Early vigor and size at once condition competitiveness and low yield potential as a consequence of excessive mutual shading and respiration. The slower vegetative growth of desirable plants confers both low competitive ability and high yield potential.

The results from these experiments show clearly that competitive ability has been a major factor in the evolution of distinct plant types in tropical and temperate areas. They also suggest that the exceptional competitive ability of undesirable plant types has contributed greatly to past failure of bulk population breeding and hybridization of diverse parents, including indica x japonica varieties, in national tropical programs.

Genetic and Cytogenetic Studies

Allelism of genes for short stature in three semi-dwarf varieties

Dee-geo-woo-gen, I-geo-tze, and Taichung (Native) 1 are three nitrogen-responsive, early maturing, semi-dwarf indicas from Taiwan which are intensively used in the Institute's hybridization program. However, the allelic relationship of the major semi-dwarf gene(s) in the three varieties was not known.

Data on F_1 hybrids of three reciprocal crosses reported in 1965 indicated that the three varieties probably carried the same major gene for short stature since the hybrids were all semi-dwarfs. For each of the crosses, F_2 populations approximating 2,000 plants each were grown in the dry season to determine the range of distribution in plant height and other traits. The data obtained from the parents and F_2 plants confirms the postulate that the same recessive gene controls the semi-dwarf height in all three varieties, since none of the F_2 plants exceeded a height of 124 cm, the upper limit of the parents (Table 4).

Among the three parents, I-geo-tze and Taichung (Native) 1 showed no appreciable difference in height, whereas Dee-geo-woo-gen was significantly taller than I-geo-tze or Taichung (Native) 1. However, the Dee-geo-woo-gen and Taichung (Native) 1 populations indicated equal variances which were not equal to the variance of I-geo-tze. Among the three populations of F_1 hybrids, those of I-geo-tze x Dee-geo-woo-gen and I-geo-tze x Taichung (Native) 1 showed positive overdominance in height, whereas Dee-geo-woo-gen x Taichung (Native) 1 hybrids indicated partial dominance. The above contrasts are explainable by the knowledge that Taichung (Native) 1 was selected from a cross involving Dee-geo-woo-gen, whereas I-geo-tze and Dee-geo-woo-gen were not known to be

Table 4. Frequency distribution and mean values of plant height (cm) in three semi-dwarfs and their F_2 populations.

Parent or F_2	Class interval											No. plants	Mean and S. E. of mean
	70 – 75	75 – 80	80 – 85	85 – 90	90 – 95	95 – 100	100 – 105	105 – 110	110 – 115	115 – 120	120 – 125		
Taichung (Native) 1			1	7	26	39	33	6				112	98.11 ± 4.85
Taichung (Native) 1 x I-geo-tze	11	10	28	138	423	646	439	117	15	1		1828	97.65 ± 4.97
I-geo-tze				2	14	42	26	5				89	99.24 ± 4.02
I-geo-tze x Dee-geo-woo-gen				2	51	186	447	608	389	96	11	1790	107.03 ± 5.69
Dee-geo-woo-gen					2	4	17	46	28	11	3	111	109.36 ± 5.33
Dee-geo-woo-gen x Taichung (Native) 1		3	8	11	84	268	610	510	123	21	1	1639	104.07 ± 5.39

related.

The two F_2 populations each involving Dee-geo-woo-gen contained a larger proportion of plants taller than I-geo-tze or Taichung (Native) 1. These two populations also had a larger mean than I-geo-tze x Taichung (Native) 1. Comparisons of F_2 populations means with one of the two parents by the *t* test indicated that the two F_2 populations involving Dee-geo-woo-gen were different from any one of the three parents at the 1-percent level of significance. The parental and F_2 distributions suggest that Taichung (Native) 1 differs from Dee-geo-woo-gen and I-geo-tze in that it has more modifying genes in the negative direction.

Dee-geo-woo-gen and Taichung (Native) 1 have an erect growth habit, whereas I-geo-tze has spreading culms. A range of segregates was noted in the F_2 populations. Three classes were recognized: erect, intermediate and spreading. A count of 1,972 F_2 plants in the Taichung (Native) 1 x I-geo-tze reciprocal crosses gave a ratio of 442 (erect):1,060 (intermediate):470 (spreading), which showed a significant deviation from the 1:2:1 ratio due to an excess of plants in the intermediate class. However, the pooling of the erect and intermediate classes gave a satisfactory fit to the ratio of 3 (erect to intermediate):1 (spreading). The data indicate that the difference in culm angle is essentially controlled by one pair of alleles.

Inheritance of short stature in U.S. strains

In addition to the three semi-dwarfs from Taiwan, Accession 6993 originating from CP 231 x SLO-17 is another strain frequently used in the breeding program as a source of short stature. CP-SLO measures about 101 cm in height and has given high yields at Los Baños. Observations made in breeding nurseries indicate that CP-SLO and Taichung (Native) 1 probably carry different genes for short stature as a wide range of segregates were found in their progenies. The inheritance of the short stature in CP-SLO was studied in three intercrosses involving three parents of related parentage: CP-SLO (Acc. 6993), CP 231 (Acc. 134), and (CP 231/3 x Bbt)/2 x PI 215936 (Acc. 9916). CP 231 measured about 138 cm in height and Acc. 9916, 108 cm.

The height distribution of the CP 231 x CP-SLO and CP-SLO x Acc. 9916 crosses is shown in Figs. 2 and 3. The F_1 hybrids of CP-SLO x Acc. 9916 showed over-dominance; CP 231 x CP-SLO, partial dominance; and CP 231 x Acc. 9916, essentially no dominance.

The distribution of F_2 plants in CP 231 x CP-SLO and CP-SLO x Acc. 9916 both approximated a normal distribution with slight skewness toward the short end. The F_2 distribution of CP 231 x Acc. 9916 was similar to that of CP 231 x CP-SLO. Data from all three crosses suggest that a polygenic-additive system controls the

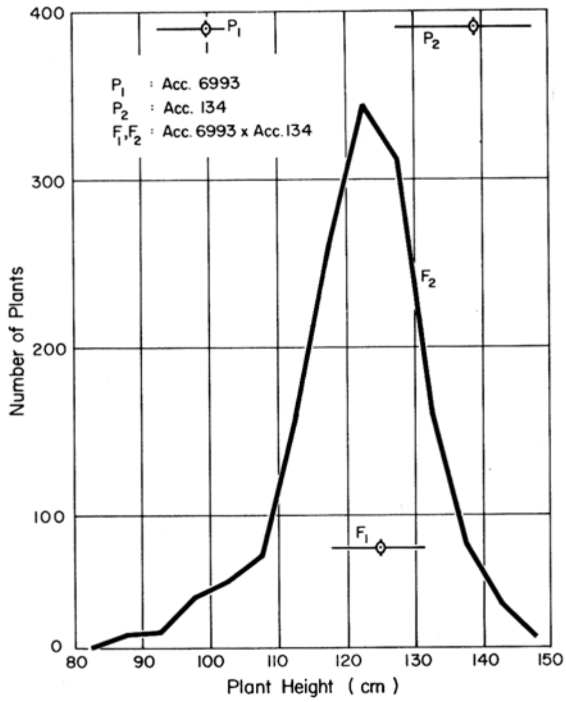

Fig. 2. Distribution and means of parents, F_1, and F_2 plants by height classes in the cross of Acc. 6993 (P_1) by Acc. 134 (P_2). Solid horizontal lines show the range of parents and F_1 plants about the means (dotted circles).

continuous distribution in the F_2 populations. The mode of inheritance in these crosses appears to be more complex than that in Taiwan's semidwarfs.

Panicle length was measured in all populations. All of the F_1 hybrids had panicles longer than those of the higher parent. The distribution of F_2 populations was multimodal in all crosses and showed a slight skewness toward the long tail in two crosses. The F_2 population means were larger than the mean of the higher parent in each case. The data indicate transgressive segregation for long-panicled individuals in all three crosses.

Dialell-cross analysis of quantitative characters

A complete set of F_1 hybrids from reciprocal crosses involving four indica varieties were analyzed by the diallel-cross method to provide genetic information on a number of quantitative characters. The four parents were Dawn, H-4, Sigadis, and Sukhwel 20. The parents differed significantly in one or more of the following traits: heading date, panicle number per plant, plant height, panicle length, and number of grains per panicle. All four parents were essentially insensitive to photoperiod and relatively cross-fertile. The parents and 12 groups of F_1 hybrids were grown during the dry season in a randomized complete block experiment including four replications and 16 plants/plot.

Additive and dominance effects of parents on F_1 hybrids. The analysis of variance showed highly significant differences among parents with respect to each of the three traits: number of days to heading, plant height and panicle number (Table 5). The genetic variation among parents were highly significant for each of the two genetic components, additive effect and dominance effect. Between reciprocal crosses, no maternal effect was detected.

From the heading date readings, earliness showed dominance over lateness. Similarly, tall plant stature was dominant to short height and

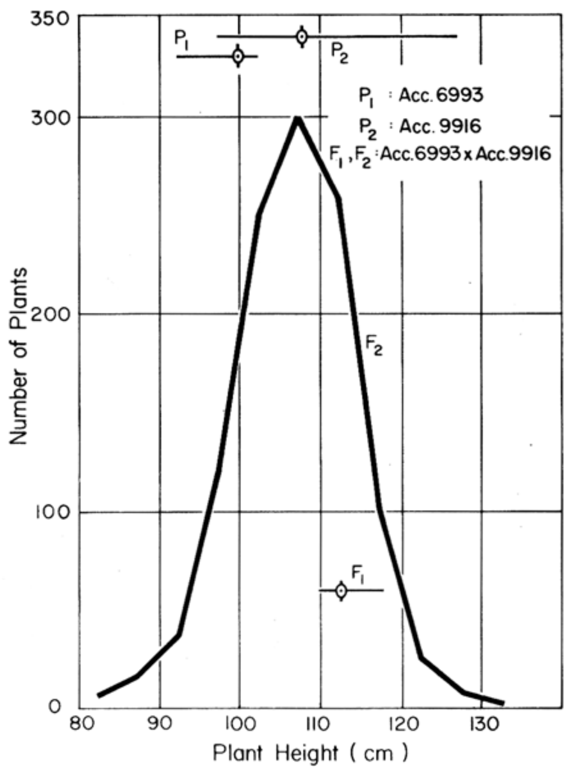

Fig. 3. Distribution and means of parents, F_1 and F_2 plants by height classes in the cross of Acc. 6993 (P_1) by Acc. 9916 (P_2). Solid horizontal lines show the range of parents and F_1 plants about the means (dotted circles).

Table 5. The mean values of parents (underlined) and F_1 hybrids in a four-parent diallel cross.

Character	Male array / Female array	Sigadis	H-4	Dawn	Sukhwel 20
Sowing-to-heading period (days)	Sigadis	101.41	84.08	79.41	75.36
	H-4	83.20	92.94	80.13	70.55
	Dawn	77.41	78.72	82.48	71.22
	Sukhwel 20	74.53	69.77	71.87	67.80
Plant height (cm)	Sigadis	189.42	189.44	200.62	160.19
	H-4	187.58	180.99	197.35	151.57
	Dawn	199.62	197.20	155.21	168.00
	Sukhwel 20	158.65	150.97	159.54	113.72
Panicle number per plant	Sigadis	19.24	22.49	16.92	32.17
	H-4	22.53	20.29	16.60	30.38
	Dawn	18.09	15.39	8.15	27.38
	Sukhwel 20	30.37	32.43	24.21	34.14

high panicle number was dominant to low count.

Degree and direction of dominance. Covariance analysis of the heading date data indicate that the four parents differ in their dominance effect on the arrays of F_1 plants. The parents may be ranked into two groups according to their degree (order) of dominance: (1) dominance of the early parents—Sukhwel 20 and Dawn, and (2) recessiveness of the late parents—H-4 and Sigadis. When the parental variances were plotted on a graph, the distribution of standardized deviations (Y_r) indicates that the positive (late) and negative (early) alleles of the maturity genes are not equal in either direction or magnitude (Fig. 4). However, the degree of dominance of all loci is in the negative direction of earliness. The above findings agree with results obtained under controlled photoperiods that dominant genes control the short basic vegetative phase.

Analysis of plant height shows that Sigadis and H-4 may be grouped together as they both possess mostly dominant genes for tallness; Dawn and Sukhwel 20 belong to the other group carrying mostly recessive genes. Between the tall parents, Sigadis, being a taller variety, probably carries a larger number of positive alleles than H-4. Between Dawn and Sukhwel 20, the shorter Sukhwel carries a larger number of negative alleles. The order of dominance in all loci is in the direction of tallness (Fig. 5).

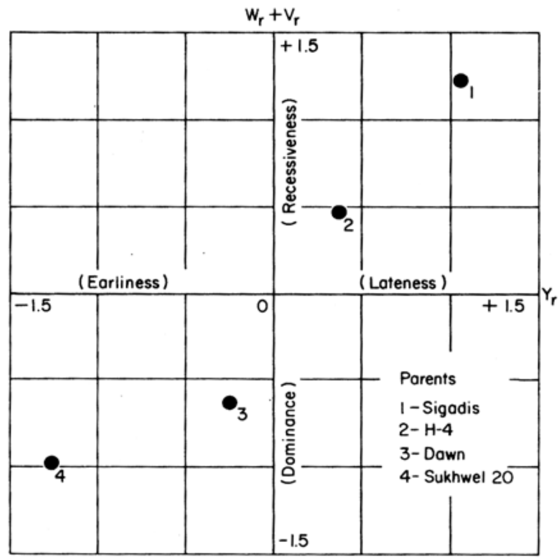

Fig. 4. Sowing-to-heading duration in the four-parent diallel cross, showing the distribution of standardized deviations of parental measurements (Y_r) and parental order of dominance ($W_r + V_r$).

Sukhwel 20 produced a mean of 34 panicles per plant, followed by Sigadis and H-4, each producing about 20 panicles, and Dawn gave a mean of 8 panicles. Covariance analysis indicates that Sukhwel 20 has a large number of dominant alleles for high tillering, Sigadis and H-4 each have a small number of recessive alleles, and Dawn carries a large number of recessives.

Therefore, it appears that high panicle number in this set of diallel-cross is largely controlled by dominant alleles.

Genetic components of variation in F_1 plants. The components of additive variance, dominance variance, and additive x dominance effects show the predominance of additive variance over dominance variance. The interaction of additive and dominance effects is appreciable in all cases.

Heritability estimates are 80.54 percent for days from seeding to heading, 65.22 percent for plant height, and 74.89 percent for panicle number, indicating that a major portion of the total phenotypic variation is genetic. The minimum number of dominant genes involved in controlling the over-all parental differences is estimated to be three for heading date, two for plant height, and three for panicle number. In conjunction with these dominant genes, other genes of an additive nature appear to control a major portion of the total genetic variance.

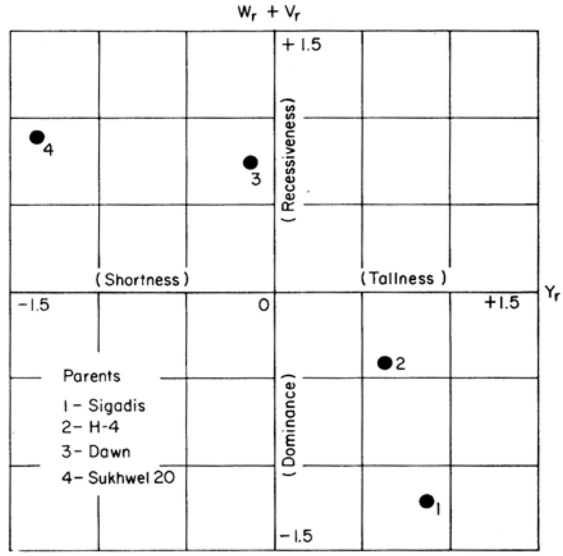

Fig. 5. Plant height in the four-parent diallel cross, showing the distribution of standardized deviations of parental measurements (Y_r) and parental order of dominance (W_r+V_r).

Genetic analysis of the components of growth duration

With the cooperation of the plant physiologists, the study on the inheritance of growth duration by component-analysis is being continued. The experimental approach is to treat the duration from seeding to panicle initiation as the function of two principal components: (1) the basic vegetative phase (b.v.p.) and (2) a photoperiod-sensitive phase (p.s.p.). By growing the parent plants, the F_1 hybrids, and the F_2 plants under a 10-hour photoperiod and treating the separated primary tiller(s) under a 16-hour photoperiod, the b.v.p. and p.s.p. of individual plants can be concurrently determined. The experimental methods were described in the 1965 Annual Report.

Three additional crosses, each involving a photoperiod-sensitive parent and an essentially insensitive parent, were studied in the above manner. The two parents of each cross also differed appreciably in the length of the b.v.p. The sensitive x insensitive crosses were BPI-76 x Norin 20, BPI-76 x Milfor-6(2) and Siam 29 x Kaohsiung 68. Moreover, two crosses each involving parents which were essentially insensitive or of low sensitivity were included in the study. These crosses are Taichung 172 x CP 231 and Norin 20 x CP 231.

F_1 behavior. In each of the three sensitive x insensitive crosses, the F_1 hybrids were photoperiod sensitive and almost as short as the short parent in b.v.p. or intermediate between the two parents as in the case of BPI-76 x Norin 20 (Fig. 6). In the case of Taichung 172 x CP 231, the F_1 hybrids were slightly shorter in b.v.p. than the short parent CP 231. The above results confirm the 1965 findings that (1) high photoperiod sensitivity is dominant to low sensitivity, and (2) short b.v.p. is dominant over long b.v.p. However, scaling tests of the parental and F_1 data indicates that the dominance effect of the short b.v.p. parent varies in different crosses. Overdominance of short b.v.p. is indicated in one cross, complete dominance in two others, and a low degree of partial dominance in BPI-76 x Norin 20.

Photoperiod response of F_2 plants. The F_2 sample of BPI-76 x Milfor-6(2) yielded 158 photoperiod-sensitive plants and 53 insensitive plants which showed good agreement with a 3:1 ratio. The F_2 data from this cross agree with those obtained in the BPI-76 x Tainan 3 cross during 1965, indicating that BPI-76 carries the dominant *Se* alleles for photoperiod sensitivity.

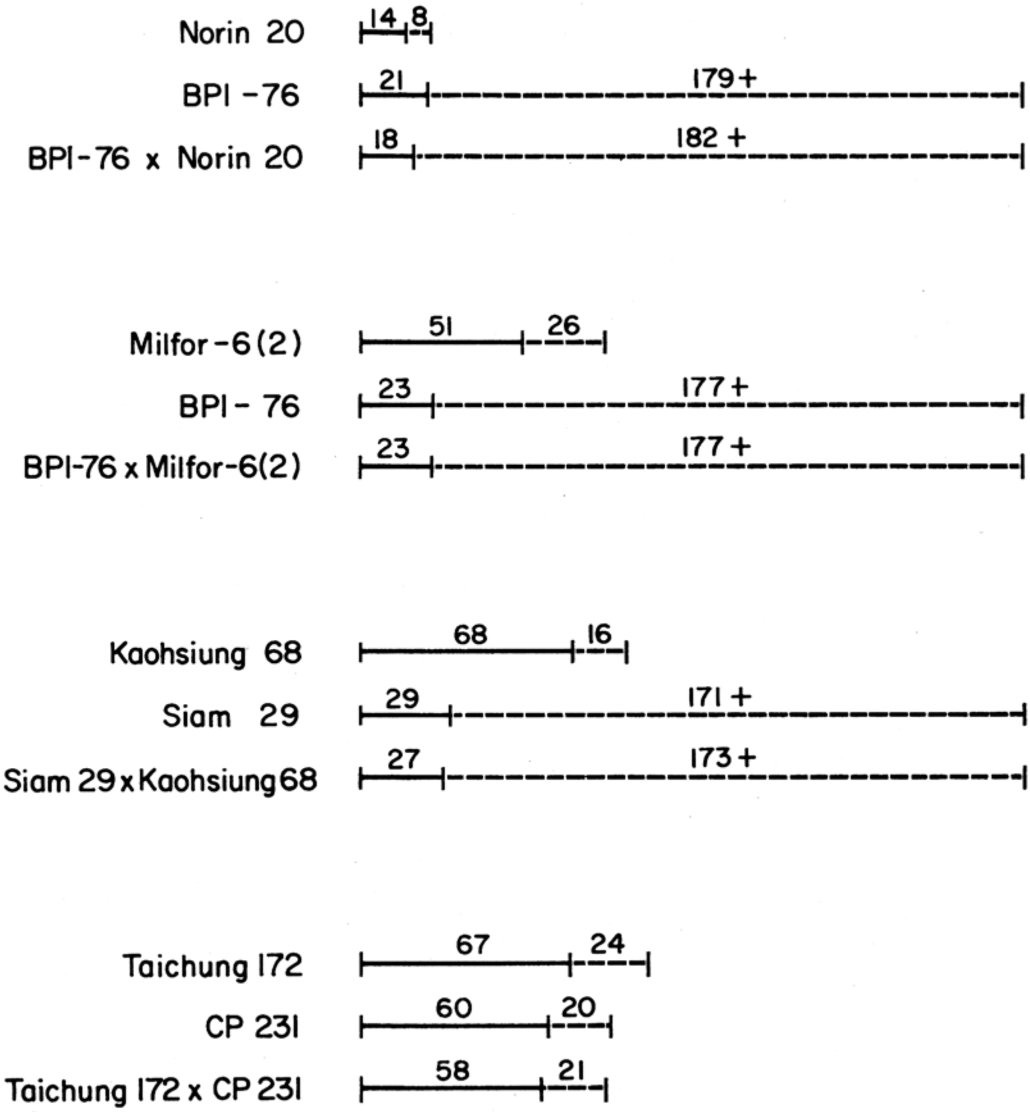

Fig. 6. Basic vegetative phase (solid line) and photoperiod-sensitive phase (dotted line) of parents and F_1 plants (days).

The F_2 population of Siam 29 x Kaohsiung 68 gave 205 sensitive and 19 insensitive plants. The observed ratio gave a satisfactory fit to the 15:1 ratio, which also applied to the 1965 data of the Siam 29 x Tainan 3 cross. Thus, Siam 29 carries two duplicate genes for photoperiod sensitivity (Se_1 and Se_2).

Basic vegetative phase of F_2 plants. In the BPI–76 x Milfor–6(2) cross, the mean b.v.p. of the two parents differed by about 29 days. The F_1 plants showed complete dominance of short b.v.p. The F_2 plants had b.v.p. values ranging from 17 to 56 days with a positively skewed distribution (Fig. 7). A total of 162 F_2 plants were distributed from 17 to 35 days in b.v.p., indicating that they carried either two dominant alleles, Ef_a and Ef_b, or the Ef_a allele(s) alone. Thirty-seven F_2 plants were distributed from 36 to 46 days in b.v.p., probably carrying the Ef_b allele(s). Thirteen F_2 plants were distributed in the same range as the long b.v.p. parent, Milfor–6(2). The distribution of the two parents, F_1, and F_2 plants indicates that the BPI–76 parent carries two pairs of dominant alleles for short b.v.p., and Milfor–6(2) has the recessive alleles for long b.v.p. The F_2 distribution shows good agreement with the ratio of 12 (shorter than the short BPI-76 parent or similar to it):3 (medium b.v.p.):1 (long b.v.p. or similar to Milfor). Cumulative gene action and different gene dosage effect are also indicated in this cross.

In the cross of Norin 20 x BPI-76, both parents had short b.v.p. and they differed by only 7 days. The mean b.v.p. of the F_1 plants was 18 days which equalled the mid-parent value. Similarly, the mean of the segregating F_2 population fell at about midway between their parents. While the eight F_1 plants were uniform in maturity, the F_2 plants showed great variation, ranging continuously from 5 to 44 days in b.v.p. The F_2 population of 463 plants was distributed almost symmetrically or normally about its mean. The binomial distribution suggests that there is essentially no dominance effect and the number of effective allelic pairs involved in this cross is at least three.

The mean b.v.p. of Siam 29, Kaohsiung 68, and F_1 plants were 29, 68, and 27 days, respectively. The difference in b.v.p. between the two parents was 39 days. The F_1 data indicate a complete dominance of short b.v.p. The F_2 plants ranging from 15 to 120 days in b.v.p. were distributed in a multimodal distribution. The F_2 distribution suggests that Siam 29 carries two pairs of dominant alleles for short b.v.p. and Kaohsiung 68 carries another pair of dominant alleles in this cross. The three pairs of *Ef* alleles are cumulative in action.

Taichung 172 and CP 231 were essentially insensitive to photoperiod. They differed only by 7 days in b.v.p. The mean b.v.p. of T. 172, CP 231, and F_1 plants were 67, 60, and 58 days, respectively. The b.v.p. of 260 F_2 plants ranges from 37 to 94 days and indicates a two-gene binomial distribution of an additive nature (Fig. 8). The distribution shows a satisfactory agreement with the phenotypic ratio of 1:10:4:1 which originates from the binomial distribution of 1:4:6:4:1.

In the cross of Norin 20 x CP 231, the mean b.v.p. of the parents were 17 and 58 days, respectively. The b.v.p. of 525 F_2 plants were distributed symmetrically in a binomial manner about midway between their parents. The mean b.v.p. of F_2 plants was 41 days which was similar to the mid-parent mean of 38 days (Fig. 9). This indicates a lack of dominance effect in this cross.

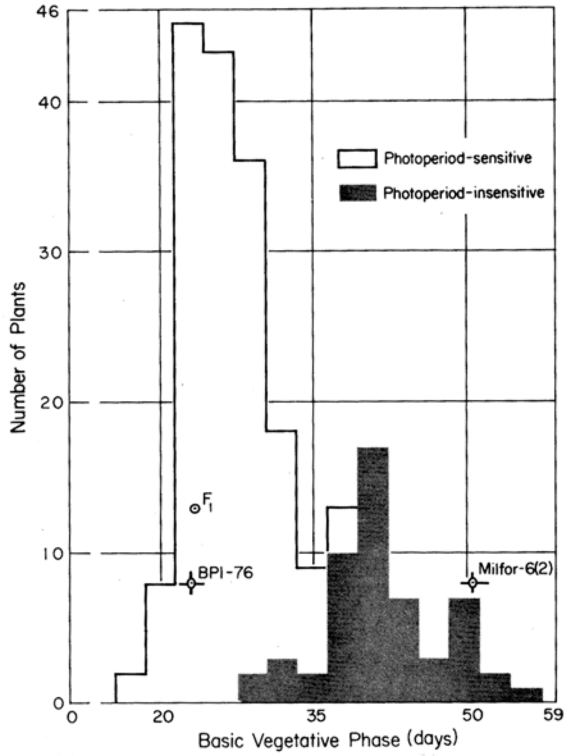

Fig. 7. Distribution and means of parents, F_1, and F_2 plants by the length of the basic vegetative phase (days)in the cross of BPI-76 x Milfor-6(2). Solid horizontal lines show the range of b.v.p. of parents and F_1 plants about the means (dotted circles). Sowing date: January 20, 1966. Tiller separating date: February 23, 1966.

Few of the F_2 plants equalled the parental values in b.v.p. The above distribution suggests that a four-locus additive model is involved, resulting in an F_2 segregation of 1:8:28:56:70:56:28:8:1. The F_2 data agree with the postulate that (1) there are at least four pairs of alleles controlling the difference in b.v.p.; (2) polygenic-additive action exists in the alleles resulting in a binomial distribution; and (3) the four *Ef* alleles are equal in effect with no dominance effect between the *Ef* and *ef* alleles. The variation in the F_2 population resulted from quantitative difference in the number of *Ef* and *ef* alleles present.

Two types of gene action concerning the b.v.p. genes are detected in the 1965-66 experiments. In the crosses of Norin 20 x BPI-76 and Norin 20 x CP 231, a polygenic system involving additive effect and a lack of dominance is indicated. In the other seven crosses, dominant genes of relatively discrete effect and cumulative action

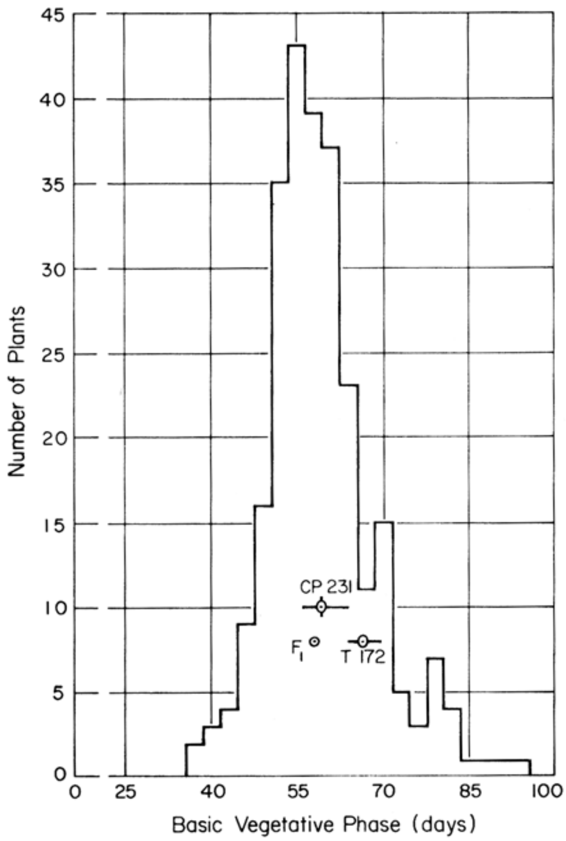

Fig. 8. Distribution and means of parents, F_1, and F_2 plants by the length of the basic vegetative phase (days) in the cross of CP 231 x Taichung 172. Solid horizontal lines show the range of b.v.p. of parents and F_1 plants about the means (dotted circles). Sowing date: August 20, 1965. Transplanting date: September 1, 1965.

control the short b.v.p.

Data obtained from the F_2 populations of photoperiod-sensitive x insensitive crosses indicate the higher potence of the sensitivity gene or genes *(Se)* over that of the b.v.p. genes *(Ef)*. Although the *Ef* genes segregated independently among themselves, an association between photoperiod sensitivity and extremely short b.v.p. is indicated in a number of F_2 plants.

Heading pattern of F_2 populations under field conditions. A duplicate F_2 population from the BPI-76 (sensitive) x Tainan 3 (insensitive) cross was grown in the field under a changing photoperiod. The natural photoperiod ranged from about 12 hours (sown on March 12) through the longest daylength of about 13 hours (June 22) to about 11 hours 55 minutes when a few late F_2 plants headed on October 4. The mean heading dates of BPI-76 and Tainan 3 were 178 and 85 days, respectively. The F_2 plants were distributed asymmetrically in the sowing-to-heading period with a positive skewness at the range from 69 to 202 days (Fig. 10). Based on the heading dates of the two parents, the F_2 distribution shows a satisfactory agreement with the ratio of 1 (early or photoperiod-insensitive) : 2 (intermediate or weakly sensitive) : 1 (late or strongly sensitive), although multiplicative gene action was indicated by the over-all variation in the F_2 population. The data suggest that under field conditions strong photoperiod sensitivity is incompletely dominant over low sensitivity, and photoperiod sensitivity is epistatic to the b.v.p. genes (compare Figs. 10 and 11).

A duplicate sample of F_2 plants from the cross of two essentially insensitive parents, Taichung 172 and CP 231, was grown in the field from September 27 to the following January. The natural photoperiod ranged from about 12 hours (September 27) to 11 hours (December 21). The number of days from seeding to the panicle initiation phase (p.i.p.) in a plant was estimated

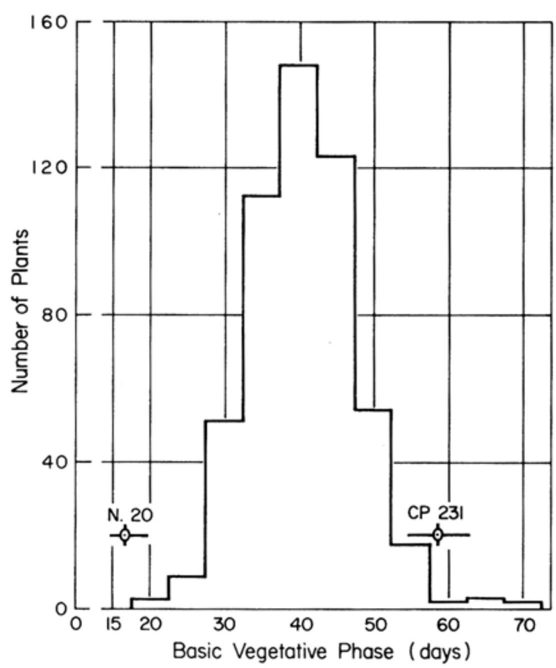

Fig. 9. Distribution and means of parents and F_2 plants by the length of the basic vegetative phase (days) in the cross of Norin 20 x CP 231. Solid horizontal lines show the range of b.v.p. of parents about the means (dotted circles). Sowing date: November 26, 1965. Transplanting date: December 10, 1965.

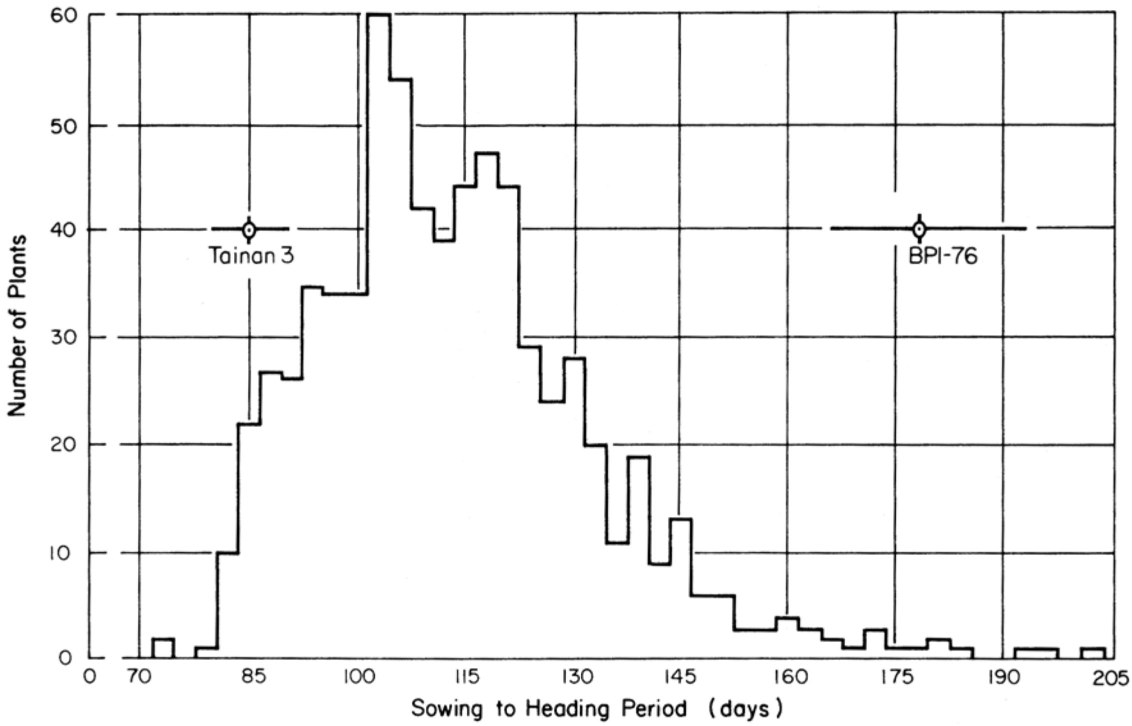

Fig. 10. Distribution and means of parents and F_2 plants by the sowing-to-heading period in the cross of BPI-76 x Tainan 3. Solid horizontal lines show the range of sowing-to-heading period of parents about the means (dotted circles). Sowing date: March 12, 1965. Transplanting date: April 1, 1965.

by subtracting 35 days from the date of panicle emergence. The b.v.p. of CP 231 under 10-hour photoperiod was 60 days (Fig. 8) and its p.i.p. in the field averaged 67 days (Fig. 12). This 7-day difference in b.v.p. and p.i.p. indicated that CP 231 was weakly photoperiod sensitive, whereas Taichung 172 was insensitive since it showed only a 2-day difference between b.v.p. and p.i.p. The relative position of the two parents with respect to b.v.p. and p.i.p. was different in the two experiments. The F_2 distribution of panicle initiation phase (p.i.p.) was also different from that of the b.v.p. under the 10-hour photoperiod treatment (compare Figs. 8 and 12). There were 363 F_2 plants in the field planting ranging from 45 to 56 days which were earlier than either parent. It suggests the cumulative effect of dominant genes for early heading dates in the field. The p.i.p. of 229 F_2 plants ranged from 57 to 73 days, similar to that of the parents. Thirty-six F_2 plants had longer p.i.p. than either parent. The above F_2 distribution suggests that the two parents each carries a pair of dominant alleles for short panicle initiation period. The segregation in p.i.p. may be interpreted on the basis of two independent genes which are cumulative in action, resulting in the F_2 ratio of 9 (short):6 (similar to the parents):1 (longer than the parents). The results of this cross show a detectable difference in the F_2 distribution and segregation ratio between the heading date under natural daylength and the b.v.p. under the 10-hour photoperiod. The data suggest that the complicating effect of other factors may be involved, such as an interaction of the optimum photoperiod and a changing photoperiod under field conditions.

Half-diallel cross of photoperiod-sensitive varieties. Four photoperiod-sensitive parents (BPI-76, Podiwi-A(8), Raminad Strain 3 and Siam 29) were intercrossed to produce a set of non-reciprocal hybrids. The parents and six F_1 populations were grown under six different photoperiods up to 200 days of culture. The response curves are shown in Fig. 13. Estimates of photoperiod sensitivity, the optimum photoperiod, and minimum heading duration were obtained by using Chandraratna's second polynomial formula. The optimum photoperiod of Raminad Strain 3 was between 9 and $9^1/_2$ hours; those of the other three parents were about 10 hours. Comparison of parent-progeny arrays indicated that a short optimum photoperiod was dominant to a long one.

All four parents belonged to the short b.v.p. group, ranging from 21 days in BPI-76 to 39 in Raminad Strain 3. Analysis of variance of the half-diallel cross indicates that (1) the parents differed in b.v.p. at the 1-percent level, largely due to additive variance, and (2) a highly significant dominance effect was present, but the parents also differed in the number and direction of dominant genes being carried. Scaling test also showed a difference in the dominance effect of parent-progeny arrays. Covariance analysis indicates that Raminad Strain 3 and BPI-76 carry mostly dominant alleles, whereas Siam 29 and Podiwi-A(8) have mostly recessives. The dominant genes present in Raminad Strain 3 were mostly positive in direction, i.e. short in b.v.p., whereas BPI-76 had largely negative dominants for very short b.v.p. Siam 29 and Podiwi-A(8) had a nearly equal number of recessive genes. Thus, the b.v.p. in this half-diallel set was controlled by both dominant and recessive genes. A shorter b.v.p. showed complete dominance to a short b.v.p. over all loci.

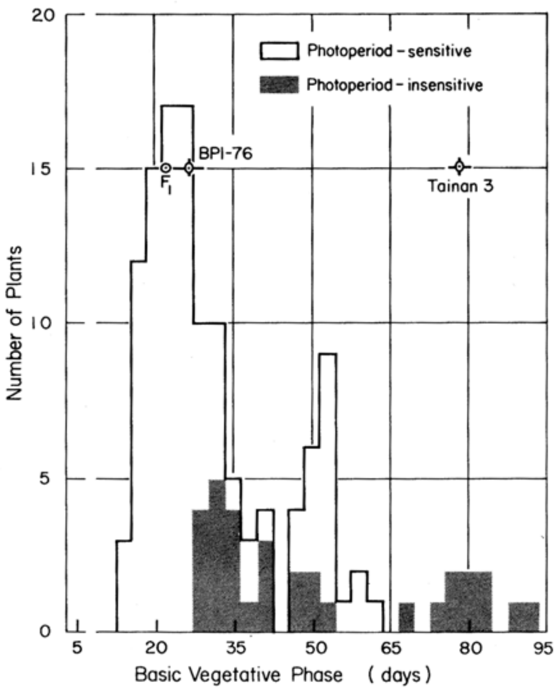

Fig. 11. Distribution and means of parents, F_1, and F_2 plants by the length of the basic vegetative phase (days) in the cross of BPI-76 x Tainan 3. Solid horizontal lines show the range of b.v.p. of parents and F_1 plants about the means (dotted circles). Sowing date: September 7, 1964. Tiller separating date: October 10, 1964.

Cytological study of F_2 sterility in indica-japonica hybrids

Cytological studies on the sterility of indica-japonica hybrids were followed into the F_2 generation. Five crosses of varying degrees of sterility were selected. Spikelet fertility of the F_2 plants used in this study ranged from 1.3 to 97.8 percent. The nine parents ranged from 79.1 to 98.8 percent in grain setting.

The F_2 populations generally showed a wider range of meiotic abnormalities both in type and frequency than the parents. For instance, pachytene pairing in the parents was largely normal except for "loose pairing" (3-7.4%) in Norin 17, Taichung (Native) 1, BPI-76 and CP 231. "Loose pairing" was observed in all five F_2 populations, ranging from 1.6 to 26.7 percent. Whether the high frequency of loose pairing (9.9 and 20%) found in T 1242 x PI 215936 and Norin 17 x BPI-76 was due to cryptic structural differentiation or to chiasma formation at the start of diplonema could not be readily ascertained.

At pachynema, inversion loops were observed in two highly sterile crosses: Siam 29 x Kaohsiung 68 (3.3-51.2%) and T 1242 x PI 215936 (1.1-7.3%). However, the frequency of bridges with accompanying fragments at anaphase I was very low: 1.5 to 1.7 percent in Siam 29 x Kaohsiung 68 and 3.8 to 4.8 percent in T 1242 x PI 215936. Bridges with fragments were also found in PI 215936 x CP 231 (1.2-2.3%) which did not exhibit any inversion loop at pachynema. None of the parents showed bridges with fragments.

Translocation configurations of the T-type (1.1-5.3%) were observed at pachynema in T 1242 x PI 215936. However, only one cell with a ring-of-four configuration was observed at diakinesis. None of the parents showed such a

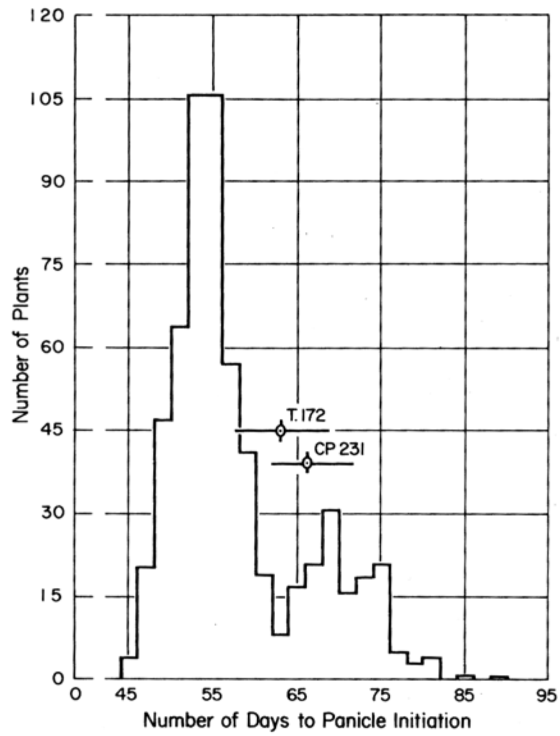

Fig. 12. Distribution and means of parents and F_2 plants by the number of days to panicle initiation period in the cross of CP 231 x Taichung 172. Solid horizontal lines show the range of p.i.p. of parent plants about the means (dotted circles). Sowing date: September 27, 1965. Transplanting date: October 15, 1965.

configuration.

One F_2 plant each in the Siam 29 x Kaohsiung 68 and T 1242 x PI 215936 crosses exhibited a low frequency (0.7-4.3%) of "interlocked bivalents", small duplication-deficiency loops, and bivalents of unequal lengths at pachynema (Fig. 14). Unequal bivalents could be interpreted as heterozygosity for terminal deletions. A single plant of Tainan 3 x Taichung (Native) 1 showed unequal bivalents at a frequency of 3.6 percent. Among the parents, only T 1242 showed "interlocked bivalents" at a frequency of 2.1 percent.

Univalents and/or quadrivalents were noted at diakinesis and metaphase I in seven parents. The frequency observed at diakinesis ranged from 0.7 percent in BPI-76 to 6.7 percent in Kaohsiung 68; metaphase readings varied from 0.3 percent in Kaohsiung 68 to 1 percent in Norin 17. An upper limit of two univalents was found in any of the parental PMC's. The number of univalents in the F_2 plants ranged from 2 to 8 per cell. The frequency at diakinesis ranged from 0.8 to 26 percent per plant; and 0.5 to 56 percent at metaphase. The highest frequency was found in T 1242 x PI 215936 at both stages. Some of the univalents were later seen as laggards at late anaphase I and telophase I. Sometimes they exhibited pre-division at anaphase I (Fig. 15). Unequal segregation (11 vs 13) of chromosomes at anaphase I was also noted. In other cases, the univalents failed to move toward the poles and they formed micronuclei instead.

Quadrivalents were observed at diakinesis and metaphase I in both parents and F_2 plants but at a higher frequency in the hybrids. Whereas only one quadrivalent per cell was observed in the parents, one cell in an F_2 plant of Siam 29 x

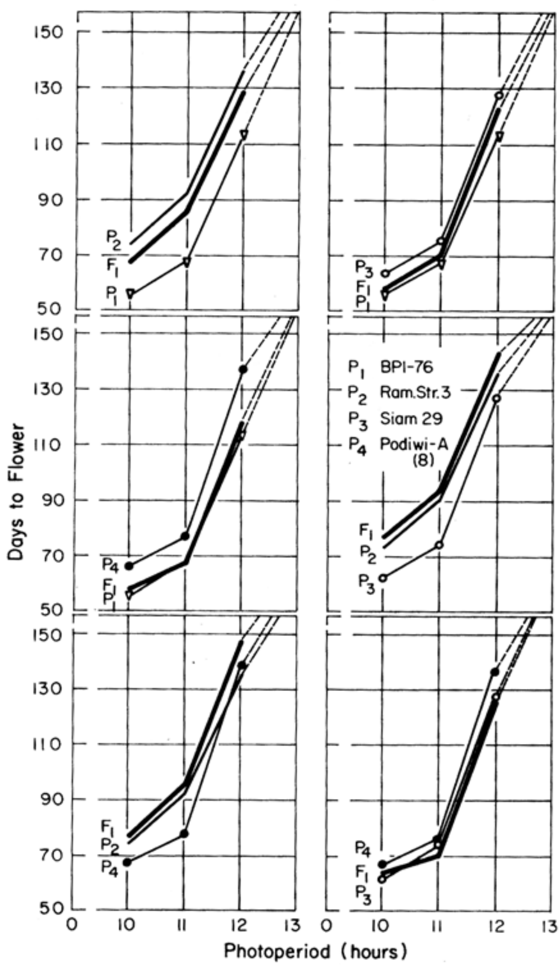

Fig. 13. Response curves of the parents and F_1 plants grown under different photoperiods. The dotted line indicates that no panicle was exserted at the end of the 200-day experiment.

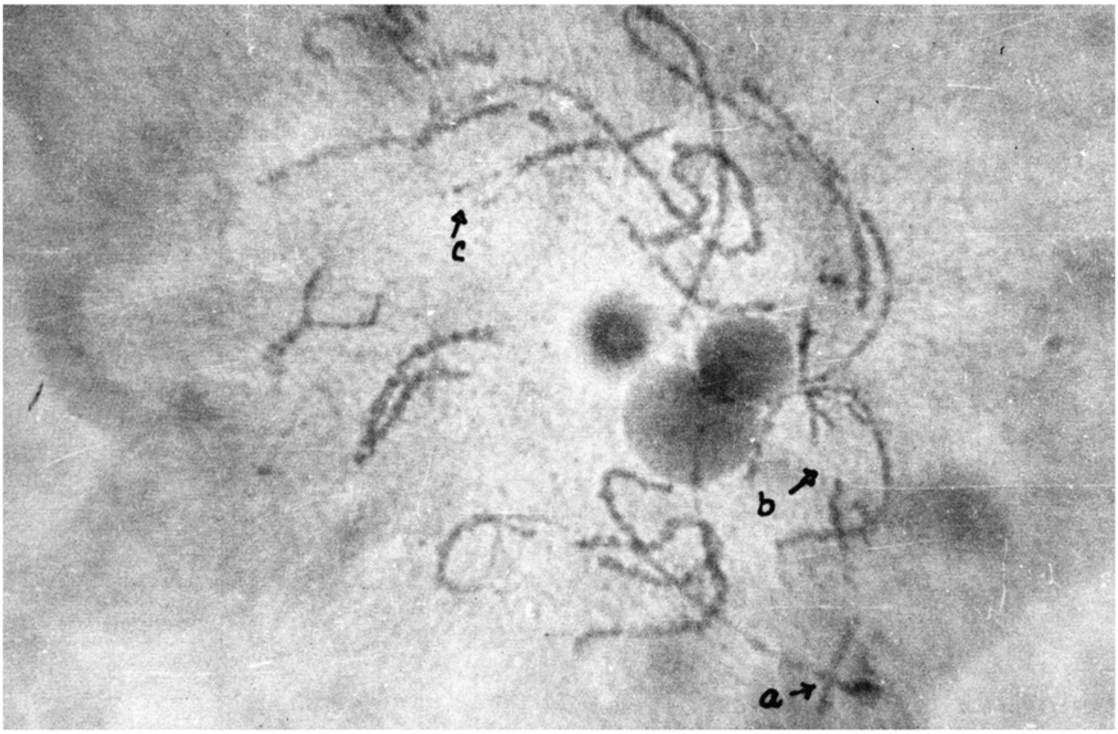

Fig. 14. Interlocked bivalents (a), duplication-deficiency loop (b), and unequal bivalent (c) at pachynema in an F_2 plant of the highly sterile cross, T 1242 x PI 215936.

Kaohsiung 68 had as many as three quadrivalents.

Three parents exhibited anaphase bridges without accompanying fragments at frequencies ranging from 1.0 to 4.5 percent. Anaphase and telophase bridges without fragments were observed in all hybrids except Tainan 3 x Taichung (Native) 1. The range of frequency for anaphase bridges was 1.1 to 13.1 percent, and 0.7 to 1 percent for telophase bridges. The bridges may be due to a delayed disjunction of homologues since they were also observed in the highly fertile parents.

Other abnormalities such as cells with 13 bivalents, extra fragments, and cells with 11 bivalents were also observed in the hybrids. One cell in the PI 215936 x CP 231 cross had 24 bivalents. Failure of cytokinesis were also observed in PI 215936 x CP 231 and T 1242 x PI 215936 F_2 populations.

The above findings indicate that hybrid sterility in the F_2 populations was associated with translocations, duplications and deletions, univalents and quadrivalents in some cases. In addition, there were other abnormalities, such as the formation of tetraploids and failure of cytokinesis. However, no clear-cut correlation was found between the extent of spikelet sterility and the frequency of any of the other abnormalities. These seem to indicate that sterility in the F_2 plants was caused by chromosomal differentiation as well as disharmonious recombinations due to genetic imbalance. The F_2 studies agreed with results obtained from related F_1 plants and also F_4 plants of other crosses.

Partial sterility in indica x japonica hybrids

A series of studies on the evaluation of sterility in indica x japonica hybrids, largely summarized in the 1965 Annual Report, was concluded with investigation of the association of F_2 and F_3 fertility in three partially sterile breeding populations. The results indicated a direct parent-progeny association of fertility among the first three plant generations, indicating that early selection for fertility is desirable and effective in

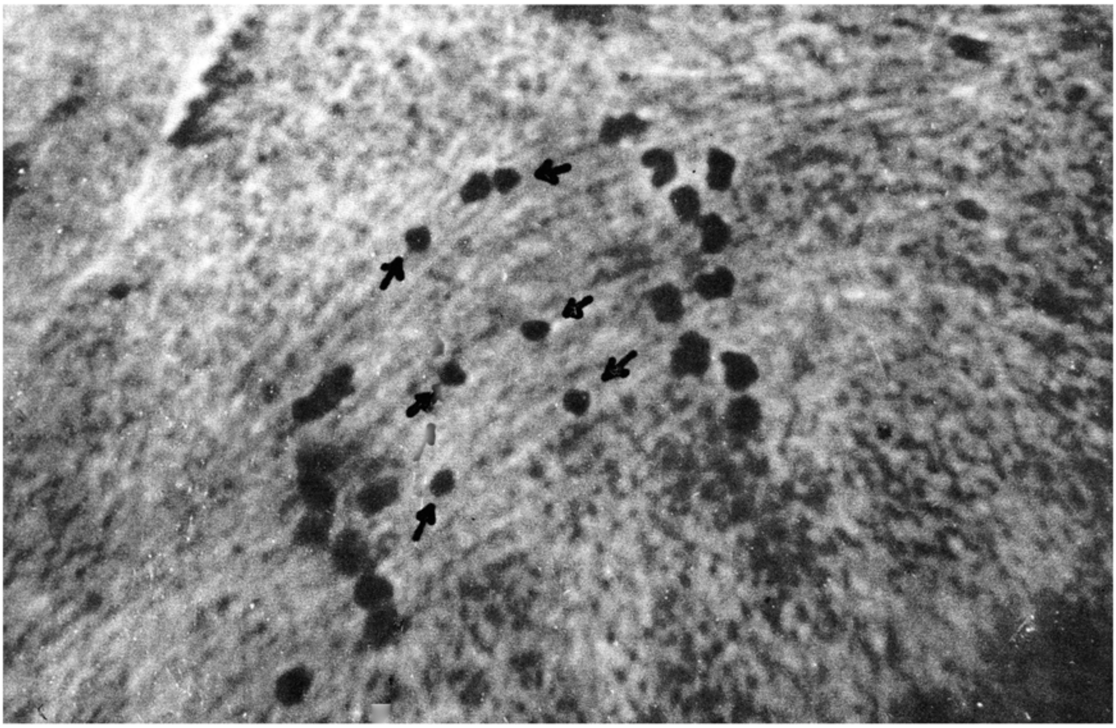

Fig. 15. Three univalents exhibiting pre-division at anaphase I in an F_2 plant of the highly sterile cross, T 1242 x PI 215936.

wide crosses. A correlation coefficient of 0.68** was calculated for mean fertility of 287 F_3 lines and F_2 parental plant fertility in three hybrids.

Studies on Lodging Resistance

Path analysis of plant characters related to varietal differences in lodging resistance

A correlation and path analysis of six component plant characters affecting the lodging resistance factor (cL_r) was completed for 10 varieties of different plant types. Pooled data from measurements made in the dry and wet seasons were used in the analysis.

The path diagram (Fig. 16) indicates that, among the six associated characters, plant height is the predominant component affecting the cL_r factor. The direct effect of height on cL_r in the negative direction ($P = -1.228$) produced the largest estimate of the six characters measured. Height was also negatively correlated with cL_r ($r = -.742$). Culm area at the BI_1 internode, and the sheath-wrapping score, gave the second and third largest estimates of direct effect on cL_r in the positive direction, respectively. The sheath-wrapping score also showed a positive correlation with cL_r ($r = .728$). However, a portion of the adverse effect of tallness was partly compensated by a positive correlation of height with culm area ($r = .874$). Height was negatively correlated with the sheath-wrapping score ($r = -.683$), which contributed positively to the cL_r estimates. Partial regression analysis shows that a combination of height, sheath wrapping and BI_2 internode length could account for about 66 percent of the total variation in the cL_r estimates among 10 varieties.

Inheritance of lodging resistance

The inheritance of lodging resistance, as measured by the cL_r estimates, was studied in two crosses. A tall, lodging-susceptible variety, MTU-15, was crossed with a short, stiff-culmed selection, Irradiated CP 231 dwarf x Rexoro, in one cross, and with the medium-tall, lodging-resistant BPI-76 in the other cross. Measure-

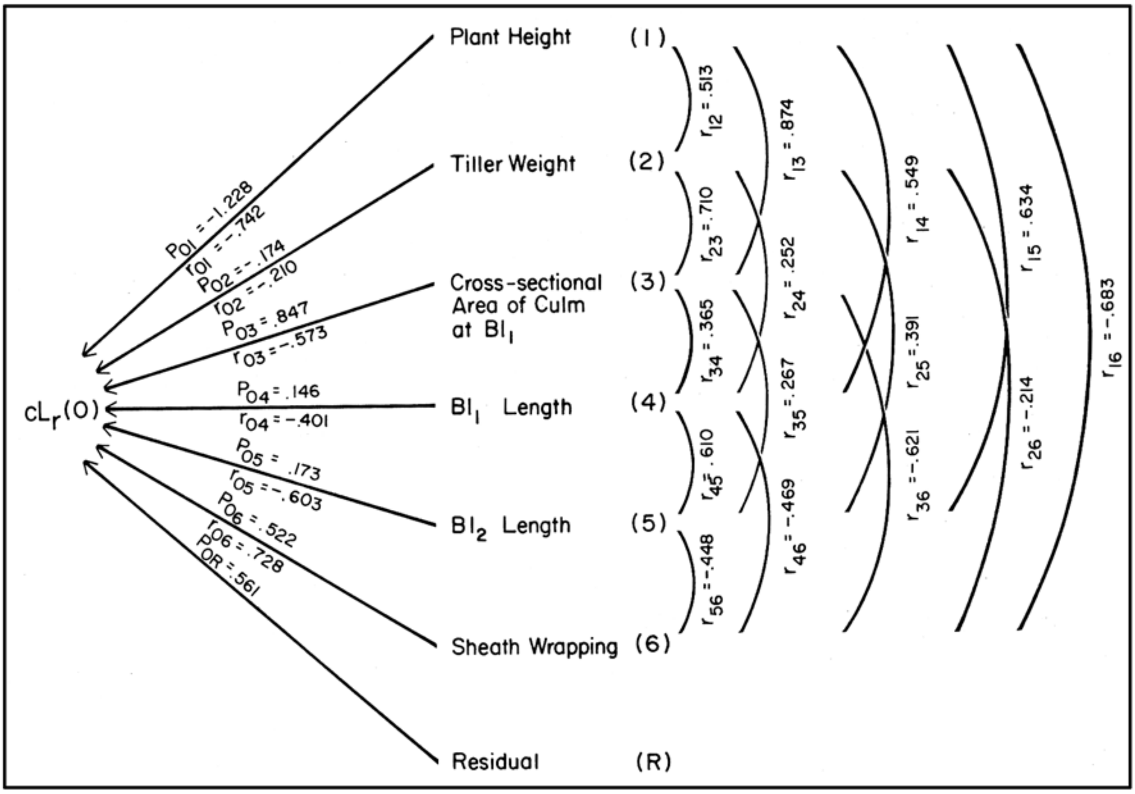

Fig. 16. Path diagram and association of 6 characters related to the lodging resistance factor, combined data of 1965 dry and wet seasons.

ments of parents, F_1, and F_2 plants included plant height, cL_r readings, and five other associated plant characters.

The Irrad. CP 231 dwarf x Rexoro selection averaged 87 cm in height and the MTU–15 parent measured 150 cm in the wet season. The F_1 plants were slightly taller than the MTU–15 plants. The F_2 population showed an essentially bimodal distribution and can be readily divided into a tall group of 637 plants and a short group of 239 plants. The above proportion shows a satisfactory fit to the 3:1 ratio, indicating that a single recessive and probably a few modifiers control the short stature of the Irrad. CP 231 selection. The distribution of cL_r estimates in the F_2 population was continuous with positive skewness (Fig. 17). The distribution of the parents, F_1, and F_2 plants suggests a multiple-locus system involving both additive and multiplicative genic action. Although the cL_r distribution is not an exact mirror image of the plant height distribution, the two traits show a highly significant negative correlation ($r = -.710$). The association indicates that the lodging resistance factor is significantly affected by plant height. Path analysis also shows that height gives the largest direct effect on cL_r in a negative direction and could account for about 50 percent of the variation in cL_r. Second to height, the sheath–wrapping score affected the cL_r in a positive direction. The length of the BI_2 internode gave a large negative contribution to cL_r. The cross–sectional culm area indicated a positive contribution to the cL_r. The combined values of height, sheath–wrapping and BI_2 length could account for 61 percent of the total cL_r variation. The importance of the three–character combination is understandable from the fact that the two parents differed significantly in height, BI_2 length, and sheath wrapping.

The F_2 population of MTU–15 x BPI–76 showed an essentially normal distribution of plant height. On the basis of the height of parents, F_1, and F_2 plants, at least four effective factor pairs appear to control the F_2 variation in height. The distribution of cL_r estimates was continuous in the F_2 with a positive skewness, indicating multiplicative–additive genic action. Both F_1 and F_2 values indicate that low cL_r is partially dominant to high cL_r in this cross. Plant height and cL_r were negatively correlated at the 1-percent significance level ($r = -.578$). Path analysis again indicates the predominantly adverse effect of tallness on cL_r. Next to height, tiller weight gave a positive contribution to cL_r. Partial correlation coefficients show that variation in height alone could control about 33 percent of the cL_r variation; height and culm area when combined would contribute 41 percent; height and sheath wrapping, 40 percent. The above predictions are related to the fact that the two parents differed appreciably in culm thickness and sheath wrapping but less in plant height.

The above findings provide the evidence that lodging resistance is a complex quantitative product which is subject to the influence and interaction of a number of component plant characters. The F_2 data on the cL_r readings suggest a genetic mechanism involving multiple genes of a multiplicative–additive nature. The component analysis of lodging resistance also refutes the prevalent belief that lodging resistance is a simply inherited recessive trait.

Among the six component characters which directly and indirectly affect the cL_r estimates, plant height is the predominant causative factor, followed by sheath wrapping, BI_2 internode length, and cross–sectional area of culm at BI_2. In different segregating populations, the relative contribution of various plant characters to cL_r is largely determined by the magnitude of the difference between the two parents in these characters. When the parents differ markedly in height, segregation for height contributes about 50 percent to the variation in cL_r. Initial selection for short plants would serve as an efficient criterion in identifying lodging–resistant progenies. In another case, where one parent is tall and the other medium–tall, but that the two parents differ appreciably in culm diameters, sheath wrapping, and basal internode length, selection based on height and culm dimensions or height and sheath wrapping would be quite effective.

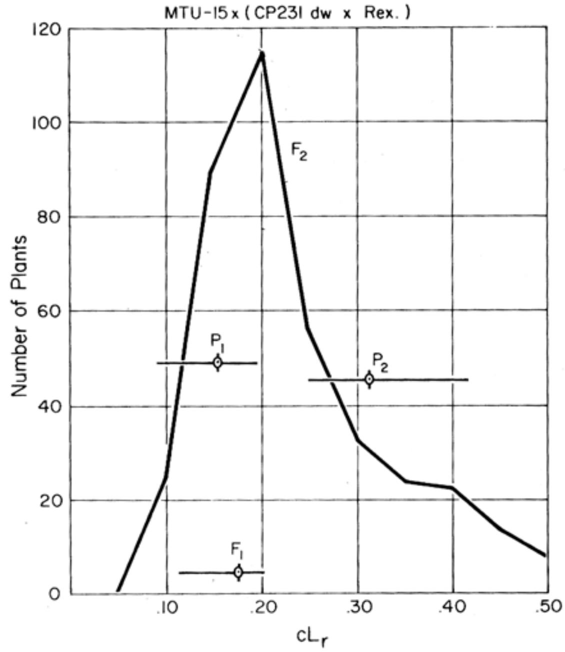

Fig. 17. Distributions and means of parents, F_1, and F_2 plants by cL_r classes in MTU-15 x (Irrad. CP 231 dw x Rex.). Solid horizontal lines show range of parents of F_1 about the means (dotted circles).

Comparison of lodging resistance between Taichung (Native) 1 and IR8

IR8 was selected from Peta x Dee–geo–woo–gen and is a half–sister of Taichung (Native) 1 which

Table 6. Culm and leaf sheath measurements of IR8 and Taichung (Native) 1 at 3 weeks after heading, 1966 wet season.

Variety	cL_r	Plant height (cm)	BI_1 internode d_1 (mm)	BI_1 internode d_2 (mm)	BI_1 internode area (sq mm)	BI_2 internode d_1 (mm)	BI_2 internode d_2 (mm)	BI_2 internode area (sq mm)	Persistent leaf sheaths
IR8	.267	104.9	7.2	5.0	2.2	5.9	4.8	1.1	4 – 5
T(N)1	.196	99.0	6.5	5.1	1.4	5.9	4.9	1.0	3 – 4

came from a cross involving Dee–geo–woo–gen. The two semi–dwarfs are similar in plant height: 105 cm for IR8 and 99 cm for Taichung (Native) 1. Both varieties have four to five elongated internodes (over 5 cm each) and a similar pattern of internode elongation. However, Taichung (Native) 1 has lodged more frequently in experimental plots than IR8, especially at high nitrogen levels. Comparative measurements made in the wet season showed that IR8 plants have higher cL_r values, mainly because of a larger cross–sectional culm area at BI_1 which results from a larger outer culm diameter (d_1) and a smaller inner diameter (d_2). IR8 also has very tight–wrapping leaf sheaths and a larger count of persistent leaf sheaths between heading and full maturity (Table 6). Taichung (Native) 1 plants have relatively thin BI_1 internodes just above the ground level. IR8 derived its thicker culms from Peta which has a large outer culm diameter but relatively thin culm. Peta is susceptible to lodging in the wet season mainly because of its tall plant stature (c. 165 cm), long basal internodes, thin culms, and poor sheath wrapping.

Plant Pathology

In searching for resistance to blast, bacterial blight, and tungro virus, many thousands of varieties and hybrid lines have been tested. Several hundred varieties have also been subjected to preliminary tests for sheath blight and stem rot resistance.

Since organisms causing disease usually include many races and strains differing in pathogenicity, studies have continued on physiological races of the blast fungus and on strains of tungro virus and the bacterium causing bacterial blight, in the hope that varieties possessing broad bases of resistance to the races and strains will be found. Many varieties with such a broad basis of resistance to blast have already been identified in the International Uniform Blast Nurseries and Cooperative Blast Nurseries in the Philippines.

Progress is being made in combining disease resistance with the short stature now recognized to be so essential to high-yielding varieties in the tropics, thus demonstrating once again the feasibility of transferring resistance from one variety to another.

Preliminary investigations have been made into the inheritance of resistance to bacterial blight and tungro virus. Other preliminary studies have been concerned with the nature of blast disease and the effects of tungro on plants.

1966 ANNUAL REPORT, The International Rice Research Institute *Mailing Address:* Manila Hotel, Manila, Philippines

Table 1. Results of cooperative blast nurseries in the Philippines—partial list of resistant varieties.

Variety	Northern Luzon	Central Luzon	Southern Luzon	Bicol	Western Visayas	Mindanao	
	Cagayan RCES	Maligaya RCES	IRRI	Pili	Iloilo RCES	CMU	Cotabato
Group I (From International Blast Nurseries)							
Te-tep	1-1	1-1-1	1-1(2)-1-1(3,4)	1-1	1-1	1-2	1
Tadukan	1-1-1	2(3)-1-1	1-1(2,3)-2,3-3	1-1	1-1	1-1	1(3)
Kanto 51	1(3)-1	1-1-1	1-1-1(4)-1	1-1	1-1	1-1	1
Kanto 51 (TW)	1(3)-1	2-1-1	1-1(2)-1-1	1-1	1-1	1-1	1(4)
Kanto 53	1(2,3)-1	-1-1	1-1-1-1	1-1	1(3)-1	1-1	-
PI 201902	2(3)-1(3)	1-2-1	1-1-1-3	1-1	1	2-1	1
Kam Bau Ngan	1-1	-1-1	1-1-1-1(3)	1-1	1-1	1-1	1
Dular	1,2-1	1-1-1	2-1-1/4-1(2)	1-1	1-1	1-1	1(2)
Kataktara DA 2	1(3)	1-1-1	1(2)-1-1-1	1-1	1-1	2-1	1
Taichung 181	1(2)	-1-1	1(3)-1-1-1(3)	1-2	1-1	1-1,2	1
Pah Leuad 29-8-11	2-1	2-1-1	1-1-1-1-2	1-1	1-1	2-2	1
CP 231 x HO 12	1(3)-1	-1-1	1-1-1-1(2)	1-1	1-1	2-1	1
Pah Leuad III	2-1	-1-1	1-1-1-1(2)	1-1	1-1	-2	1
Group II (IRRI tested varieties)							
Ram Tulasi	1-1	1	1-1-1-1-1-1-1	1-1	1	1-1	1(2)
Nhta-10	1-1	1	1-1-2-1-1-1-2	1-	-	1-	1(2)
Rei-shi-ko	1-1	1(3)	1-1-1-1-1-1-1	1-1	1	1(2)-1	1(2)
Charnock	1-1(2)	1	1-1-1-1-1-1-1	1-1	1	1-1	1(2)
Lantjang	1-1	1	1-1-1-1-1-1-1	1-1	1	1-1	1
Td 57	1-1	1	1-1-1-1-1-1-1	1-	1	1-1	1
Td 70	1-1	1	1-1-1-1-1-1-1	1-1	1	1-1	1
DNJ - 146	1-1	1	1-1-1-1-1-1-1	1-1	1	1-1	1
DNJ - 66	1-1	-	1-1-1-1-1-1-1	1-1	1	1-1	1

Scale: 1,2—highly resistant, 3—moderately resistant, 4—susceptible, 5-8—very susceptible; ( ) = in small percentage; - = separate tests.

Rice Blast

International uniform blast nurseries

Results received during 1964 and 1965 from 58 field tests in 39 cooperative nurseries in 19 countries, and, in addition, those from Japan where eight races were used for inoculation in greenhouse tests, have been assembled. A number of varieties were resistant at all test locations in each of the four major regions of Asia: (1) South Asia (India-Pakistan), (2) Continental Southeast Asia (Malaysia-Thailand-Vietnam), (3) Insular Southeast Asia (Indonesia-Philippines), and (4) Temperate Asia (Japan-Korea). Many japonica varieties, such as Norin 22, Taichung 65, Taichung 155, etc., showed complete resistance in South Asia but were very susceptible in Temperate Asia, whereas many indica varieties, H-4, M-302, Ram Tulasi (sel), C-46-15, etc., showed resistance to all races in Temperate Asia. Peta, Taichung (Native) 1, etc., were resistant in all tests in South Asia and Temperate Asia but were very susceptible in Southeast Asian regions. Other varieties, such as Tetep, Tadukan, Ram Tulasi (sel), Pah Leuad, Kataktara DA 2, etc., appear to have an even broader spectrum of resistance, being resistant at several of these regions. It seems that varieties with a broad basis of resistance against races of the blast fungus occurring in a country or region or neighboring regions may be identified. Further tests in different seasons and localities are required to insure that the varieties have been exposed to all prevailing races of the blast fungus.

Cooperative blast nurseries in the Philippines

Two sets of rice varieties—those tested at the International Uniform Blast Nurseries, consisting of about 250 varieties, and about 450 tested for blast resistance at the Institute—have been tested several times at seven cooperative stations located from the northern to the southern Philippines. About 75 varieties have been found resistant in all the test stations at all times. Table 1 shows a partial list of the resistant varieties and the reactions at different regions and times. These varieties may be used as sources of blast resistance, and also as additional defense lines against new races of the blast fungus.

Physiological races of *Piricularia oryzae*

An earlier study (Annual Report, 1964) identified 26 physiologic races based upon Philippine differential varieties. During 1965 and 1966, 21 additional races have been found. The number of races in the Philippines now is 47 as shown in Table 2.

According to the suggested international differential varieties, these races belong to 28 international race groups (Table 3).

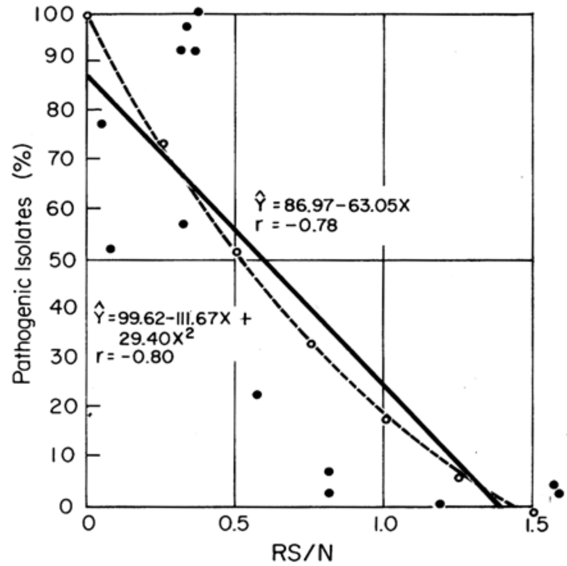

Fig. 1. Correlation between reducing sugar: total nitrogen ratio (RS: N) and percentage of pathogenic isolates.

Chemical constituents of leaves in relation to blast resistance

Chemical analysis of sugars and nitrogenous compounds in rice leaves from varieties resistant or susceptible to blast indicated that both have similar kinds of sugars, amino acids, and other nitrogenous compounds, although susceptible varieties have a relatively high soluble nitrogen content. At higher levels of soil nitrogen, however, the soluble nitrogen in resistant varieties also increases, and this factor probably does not account for susceptibility. It was noticed, however, that reducing sugar: total nitrogen ratio (RS: N) was correlated with resistance; a higher ratio indicates resistance. This was evidenced by: (1) a higher ratio in resistant varieties than in the susceptible ones, (2) a higher ratio in older

Table 2. Physiological races of *Piricularia oryzae* in the Philippines based on the Philippine differential varieties.

Variety	P-1	P-2	P-3	P-4	P-5	P-6	P-7	P-8	P-9	P-10	P-11	P-12	P-13	P-14	P-15	P-16	P-17	P-18	P-19	P-20	P-21	P-22	P-23	P-24	P-25	P-26	P-27	P-28	P-29	P-30	P-31	P-32	P-33	P-34	P-35	P-36	P-37	P-38	P-39	P-40	P-41	P-42	P-43	P-44	P-45	P-46	P-47
Kataktara DA 2	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	M	R	R	S	R	R	R	R	R	R	R	R	R	R
CI 5309	S	M	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	S	R	R	S	R	R	R	R	R	R	R	R	R	R
Chokoto	R	S	S	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	R	R	R	S	S	R	R	S	R	R	R	R	R	R	R	R	R	R
CO 25	R	R	S	S	S	S	S	R	R	R	R	M	R	R	R	R	R	R	R	R	R	R	R	M	R	R	R	S	R	R	R	R	R	S	R	R	R	R	R	R	S	R	R	R	R	R	R
Wagwag	R	R	R	R	R	R	R	S	S	S	S	S	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	S	S	R	R	S	S	R	S	R	R	R	S	S	R	R	R
Paikantao	R	M	S	R	S	S	S	R	R	S	S	S	S	S	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	R	S	R	R	S	R	R	S	R	S	R	R	S	R	R
Peta	R	R	R	S	R	S	S	S	R	R	R	S	R	R	S	S	S	S	S	R	R	R	R	R	R	R	S	S	R	S	R	R	R	S	S	S	R	S	R	R	R	R	R	R	S	R	S
Raminad Str. 3	R	R	R	R	S	S	R	S	S	R	S	S	R	S	R	S	S	R	R	S	S	S	R	R	R	R	R	S	S	S	R	S	M	R	R	R	M	R	R	R	R	R	R	R	R	S	R
Taichung T.C.W.C.	R	S	S	S	S	S	S	S	S	S	S	S	S	S	R	R	S	R	S	R	S	R	S	R	R	R	S	S	R	R	R	R	S	S	S	S	S	R	R	R	R	R	R	R	R	S	S
Lacrosse	R	S	S	S	S	S	S	S	S	S	S	S	S	S	R	R	S	S	S	R	S	S	S	S	R	R	S	S	R	S	S	S	S	S	R	S	S	R	R	S	R	R	R	S	R	R	S
CI 8970 (S)	S	S	S	R	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	R	S	R	S	S	S	S	S	S	S	S	S	S	S	R	R	S	S	S	S	S	S	S	R
KTH 17	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S
Total no. isolates	2	1	1	2	2	1	4	13	28	4	19	3	8	7	9	3	7	8	6	10	16	7	16	2	24	5	2	2	7	7	2	3	1	1	1	1	1	1	1	1	2	1	1	1	1	1	1

Table 3. Physiological race groups of *Piricularia oryzae* in the Philippines based on the international set of differential varieties.

Variety	IA-1	IA-2	IA-3	IA-4	IA-5	IA-6	IA-7	IA-8	IA-9	IA-10	IA-11	IB-1	IB-2	IB-3	IB-4	IC-1	IC-2	IC-3	IC-4	ID-1	ID-2	ID-3	ID-4	ID-5	ID-6	IG-1	IG-2	IH
Raminad Str. 3	S	S	S	S	S	S	S	S	S	S	S	R	R	R	R	R	R	M	M	R	R	R	R	R	R	R	R	R
Zenith	S	R	R	R	S	R	R	S	S	R	R	S	S	S	S	R	R	R	R	R	R	R	R	R	R	R	R	R
NP 125	R	R	R	S	R	R	R	S	S	R	R	R	R	S	R	S	S	S	S	R	R	R	R	R	R	R	R	R
Usen	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	S	R	R	R
Dular	R	R	R	R	R	R	S	R	S	S	R	R	R	S	R	S	R	S	R	R	R	R	R	R	R	R	R	R
Kanto 51	R	R	R	R	R	R	R	S	R	R	S	R	R	S	R	R	R	S	S	S	R	R	R	R	S	R	R	R
CI 8970 (S)	S	S	S	S	S	R	S	S	S	S	S	S	S	S	R	S	S	S	S	S	S	S	R	R	S	S	S	R
Caloro	S	S	R	S	R	S	S	S	S	R	S	S	R	S	R	S	S	S	S	S	S	R	S	R	R	R	S	S
Total	35	73	14	2	7	3	1	1	1	1	1	12	5	3	1	1	1	1	1	3	36	27	4	5	1	5	1	1

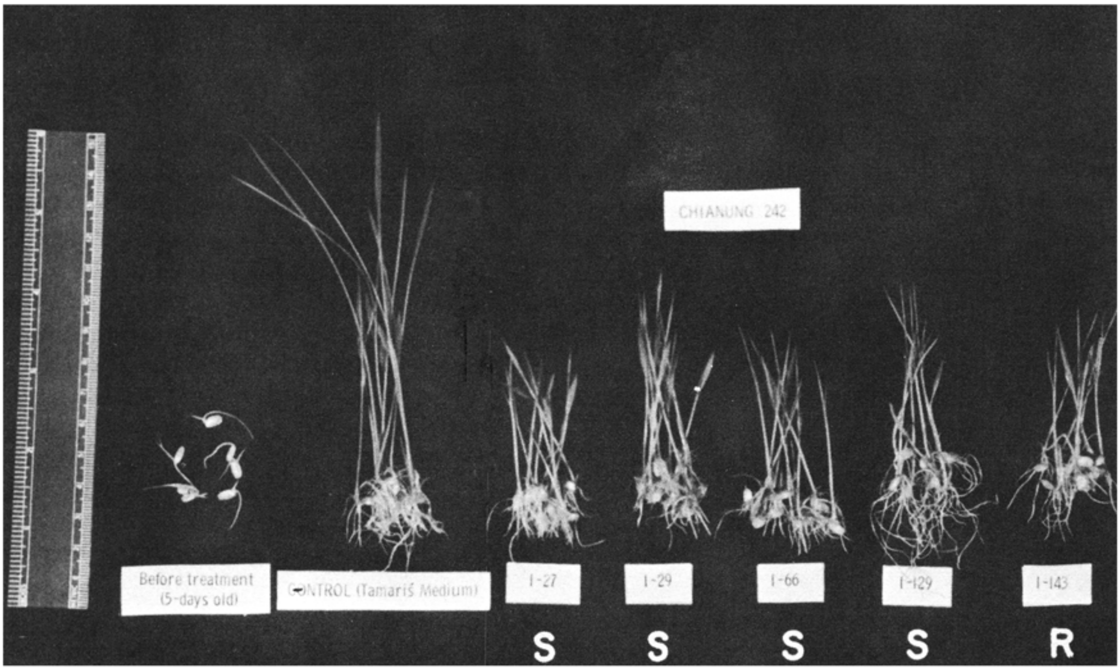

Fig. 2. Effect of toxins produced by *Piricularia oryzae* on rice seedlings. S = the variety susceptible to the isolate, R = resistant to the isolate when inoculated with spore-suspension.

leaves of seedlings, which are more resistant, than in the younger leaves, and (3) more lesions on detached leaves in which the ratio dropped quickly after detachment.

Fifteen other varieties, on which 100 (7 varieties) to 242 (8 varieties) isolates of blast fungus had been inoculated, were analyzed, and the RS:N ratio of the leaves of 1-month-old seedlings determined. There appears to be a good correlation between high ratio and resistance; a higher percentage of isolates can infect the leaves of varieties with a low RS:N ratio (Table 4, Fig. 1). This, however, did not explain why a few isolates (races) infected varieties with high RS:N ratio.

Toxins produced by ***Piricularia oryzae***

A culture of *P. oryzae* is known to produce toxins in the filtrate. Preliminary experiments were conducted to determine whether the toxins were specific, i.e. affected susceptible but not resistant varieties, as in the case of victorin.

Five isolates, I-27, I-29, I-66, I-129, and I-143 were grown on Tamari's medium and filtrates were obtained. The effect of the filtrates were tested by observing the growth of germinated seeds and the production of lesions on detached leaves of seven rice varieties for which the reactions (resistant or susceptible) of the five isolates were previously known.

The results show that the filtrate retarded the growth of seedlings in general, indicating the presence of toxins (Fig. 2). There were also indications, in some isolates in relation to some varieties, that resistant varieties were less affected than susceptible ones. In detached leaf tests, large lesions were usually produced on susceptible varieties, and minute brown specks were found on resistant varieties (Fig. 3). However, this was not true for other varieties and isolates. Moreover, similar lesions were also produced by the filtrate of a stem rot fungus.

It seems, therefore, that the toxins produced by *P. oryzae* in the filtrate are non-specific or semi-specific. Possibly the filtrates contain a mixture of both non-specific and specific toxins.

Variability of ***Piricularia oryzae*** **in culture**

Many physiological races of the blast fungus are known to occur in nature. Some preliminary experiments were conducted to determine the variability in culture of pathogenicity.

Table 4. Reducing sugar and total nitrogen ratio of rice leaves in relation to the percentage of pathogenic isolate.

Variety	RS : N ratio	No. pathogenic isolate/ no. inoculated	Pathogenic isolate (%)
Caloro	0.06	187/242	77.3
Cutsugulcul	0.08	52/100	52.0
Taichung (N) 1	0.32	92/100	92.0
FK 165	0.33	57/100	57.0
Usen	0.35	235/242	97.1
CI 8970 (P)	0.36	92/100	92.0
Khao Tah Haeng 17	0.37	242/242	100.0
Paikantao	0.57	54/242	22.3
Norin 22	0.72	39/100	39.0
CO 25	0.81	15/242	6.2
Chokoto	0.81	7/242	2.9
Kaohsiung 64	1.03	16/100	16.0
Taichung 181	1.19	0/100	0.0
Kanto 51	1.57	10/242	4.1
PI 180061 (Dular)	1.58	7/242	2.9

One experiment was to study variability within single isolates. A number of monosporial cultures, obtained from isolates I-42, I-120, I-129, and I-143 after several spore-mass transfers, were tested on the 12 Philippine differential varieties.

Among the 22 single-spore cultures of I-42 inoculated to the 12 varieties, 13 lost their pathogenicity to one, two, or three of four varieties (Chokoto, PI 231128, CI 8985 and CI 8970 straw). Some appeared to be pathogenic only to one or two varieties and then caused few lesions. A few gained pathogenicity on variety Peta. The isolate I-42 seems to be very unstable. Its variability was also noticed in culture appearances.

Re-isolation of lesions produced by I-42 on Khao-Tah-Haeng 17, and inoculation of the differential varieties, showed that the new isolate regained its original pathogenicity to these varieties. The test was repeated three times.

Of the 37 single-spore cultures of I-120 inoculated, most of the reactions remained similar to the original. Increased pathogenicity was observed on variety CO-25, and loss of pathogenicity on CI 5309, for many of the single-spore cultures. Some gained pathogenicity on the variety Pai-kan-tao. The isolate I-120 was also noticed to be more stable in cultural characters.

For isolate I-129, 10 single conidial cultures were inoculated. Many of them lost pathogenicity to varieties PI 231128 and PI 231129, and some to variety CI 8985.

Twenty-two inoculations with single-spore cultures from I-143 showed increased pathogenicity on variety Peta but lost pathogenicity on variety Chokoto, CO-25, and Pai-kan-tao which were originally susceptible. Three of the cultures lost pathogenicity on variety CI 8985 straw.

Another experiment used a mixed culture of the four isolates mentioned above. Spore-mass transfers were made for three generations, and then single spores were isolated and grown and inoculated to the 12 varieties. It was intended to determine if any genetic changes might have occurred during the mixed culturing. Forty single-spore isolates from the mixed culture were inoculated. Seventeen isolates showed reactions close to I-120, 2 to I-42 and 1 to I-129. The reactions of the other isolates did not resemble any of the reactions of the four original isolates. Many of the isolates lost pathogenicity to several varieties, and a few lost it almost completely, being pathogenic not even to Khao-Tah-Haeng 17 which is known to be susceptible to all races in the Philippines.

Results from the above experiments, seem to show that the conidia from a single pure culture did vary in pathogenicity even though the pure culture was started with a single spore. Some isolates change more frequently than others. In general, there were more isolates that lost pathogenicity to varieties that were originally susceptible than those that gained pathogenicity. Whether mixed culture initiated any new races can not be determined because variability was found even within single isolates. Further experiments are required to confirm that original pathogenicity may be regained by re-isolation from infected varieties.

Stem Rot and Sheath Blight

Stem rot resistance

From the earlier experiments, the cut stem wound inoculation method has been adopted for testing varietal resistance to stem rot. A tentative scale of 10 units has been suggested. The description of the scale and results from testing 509 varieties are shown in Table 5. The results indicate that most of the varieties possess considerable resistance of the isolates of *Helminthosporium sigmoideum* and *H. sigmoideum* var. *irregulare* used. A number of varieties showed more resistance to one fungus than to the other. However, since the organisms often occur together in the same field, resistance was evaluated for the one to which the variety was more susceptible.

Prevalence of stem rot in the Philippines

Two hundred and ninety-nine samples (stubbles, about 20 hills each) were collected from 24 townships on the islands of Luzon and Mindanao, Philippines. Examinations revealed that all the samples contained the sclerotia of the stem rot organism; 190 samples contained both of the causative organisms; 52 contained *H. sigmoideum* alone; and 57 contained *H. sigmoideum* var. *irregulare* alone. About 84 percent of the hills, and 67 percent of the tillers, were infected. In other words, two out of every three tillers in the stubbles had been infected by the organisms

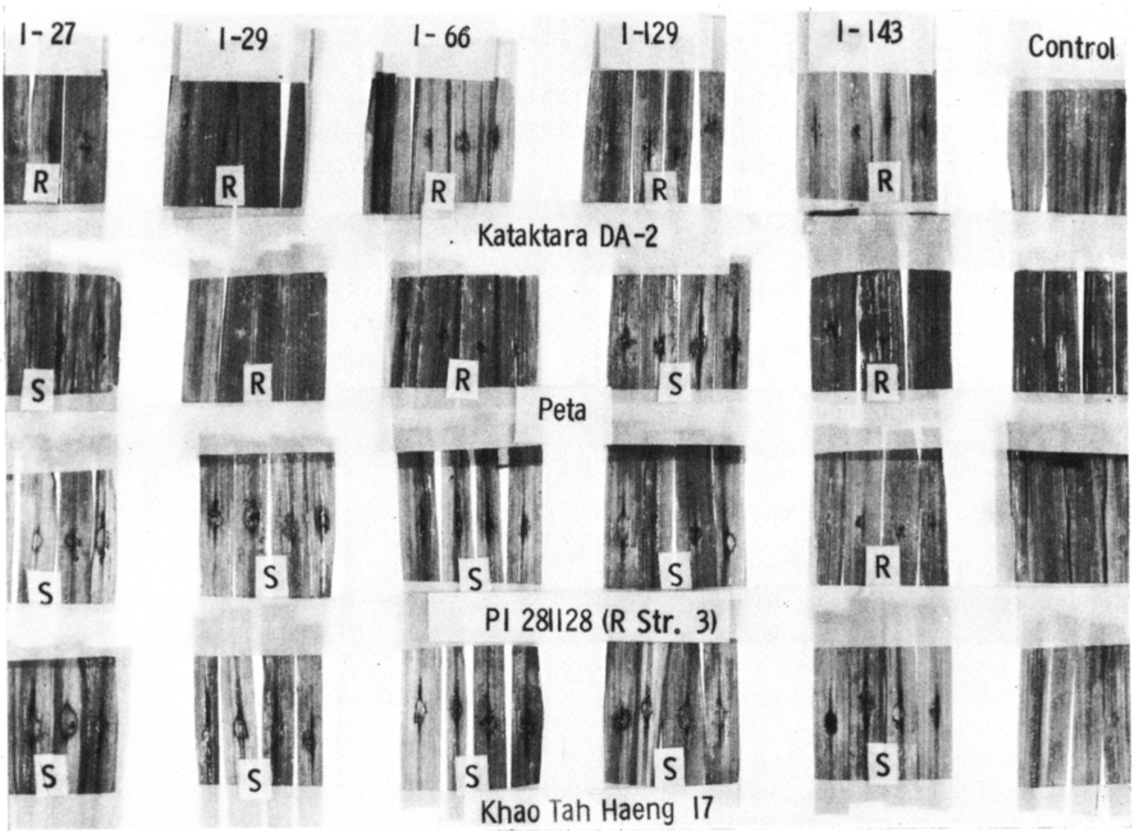

Fig. 3. Lesions produced by toxins of *Piricularia oryzae* on detached leaves of varieties resistant (R) or susceptible (S) to various isolates.

Table 5. Scales for stem rot resistance (testing by cut stem (without sheath) wound inoculation method).

Scale	Length of lesion and description	1966 test results
0	No lesion developed	0
1	Lesion less than 10 mm long	76
2	Lesion less than 20 mm long	239
3	Lesion less than 30 mm long	94
4	Lesion less than 40 mm long	47
5	Lesion less than 50 mm long	16
6	Lesion less than 60 mm long	21
7	Lesion less than 70 mm long	7
8	Lesion less than 80 mm long	4
9	Lesion more than 80 mm long and stems become flabby	5
	Total	509

of stem rot. This further confirms the observation that stem rot fungi are very widely present in rice fields. Most of these fungi, however, are believed to be facultative saprophytes which do not cause great damage before the rice is harvested.

Varietal resistance to sheath blight

Several preliminary trials have been conducted to find an efficient method for testing resistance to sheath blight *(Corticium sasakii)*. A seedling inoculation technique seems to work well. A short row of seedlings (1 g seed, 5 cm) were grown in a wooden flat (an 18 x 18 inches flat will accommodate 18 varieties), and a week-old culture of the fungus on rice straw (3-5 inches) was placed on the soil surface near the short rows of seedlings when they were at the 4- to 5-leaf stage. The entire flat was subjected to high humidity in a chamber provided with a continuous mist blower. After 4 days, when the mycelium had grown up the seedling, the flats were taken out for 1 day to allow the infected leaf sheath to dry. Readings were made the next day by counting the number of leaves (leaf sheaths) killed (Fig. 4). A disease index was then calculated. The results of a preliminary test of 504 varieties, and a tentative scale for recording degree of reaction, are shown in Table 6.

Very few varieties so far tested are resistant to the disease. The general reaction of varieties to the disease is very similar to that of thousands of varieties tested in the field during 1962 to 1965 at the Kaoshiung District Agricultural Improvement Station in Taiwan.

Since the fungus may have various pathogenic strains, information on the variability of the fungus has to be gained before further testing of varietal resistance.

Bacterial Blight

Varietal resistance

Three thousand six hundred and seventy-six (3,676) varieties from the world collection (from Acc. No. 1-4500) were preliminarily screened for bacterial blight resistance by inoculating isolate B15, one of the most virulent strains, on the flag leaves. Over 200 varieties have shown resistant reactions (disease scale 0-3). The summarized

Table 6. Scales for sheath blight resistance tested at seedling stage.

Scale	Disease index*	1966 test results
0	Below 10	0
1	10-20	0
2	20-30	1
3	30-40	2
4	40-50	14
5	50-60	46
6	60-70	97
7	70-80	166
8	80-90	113
9	90-100	65
	Total	504

* Disease index $= \frac{\text{No. leaf sheaths killed}}{\text{Total no. leaf sheaths}} \times 100.$

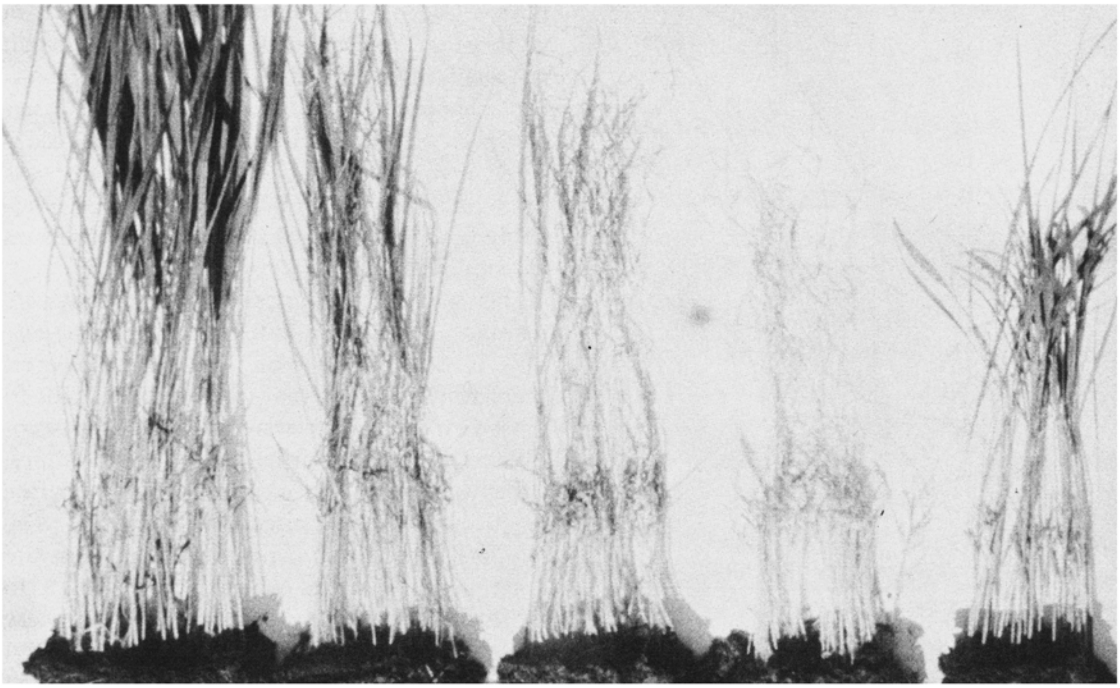

Fig. 4. Varietal resistance to sheath blight tested at seedling stage.

results are presented in Table 7. These varieties, together with another 110 varieties found to be resistant in 1965 screening tests, using isolate B72, were further tested at seedling stage, using isolates N3, B2, B6, B15 and B17. The following varieties have so far been shown to be highly resistant.

Tainan 1	268b/Pr/22/1/2
Zenith	DF-1
PI 209938	DNJ-152
Tainan 8	DD-100
Tainan 9	UCP-28
Tainan-iku 446	DM-36
Takao 21	DV-29
Early prolific	M. Sungsong
Yen Tu	Nagkayat
PI 162319	Bolillo
Baifufugoya	Lang Chung Yi Lung Ju
BJI	Taino 38
TKM-6	Sollana

Table 7. Results of screening World Collection Varieties (Acc. no. 1-4500) for resistance to bacterial blight (isolate B15 on flag leaves).

Disease scale	Variety number	Percentage
0	67	1.82
1	63	1.71
2	33	0.90
3	100	2.72
4	155	4.22
5	230	6.26
6	788	21.43
7	1029	28.00
8	1137	30.93
9	74	2.01
Total	3676	100

Pathogenicity patterns of strains of *Xanthomonas oryzae*

Over 100 isolates of *X. oryzae* have been obtained from various parts of the Philippines. They differ in virulence to rice varieties. In testing varietal resistance, virulent strains have to be used to identify varieties with a broad basis of resistance. Also the pathogenicity patterns or behavior of the strains have to be understood in order to provide proper information for selecting resistant varieties. For studying these patterns, 50 isolates of the more virulent group were inoculated to 24 rice varieties of resistant, intermediate and susceptible groups at seedling stage.

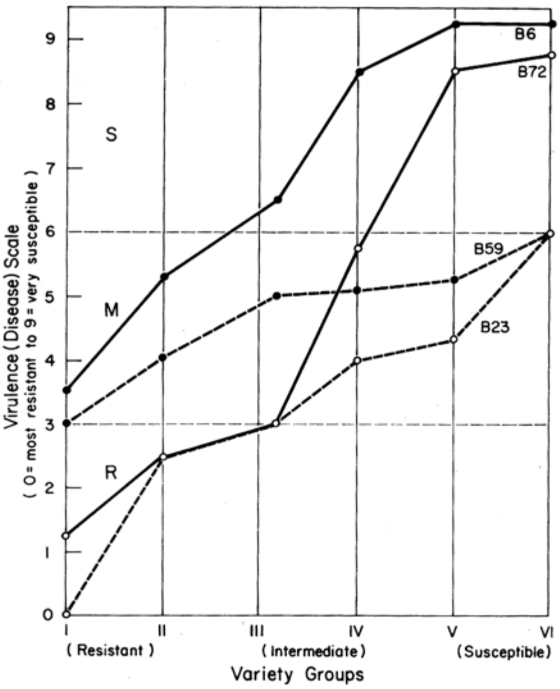

Fig. 5. Pathogenicity patterns of strains of *Xanthomonas oryzae*.

The results show that isolates B2, B6, B13, B15, B17, and B38 are the most virulent strains. These strains will be used to further test varieties selected from preliminary screening. It was also noticed that testing virulence on single varieties does not present a complete picture of the virulence of strains. A strain showing a moderate reaction on one variety may show a susceptible reaction on others.

The general patterns of pathogenicity of the 50 bacterial strains studied are presented in Fig. 5. Pattern 1, represented by isolate B6, is very virulent, causing moderate reaction on resistant varieties, susceptible reaction on intermediately resistant varieties, and completely killing seedlings of the susceptible varieties. Pattern 2, represented by isolate B23, is least virulent among the strains tested. (Even less virulent strains were revealed in other experiments.) These strains caused immune reaction on resistant varieties, resistant reaction on the intermediate group, and even on susceptible varieties caused only intermediate reaction. Pattern 3, illustrated by isolate B72, is slightly less virulent than Pattern 1 but exhibits a wider range of reaction between resistant and susceptible varieties. Pattern 4, represented by isolate B59, in contrast to Pattern 3, exhibits a relatively small range of reactions between resistant and susceptible varieties, all being more or less intermediate. Another pattern that may be recognized is that of strains causing a more or less moderate reaction on both resistant and intermediate varieties, but very severe symptoms on susceptible ones.

There were no instances of varieties that were resistant to virulent isolates being highly susceptible to other isolates or *vice versa*. However, there were varieties that, although resistant to most virulent strains, were nevertheless susceptible to some other virulent ones. Furthermore, a few virulent strains produced only a moderate reaction on some susceptible varieties. The strains Kc and Kd sometimes caused a moderate reaction on varieties which were resistant to most virulent strains. Variety BPI-76 was very susceptible to most of the virulent strains but only moderately so to a few other virulent strains. If only such reactions as these were considered, one could assume the existence of races similar to those occurring in the blast fungus. Such an assumption, however, would not represent the general pattern of pathogenicity of the bacterial strains.

Inheritance of resistance to bacterial blight

Two resistant and three susceptible varieties were crossed in various combinations to obtain some general information on the inheritance of resistance to bacterial blight. Two strains, B15 (very virulent) and B72 (virulent) were used. The results are shown in Table 8. The data generally indicate that resistance to the disease is a recessive character.

Inoculation technique

Lesion expansion and available nitrogen. The size of lesion on leaves has been used as a criterion to indicate varietal resistance. Experiments were conducted to determine the rate of lesion expansion in relation to levels of nitrogen available to the plants. One experiment consisted of growing 6 varieties: 2 resistant, 2 intermediate, and 2 susceptible, at two levels of nitrogen: 6 g of ammonium sulfate to a pot containing 10 kg of dry soil, and without added nitrogen. Leaves of

Table 8. Reaction* of F_1 plants of different crosses to two isolates of *Xanthomonas oryzae*.

Parent or cross	Isolate B15		Isolate B72	
	Seedling leaves	Flag leaves	Seedling leaves	Flag leaves
Taichung (N) 1 (S)	8	7	3.5	6
IR8 (S)	6	7	4	4
BPI-76 (NS) (S)	8	8	3.5	6
Zenith (R)	2	1	1	0
Hsinchu 56 (R)	3	1	1	0
Taichung (N) 1 x Zenith	–	6	4.5	3
Zenith x Taichung (N) 1	–	7	3.5	1
Hsinchu 56 x Taichung (N) 1	–	7	3.5	2.5
IR8 x Zenith	4.2	2	3	1
IR8 x Hsinchu 56	6	6	3	2.6
Hsinchu 56 x IR8	6	6	3	1
BPI-76 x Zenith	–	6	3.3	1
Zenith x BPI-76	–	6	3	1
BPI-76 x Hsinchu 56	–	7	3	1.5
Zenith x Hsinchu 56	–	1	0	1
BPI-76 (NS) x Taichung (N) 1	–	–	4	6

* Based upon disease scale 0, 1-9; 0 = resistant; 9 = most susceptible.

Table 9. Effect of nitrogen levels on the development of bacterial leaf blight lesions.

Variety	Size of lesion (cm)					
	0 g $(NH_4)_2SO_4$/10 kg soil			60 g $(NH_4)_2SO_4$/10 kg soil		
	Replication					
	I	II	III	I	II	III
Hsinchu 56 (R)	1.69	2.02	0.58	5.36	1.90	2.25
Zenith (R)	2.20	2.45	1.21	0.56	0.86	4.26
Ta-poo-cho-2 (M)	4.54	6.52	5.44	7.32	7.85	8.95
Ctg 1526 (M)	8.49	5.84	16.31	12.99	5.80	11.60
BPI-76 (S)	11.74	19.00	11.97	15.05	15.62	9.68
JC-70 (S)	22.32	23.68	23.25	15.82	21.01	19.63

young plants were inoculated and lesions were measured 30 days later. The results are shown in Table 9. Analysis of the data indicate that there was no significant difference between the two nitrogen treatments nor between replications, but a highly significant one among varieties.

In another experiment, two varieties, Malo-mone (susceptible) and Mayang Sagumpal (resistant) were grown in nutrient solutions with different levels of nitrogen, 5, 10, 20, 40, 80, 120, 160 ppm. The leaves were inoculated at 5-leaf stage and lesions were measured. On Mayang Sagumpal, small lesions developed, being 1.6 to 1.8 cm at 5 and 10 ppm N, and 1.8 to 2.3 cm at 20 to 160 ppm N after 14 days. On Malo-mone, the lesion size was 5.8 cm at both 5 and 10 ppm N, and 6.3 to 6.6 cm at 20 to 160 ppm N after 14 days. However, there were no "kresek" symptoms at 5 and 10 ppm N while in all other treatments symptoms developed after 30 days. There was no significant difference among plants grown in 20

Table 10. Percentage of plants showing "kresek" symptoms by various inoculation methods.

Inoculation method	Variety	Plants showing "kresek" symptoms (%)			
		4	12	15	30
Root cutting	Hsinchu 56 (R)	0	0	0	0
	Ctg 1524 (M)	1	2	2	2*
	JC-70 (S)	9	33	56	95†
Leaf cutting	Hsinchu 56	0	0	0	0
	Ctg 1524	8	8	10	10
	JC-70	5	5	9	20‡
Spraying	Hsinchu 56	0	0	0	0
	Ctg 1524	0	0	0	0
	JC-70	0	0	0	12‡
Control	Hsinchu 56	0	0	0	0
	Ctg 1524	0	0	0	0
	JC-70	0	0	0	0

* 25% of the remaining plants show pale yellow symptoms.
† All of the remaining plants show pale yellow symptoms.
‡ 40% of the remaining plants show pale yellow symptoms.

to 160 ppm solutions.

It is generally true in the field that disease is more severe when the soil contains more nitrogen. The severity is perhaps due to factors associated with high nitrogen. As far as individual lesions are concerned, higher nitrogen in the soil does not seem to affect the size of lesions. In other words, the size of lesion is a useful criterion for evaluating varietal resistance, even though there may be some difference in soil nitrogen from one experiment to another.

Methods of inoculation. Methods of inoculation for bacterial blight, other than needle inoculation, have been tried. They include: (a) cutting the root of seedlings, dipping for 2 to 3 minutes in bacterial suspension, and then transplanting in pots, (b) cutting the upper portion of leaves and dipping in bacterial suspension, and (c) spraying bacterial suspension on ordinary seedlings. Three varieties, representing resistant, intermediate, and susceptible, and 100 seedlings for each test were used. The results are shown in Table 10.

The root cutting method induced "kresek" symptoms most quickly. This is probably the most common route of infection in the field. Leaf cutting also induced "kresek", but spraying was the slowest method. Even the root cutting method, in which it still took 30 days for symptoms to develop in all the inoculated plants, is no faster than the needle inoculation method.

Virus Diseases

Varietal resistance to tungro disease

Testing for tungro resistance. By using the mass screening technique and the classification for tungro resistance developed in 1965, testing for tungro resistance was further intensified. Since the capacity of testing is limited by the facilities and space, the testing procedure has been modified to suit the major purpose and increase efficiency. For instance, screening rice varieties is primarily aimed at searching for the source of tungro resistance rather than obtaining a high degree of accuracy respecting the percentage of infected seedlings after inoculation. Consequently the duplicate for each variety used in the previous procedure seems unnecessary. With the same testing capacity, reducing the duplicates would increase the number of varieties being screened, and resistant varieties identified by preliminary screening may be confirmed by further testing.

The objective of testing IR lines for tungro resistance is not to search for a tungro resistance source, however, but to identify possible commercial varieties with a degree of resistance. Susceptibility to virus infection generally decreases with increasing plant age at inoculation.

A variety resistant to tungro after 20 days of age — when seedlings are commonly transplanted —could be regarded as having adequate resistance, since infection in the seedbed may be prevented with insecticides. Consequently IR lines were inoculated at 20 days after sowing instead of at 11 to 13 days as in the previous method.

On the other hand, to compare the susceptibility of a group of varieties or a number of selections to tungro disease by the mass screening method, the number of replicates can be increased to obtain more precise figures and allow for adequate statistical analysis.

Resistant varieties. In addition to the resistant varieties listed in the 1965 annual report, a further 697 varieties were tested in preliminary screening tests, and, of these, the following recorded less than 30 percent infected seedlings:

59-334 (B-11 x Mas)
221/BC IV/1/45/10
221/BC IV/1/178/11
Adday (sel.)
Adday local (sel.)
Dee-geo-mean-don
Podiwi A 8
Rajamandal Baran
Ram Tulasi
Tilakkachray

Sixteen varieties were selected for intensive testing. The results from 8 replications, summarized in Table 11, indicate that: (1) Pankhari 203 is most resistant to tungro disease since not a single seedling out of about 460 inoculated developed tungro symptoms; (2) IR8 is less susceptible than Taichung (Native) 1 since the difference between the percentages of infected seedlings is statistically significant, although both of them are arbitrarily classified in the susceptible group.

Fig. 6. Resistance to tungro of F_1 plants (center) from a cross between Pankhari 203 (R, right) and Taichung (Native) 1 (S, left).

Since percentages of infected seedlings of IR8 varied among samples, 11 selections of this variety supplied by the Varietal Improvement Department were tested at 10, 20, and 30 days after sowing. Six replications were used for each test. The results indicated that the susceptibility of selections to tungro disease was not identical. Selection No. 14 provided the highest percentage

Table 11. Susceptibility of 16 rice varieties to the tungro disease determined by mass screening technique.

Variety	Infected seedlings (%)	LSD 5%/1%	Degree of severity
Taichung (Native) 1	97.5		3
BPI-76, sensitive	88.5		2
IR8-288-3	84.4		2-3
TKM-6	63.7	6.8/9.5	1
T.P. x Rexoro-S.B.	30.8		1-2
Sigadis	25.0		1
H-4	20.2		1
Tjeremas	19.4		1
Latisail (Bandong)	18.8		1
221b/212/2/2/2/1	16.3		1
Peta	15.5		1
Latisail (T. Aman)	15.3		0-1
221b/236/2/3/2/1	11.9		1
Badshabhog T412	8.6		1
Andi from N. Pokhara	8.4	7.4/9.9	1
Pankhari 203	0		–

of infected seedlings, and selection No. 68 the lowest.

Resistance of IR lines. A total of 1,860 selections of 53 IR lines has been tested for resistance to the tungro disease by the mass screening method with inoculation at 20 days after sowing. One hundred and fifty-five (155) selections from 18 lines were classified in the resistant group, while the rest were either intermediate or susceptible to the disease (Table 12). In most cases, the resistant selections are progenies of resistant varieties such as Peta, Sigadis, etc.

Materials for genetical studies. Of 732 entries tested for genetical study, 1.1, 10.1, and 88.8 percent were resistant, intermediate, and susceptible respectively to the tungro disease.

Inheritance of tungro resistance

Many crosses have been made to seek information on the inheritance of tungro resistance. Difficulties have been encountered in identifying healthy and diseased plants in the hybrid population, because both the percentage of seedling infection and the tolerance or "recovery" in later growth have to be considered. Sometimes tungro-like leaf discolorations on the seedlings do not necessarily indicate diseased plants, and the percentage of infected seedlings varies somewhat from test to test. Furthermore, some crosses have a very high percentage of sterility in both the F_1 and F_2 generations.

Three crosses, however, seem quite meaningful: (1) Pankhari 203 (R) x Taichung (Native) 1 (S). From this cross of highly resistant with highly susceptible, 22 F_1 seedlings showed a complete resistant reaction (Fig. 6). Of about 520 F_2 plants inoculated, the healthy and diseased plants seemed to segregate in a ratio of 9:7. Both F_1 and F_2 have high percentage sterility in seed setting. (2) 221C/53/1/3/1 (R) x Taichung (Native) 1 (S), (3) 221C/BC III/Bn/62/2 (R) x Taichung (Native) 1 (S). Both resistant parents of the two crosses usually show 5 to 15 percent infected seedlings; unlike Pankhari 203 they are not highly resistant. F_1 seedlings of these two crosses included both resistant and susceptible ones. F_2 plants segregated 9:7 among 300 to 400 tested.

From these three crosses and others which are at the F_1 generation only, it seems that resistance

Table 12. Reaction to tungro disease of IR lines tested by mass screening method.

Line	No. selections showing infection (%)		
	0-30	31-60	61-100
IR 95, Peta/2 x Taichung (N) 1	36	54	50
IR 126, Bluebelle x Sigadis	11	23	102
IR 127, (CP 231 x SLO 17) x Sigadis	18	47	113
IR 140, (CP 231 x SLO 17) x Mas	2	24	58
IR 142, B581A6-545 x Mas	2	5	22
IR 262, Peta/3 x Taichung (N) 1	11	36	54
IR 272, (CP 231 x SLO 17)/2 x Sigadis	9	16	128
IR 276, (B581A6-545)/2 x Peta	2	10	139
IR 283, Peta/2 x Dawn	3	0	1
IR 297, (CP 231 x SLO 17)/2 x Mas	3	17	67
IR 298, BPI-76 x [(CP 231 x SLO 17) x Peta]	2	15	63
IR 300, Peta/2 x (CP 231 x SLO 17)	1	2	6
IR 407, Peta/3 x Dawn	29	37	5
IR 408, Peta/3 x Belle Patna	16	18	12
IR 414, (B572A3-47-15 x Sigadis) x (CP 231 x SLO 17)	4	12	23
IR 419 (B572A3-47-15 x Mas) x (CP 231 x SLO 17)	1	4	2
IR 447 Peta/4 x Belle Patna	3	6	1
IR 525 (B505A1-28/2 x Sigadis) x (BPI-76 x Dgwg)	2	2	5
Other 35 lines		45	481
Total	155	373	1332

Table 13. Transmission results for "S" and "M" strains when 140 isolates from different localities were tested.

Source (province)	No. leaf samples or isolates tested	No. isolates infected with: "S"	No. isolates infected with: "M"
Batangas	7	5	0
Bukidnon	5	0	0
Bulacan	11	11	0
Cagayan	9	9	0
Camarines Sur	12	2	10
Cotabato	8	5	0
Davao	10	8	0
Iloilo	14	2	12
Laguna	12	12	0
Leyte	7	6	0
Nueva Ecija	10	10	0
Pampanga	12	12	0
Pangasinan	9	8	0
Sorsogon	8	1	6
Zamboanga	6	5	0
Total	140	96	28

to tungro virus is more or less a dominant character. The resistant individuals can be selected in F_2 and later generations.

Strains of tungro virus

In early transmission experiments with rice tungro virus, a characteristic interveinal yellow stripe, apart from stunting and mottling, was observed on rice varieties Acheh, FK-135, and Pacita following infection from certain virus sources. However, on other varieties, such as IR8, Milfor-6(2), Palawan, Taichung (Native) 1, and Tainan 3, virus from the same source produced normal stunting and mottling symptoms. On other occasions different virus sources produced identical normal symptoms on both groups of varieties. There appeared to be two strains of tungro virus which could be separated only by inoculation on FK-135, Acheh, and Pacita.

In repeated tests, it was found that the stunting-striping and stunting-mottling symptoms were consistent after several consecutive transmissions through differential varieties, such as FK-135, and non-differential varieties, such as Taichung (Native) 1. When the striping or the mottling strain was inoculated on FK-135, the respective symptoms were produced repeatedly. When Taichung (Native) 1 was used, the symptoms were not distinguishable but the appropriate symptoms were recovered on FK-135. The stunting-striping type was designated "S" strain, and the stunting-mottling type as the "M" strain of tungro virus.

Preliminary experiments indicated that the two strains were cross-protective. The leaves of FK-135 plants already showing symptoms of "M" strain, when inoculated with "S" strain remained mottled with no visible stripes. Likewise, FK-135 plants already infected with "S" strain showed no change in symptom pattern when inoculated with "M" strain. However, when cross inoculations of "M" and "S" strains were made with a 1-day interval, the symptoms were in accordance with whichever strain was used last.

In other tests with 56 varieties, there was no significant difference in varietal reaction between the two strains. Preliminary results also showed no difference in incubation periods in the vector or in the plant between "S" and "M" strains.

A survey of 43 rice areas in 15 provinces of the Philippines was made to determine the distribution of the two strains. The results are shown in Table 13. The "S" strain appeared to be present in all areas of infection, but the "M" strain has so far been found only in Camarines Sur, Iloilo, and Sorsogon. Of the 140 isolates tested, 96 were infected with "S" strain and 28 with "M" strain; no transmission was obtained of the remaining isolates.

Distribution of tungro virus in the rice plant

The distribution of the tungro virus in a diseased plant was determined by testing the infectivity of insects after they had been confined on various plant parts for acquisition feeding. The results revealed that the virus was not localized in certain leaves; insects were able to acquire the virus from young leaves without symptoms, mottled, yellowing, and partially dried leaves, and leaf sheaths. However, the lowest percentage of infective insects were from partially dried leaves, indicating either a low virus concentration in such leaves or that the insects were incapable of acquiring the virus from them.

Seed transmission studies. The transmission of tungro disease through the seed was studied by

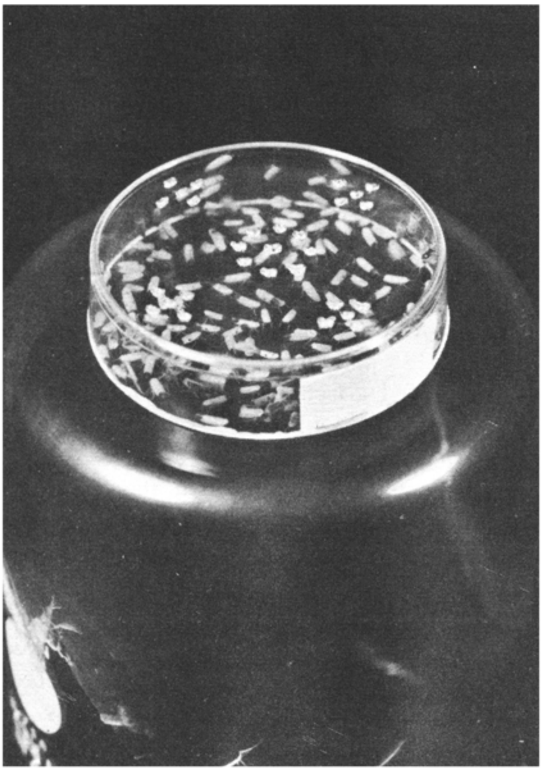

Fig. 7. A device for feeding a solution of *Nephotettix impicticeps* through membrane.

observing seedlings grown from seeds harvested from diseased plants of Taichung (Native) 1 and IR9-60. A total of 5,655 seeds were tested but none of the 3,442 seedlings developed symptoms. Of the tested seeds, 56.9 percent were discolored. The percentage germination was 72.0 and 52.4 for non-discolored and discolored seeds, respectively.

Bioassay of tungro virus

An attempt has been made to develop a bioassay technique for the tungro virus. Several hundred seedlings were inoculated by various methods with different preparations of sap from diseased leaves. None gave a positive result and subsequent work was therefore focused on "virulification" of insects with the sap of diseased leaves. For leafhopper-borne viruses, there are only two known methods for "virulifying" insects: injection and feeding. The results obtained in 1965 from studies on virus-vector interaction indicated that the tungro virus does not persist in the vector. In other words, the tungro virus probably does not multiply in the vector; it is not known if it circulates. For these reasons, and because a negative result was obtained from injecting the insects with the sap of diseased leaves with a capillary glass needle, work has been concentrated on the feeding technique.

The feeding method developed takes into consideration the available quantity of sap from diseased leaves, provides maximum space for insects, and is designed for simplicity of manipulation. The method consists of placing the sap of diseased leaves on the outside of the base of a beaker covered by a piece of stretched parafilm. On the membrane, a plastic cover was placed in which a few openings were made for ventilation and entrance of insects from an aspirator (Fig. 7). Unfortunately, rice seedlings inoculated by insects that had fed on the sap of diseased leaves through the membrane did not develop symptoms. The negative results may have been caused by ineffective feeding by the insects or be connected with the stability or concentration of the virus in the sap. The following evidence suggests that the failure of transmission was not caused by an inability of the insects to feed through the membrane: (1) a number of minute pores were apparent on the membrane after the insects had been confined on it; (2) penetration of insect stylets through the membrane has been observed under the stereoscopic microscope; (3) the life span of insects on the membrane with a solution underneath was definitely greater than those on a membrane without a supply of solution; (4) if the solution contained insecticides or a toxic substance, the insects were killed; and (5) the uptake of solution by insects through the membrane was proven by radioactive tracing technique. Consequently, successful bioassay of the tungro virus depends upon perfecting a technique for extracting the virus from diseased plants and stabilizing or concentrating it.

Effect of tungro virus on rice plants

Tungro inoculation at different ages. Crop losses from tungro virus are determined by the incidence and intensity of the disease. Other things being equal, susceptibility to virus infection often decreases with increasing age of the plant

Table 14. Percentage of IR9-60 plants showing symptoms of tungro disease after inoculation at different ages with various numbers of viruliferous adults of *Nephotettix impicticeps.*

Plant age at inoculation (days)	No. insects/plant					Average
	1	2	5	10	15	
15	78	89	100	100	100	93
30	67	92	100	96	100	91
45	39	50	72	89	89	68
60	25	46	54	58	54	47
90	0	0	0	0	0	0
Average	42	55	65	69	69	60

at the time of infection. The results (Table 14) from a test of 540 plants of IR9-60 indicated that the percentage of plants showing symptoms decreased with increasing age of plants at inoculation. Plants inoculated when 90 days old did not show any symptoms before harvest 20 days after inoculation. This does not necessarily indicate that these plants were not infected; the time between inoculation and harvesting was probably not long enough for them to develop characteristic symptoms, because, when ratooned, some of them showed typical symptoms on new growth.

The growth of the rice plant, as expressed by plant height, was consistently retarded by infection with the tungro virus. However, the degree of retardation not only varied among varieties but was also influenced by the age of the plant at the time of infection. The retardation of growth of Taichung (Native) 1 and IR9-60 due to the tungro virus was greater than that of BPI-76, IR8, or Peta. Plant height reduction of IR8 was 36, 30, 14, 3 and 2 percent for inoculations made at 15, 30, 45, 60 and 75 days old, indicating that the reduction decreased with increasing age of the plant at the time of inoculation. This is also generally true for other tested varieties, namely BPI-76, IR9-60, Peta, and Taichung (Native) 1.

Infected plants took a long period to mature because of delayed flowering, and the earlier the

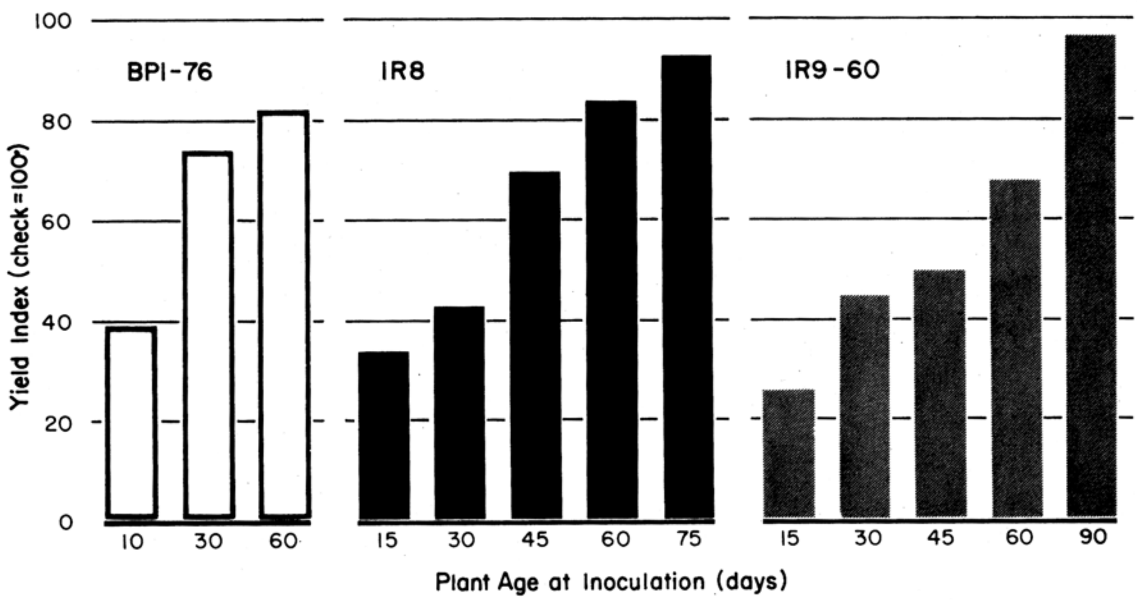

Fig. 8. Relative yield of rice plants infected with the tungro virus at various plant ages.

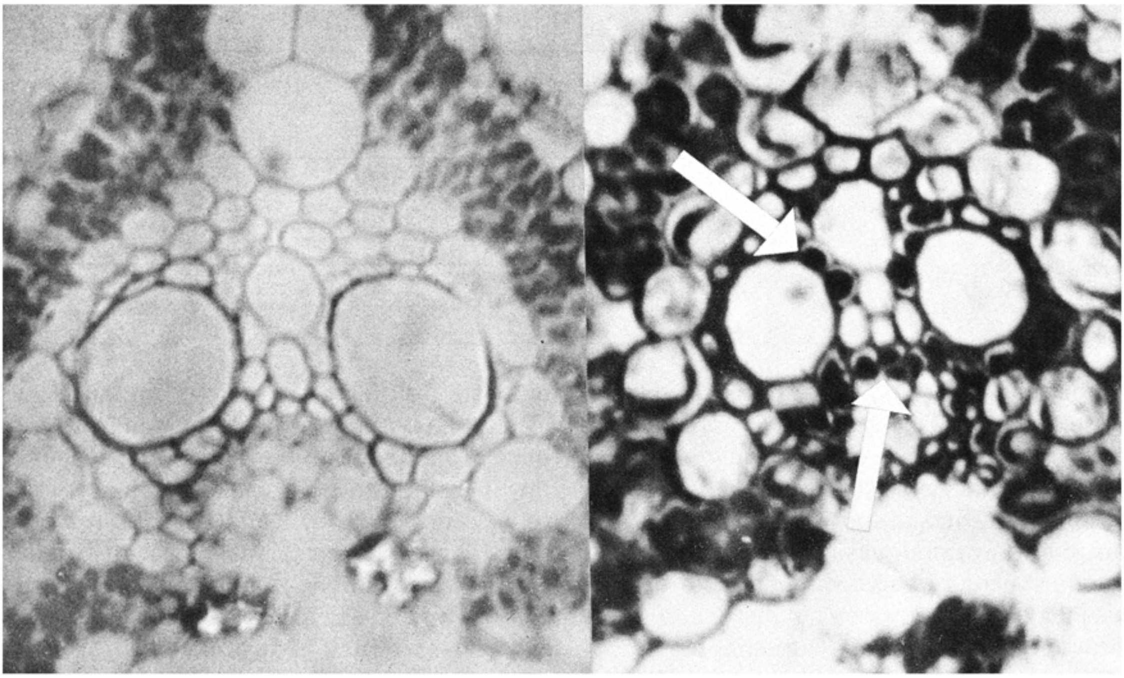

Fig. 9. Cross section of healthy (left) and tungro virus-infected (right) leaves showing the inclusions (indicated by arrows) in vascular bundle of parenchyma cells of the diseased one.

infection the greater the effect. But the period between flowering and maturity was almost the same for both infected and control plants.

Infected plants had fewer spikelets and higher percentage of empty grains and, therefore, fewer filled grains than the healthy control plants. The grain weight produced by infected plants was less than that of healthy plants, but the low yield was mainly a reflection of fewer grains being produced. The yield reduction varied among varieties and according to the age of plant at which infection took place. The reduction decreased gradually with increasing age at inoculation. For example, the yield reduction of IR8 inoculated at 15, 30, 45, 60 and 75 days after sowing was 68, 57, 30, 16 and 7 percent, respectively (Fig. 8).

Grain quality data did not reveal any consistent or marked effect of the tungro virus on grain quality such as percentage of milled rice, protein content, amylose content, and gelatinization temperature.

Inclusions associated with tungro disease. Inclusions can often be found in cells of plants infected by a virus and may be valuable for characterization and identification of the disease. Sections of both healthy and tungro virus-infected leaves were prepared from materials embedded in paraffin after fixing in alcohol-iodine-formalin solution. The Giemsa solution was used for staining the sections. Microscopic examination revealed that there were stained, somewhat round, inclusion bodies in some vascular bundle parenchyma cells of the diseased leaves but not in those of healthy leaves (Fig. 9). The size of inclusion bodies seemed to vary in accordance with the size of cell. Further study is underway.

Effect of grassy stunt virus. Plants of BPI-76 were inoculated with grassy stunt virus by *Nilaparvata lugens* at 10, 30 and 60 days after sowing. Plant heights at maturity for inoculations made at 10 and 30 days old were 40 and 48 percent respectively of the healthy control. The yield reduction was about 96 percent although there were more panicles on infected plants. Plants inoculated when 60 days old did not develop characteristic symptoms before harvest, and there was no reduction in plant height or yield.

Effect of yellow dwarf virus. Plants of BPI-76 inoculated at 10 and 30 days after sowing with yellow dwarf virus by viruliferous *Nephotettix impicticeps* were very stunted and produced more panicles but fewer spikelets than the controls. The yield reduction was 100 percent since grains were unfilled. However, those inoculated when 60 days old did not differ significantly from the check plants.

Tungro infection of plants after treatment with insecticide

To determine the effectiveness of foliar application of carbaryl in preventing tungro virus infection, seedlings of Taichung (Native) 1 were exposed to viruliferous insects for various periods after treatment with carbaryl. The percentage of infected seedlings was 80, 100, 80, 80, 60, 70, 60, 80, 20, and 20 for inoculations made at 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10 hours after spray application, respectively. There were 40, 50, 50, 60, 80, 80, 80, and 90 percent seedlings infected for inoculations made 1, 3, 5, 7, 9, 11, 13, and 15 days after spray application, respectively. These results emphasize the importance of killing the insects before they introduce the virus into the plants. The mortality of insects feeding on the treated plants was high, however, and carbaryl applications should reduce disease spread.

Starch in leaf blade infected with tungro virus

The starch in the leaf blade of a normal rice plant is scarcely detectable. It was incidentally found that the leaves of rice plants infected with the tungro virus often became dark in color after treatment with iodine solution—in striking contrast to the absence of color reaction for healthy plants. An attempt to apply the iodine test as an additional diagnostic technique for tungro disease was therefore made.

Positive reaction of most infected leaves. Tests on healthy and infected rice plants resulted in 94 percent of the leaves of diseased plants exhibiting a positive reaction to the starch test. None of the 220 leaves from healthy plants gave a positive reaction. However, if the test is to be used as a diagnostic technique for tungro on a single leaf basis, cognizance should be taken of the fact that not all the infected leaves gave a positive reaction.

Distribution of starch in the leaf blade. The starch distribution in the leaf blade of tungro virus-infected plants has no definite pattern (Fig. 10). It might localize at the tip (13%), middle (4%) or basal portion (1%) of the leaf; or it might concentrate at the tip and middle (9%), tip and basal (1%), or middle and basal portion (6%). However, in most cases (65%) the starch was evenly distributed throughout the entire leaf.

Color intensity. There were different degrees of color intensity in the leaf blades of infected plants after treatment with iodine solution, which might be related to the concentration of starch in the leaf blade. However, 48 percent of a total of 169 leaves tested showed very dark color.

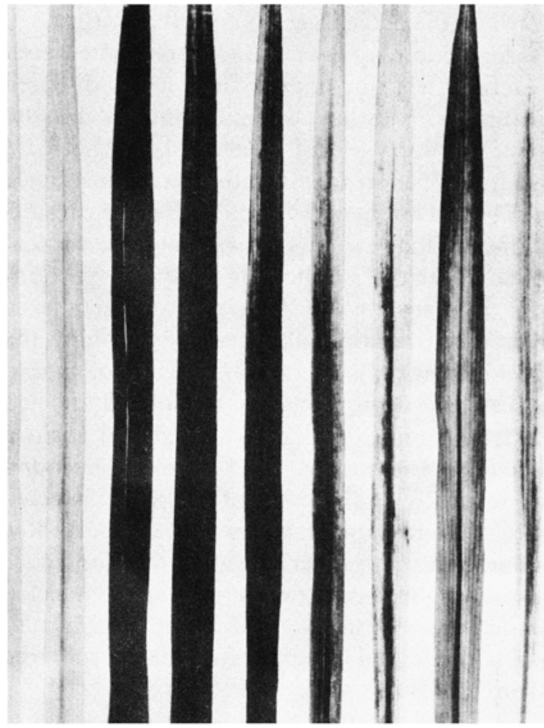

Fig. 10. Reaction of rice leaves to iodine test. All leaves were from tungro diseased plants except the two on the left from healthy plants.

Time of inoculated plant showing starch reaction. Seedlings of Taichung (Native) 1 were tested for the starch reaction at various periods after inoculation with the tungro virus to determine when the starch accumulated in the leaf blades. Since, as mentioned above, not every leaf of infected plants showed a positive reaction to the iodine test, all leaves of every seedling were tested. The earliest occurrence of a positive starch reaction was on the 5th day after inoculation. The percentage of seedlings showing positive reaction increased gradually from 40 percent on the 5th day after inoculation to 100 percent on the 11th day, at which level it remained for the rest of the test (Fig. 11). On the basis of number of leaves tested, the percentages of leaves showing starch reaction were 0, 0, 10.5, 26.7, 32.5, 72.1, and 78.6 for 2, 4, 5, 7, 8, 11, and 12 days after inoculation, respectively. But after 12 days, the percentage fluctuated over time.

Significance of starch reaction test. The starch reaction test for identifying tungro-diseased plants seems to have some limitations. Firstly, since not every leaf of infected plants showed a positive reaction, identification based on a single leaf would not be valid. Nevertheless, the results indicated that there was always at least one leaf of an infected plant showing the starch reaction; the accuracy of the diagnosis would thus be increased by examining every leaf. Secondly, the starch reaction is not highly specific for tungro disease since the leaves of rice plants infected with the orange-leaf virus also showed positive reaction. The positive reaction has been found occasionally on the leaves of rice plants infected with the grassy stunt virus but not the yellow dwarf virus. However, negative reactions were obtained for leaves, excluding lesions, infected either by *Piricularia oryzae* or *Cochliobolus miyabeanus*, and for leaves from plants suffering from bronzing disease or nitrogen deficiency.

It is obvious that the starch accumulated in the leaf blade due to the effect of the virus on the metabolism of carbohydrates. The accumulation might be due either to increase of starch synthesis, decrease of starch hydrolysis, or both. The chemical analysis indicates that not only the starch but also the specific activity of amylase and invertase are in some cases increased in diseased leaves. Further study is needed.

In addition to stunting, the conspicuous symptom of tungro disease is the yellowing of leaves. It is suspected that the accumulation of starch in the leaf could possibly be one of the causes of yellowing. Because the starch in the leaf was detectable earlier than the symptoms, it could not be the product of yellowing. Starch has also been found in the leaves of rice plants infected with the orange-leaf virus. The discoloration typical of this disease seems to be similar to that of tungro disease except that the color of the former has a more prominent red component.

Further experiment on "penyakit merah"

Earlier transmission experiments have shown that "penyakit merah" of Malaysia was caused by a virus transmitted by a leafhopper, *Nephotettix impicticeps.* In cooperation with the Department of Agriculture, States of Malaya, Malaysia, a further experiment was conducted to determine if soil conditions in diseased fields may contribute to the development of the disease.

The experiment was conducted in a field in the Krian area of Perak State, where symptoms of "penyakit merah" on transplanted seedlings had already appeared. The affected crop over a small area was cleared and two small plots were planted with healthy seedlings of variety Seraup 50. The plots were covered with nylon cages to exclude virus vectors. Another small plot was also covered with a nylon cage but the seedlings were artificially inoculated just before transplanting. A further three plots were planted with the same seedlings and inoculated with the virus, but were not covered by cages so that the

Table 15. Effect of protecting rice plants from virus reactions in an area afflicted with "penyakit merah," Malaysia.

Treatment	No. hills	Yield (g) (sun-dried and winnowed)	Calculated yield (m ton/ha)
A1 (healthy seedlings, caged, 2 x 2 m)	36	1,631	4.08
A2 (healthy seedlings, caged, 1 x 1 m)	9	513	5.13
B1 (inoculated seedlings, caged, 2 x 2 m)	36	511	1.28
B2 (inoculated seedlings, not caged, 2 x 2 m)	36	113	0.28
B3 (inoculated seedlings, not caged, 2 x 2 m)	36	367	0.92
B4 (inoculated seedlings, not caged, 2 x 2 m)	36	309	0.77

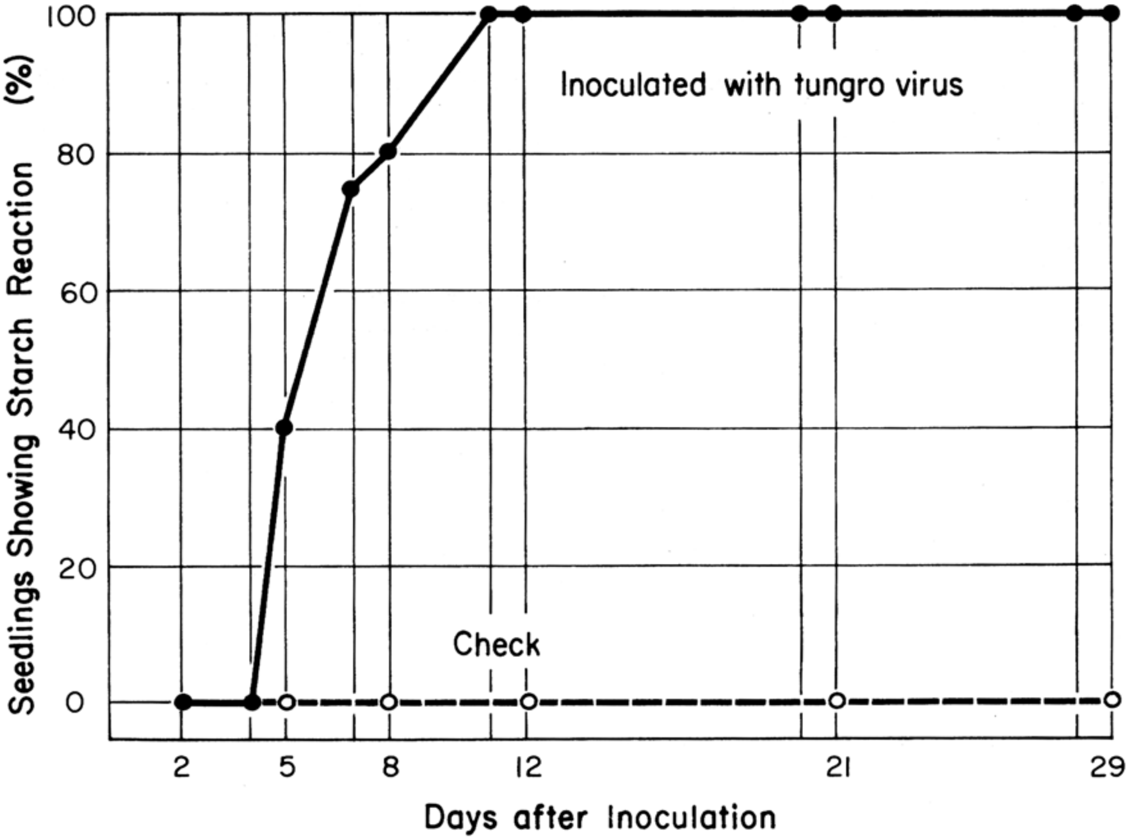

Fig. 11. Starch reaction of Taichung (Native) 1 seedlings at different periods after inoculation with the tungro virus.

plants were accessible to leafhoppers present in the big diseased field.

During the growing period, severe symptoms of "penyakit merah" appeared in all plots except those containing the caged healthy seedlings which produced a normal crop. The remaining plots produced only a few normal panicles. The grain yields of each plot are shown in Table 15.

The experiment demonstrated that a normal crop could be produced from the soil if the plants were protected from the vectors. There was no evidence that soil condition caused or contributed to the development of the disease.

Synthesis of Short-Statured, Disease-Resistant Varieties and Isogenic Disease-Resistant Lines

The short-statured parents frequently used in the Institute's breeding program are unfortunately often susceptible to common diseases, and give rise to susceptible progeny which must then be involved in a time-consuming program of backcrossing before resistant varieties are developed. Much time would be saved if the short-statured parents were disease resistant in the first place. Attempts to introduce such resistance in the potential parents are therefore being made. Also, efforts are being directed toward producing isogenic disease-resistant lines by repeated backcrosses to susceptible parents.

For blast resistance, the following crosses are in progress:

Cross	Short-statured selection	Isogenic lines
Dawn (R) x Taichung (N) 1 (S)	F_4 seedling	2nd backcross
Chianung 280 (R) x Taichung (N) 1	F_4 seedling	2nd backcross
Ta-poo-cho-2 (R) x Taichung (N) 1	—	4th backcross
IR8 (S) x Kataktara DA 2 (R)	F_2 seed	—
IR8 x Dawn	F_2 seed	—
IR8 x Taichung 181 (R)	F_1 seed	—
Suwon 82 (S) x Taichung 181	—	3rd backcross
Suwon 82 x Pah Leuad 111 (R)	—	3rd backcross
Suwon 82 x Kataktara DA 2	—	3rd backcross
Suwon 118 (S) x Taichung 181	—	3rd backcross
Suwon 118 x Pah Leuad 111	—	3rd backcross
Suwon 118 x Kataktara DA 2	—	3rd backcross
Dawn x BPI-76	—	4th backcross

For bacterial blight, the following crosses have been made.

Taichung (N) 1 (S) x Zenith (R)	F_2 seedling
No-iku-mo-chi (R) x Taichung (N) 1	F_2 seedling
Hsinchu 56 (R) x Taichung (N) 1	F_2 seedling
221C/BC III/BN/62/2(R) x Taichung (N) 1	F_2 seedling
221C/53/1/3/1 x Taichung (N) 1	F_2 seedling
IR8 (S) x Hsinchu 56	F_2 seedling
IR8 x Zenith	F_2 seedling
BPI (NS) (S) x Hsinchu 56	F_2 seedling
BPI (NS) x Zenith	F_2 seedling
BPI (NS) x No-iku-mochi No. 34	F_2 seedling

Most of the crosses are in the F_2 generation. Since all the F_1 plants showed susceptible reaction, indicating that resistance to bacterial blight is a recessive character, selection of resistant progeny and further backcrosses will be made after the F_2 plants are tested.

For tungro virus, the following crosses are in progress:

Cross	Short-statured selection	Isogenic lines
Taichung (N) 1 (S) x Pankhari 203 (R)	F_3 seed	1st backcross
Remadja (R) x Taichung (N) 1	F_2 seed	—
221C/BCIII/BN/62/2 (R) x Taichung (N) 1	F_3 seed	1st backcross
221C/53/1/3/1 (R) x Taichung (N) 1	F_3 seed	1st backcross
IR8 (S) x Pankhari 203	F_2 seed	1st backcross
IR8 x Sigadis (R)	F_2 seed	—
IGT (S) x Pankhari 203	F_2 seed	—
Remadja x IGT	F_2 seed	—
Remadja x DGWG (S)	F_2 seed	—

Soil Chemistry

Basic studies in soil chemistry were continued with greater emphasis on the practical application of theoretical and experimental findings.

Thermodynamic evidence was found for the presence of ferrosoferric hydroxide in reduced soils and the significance of this to soil testing was investigated. The theoretical equations derived earlier to describe carbonate equilibria in flooded soils were confirmed experimentally with greater precision and applied to the amelioration of iron deficiency on flooded calcareous and alkali soils. Further evidence was obtained of the unreliability of redox potentials of flooded soils measured in situ, *for quantitative studies of redox equilibria.*

The ecological significance of water management practices in rice culture was examined from the standpoint of the chemical kinetics of flooded soils. The benefits of prolonged submergence of the soil prior to transplanting were associated chiefly with: (a) a favorable pH and (b) lower concentrations of CO_2 and organic reduction products. The incorporation of dry organic matter in reduced soils produced no chemically recognizable deleterious effects. Mid-season drainage followed by reflooding was found to increase the concentration of reduction products in the soil solution instead of decreasing it. Internal drainage at 1 cm/day increased the yield of rice on three acid soils but depressed it on a calcareous soil, and caused heavy nutrient losses in all soils. Further proof was obtained that one of the important chemical benefits of flooding rice soils is increased availability of iron especially in the reproductive phase of the plant's development.

These findings are reported under: (a) the physical chemistry of flooded soils, (b) chemical kinetics of flooded soils, and (c) water regime in rice soils.

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The Physical Chemistry of Flooded Soils

Thermodynamic evidence for the presence of ferrosoferric hydroxide in reduced soils

In studies of redox equilibria in flooded soils reported last year (Annual Report, 1965), ferrosoferric hydroxide, a metastable hydrated variant of Fe_3O_4, was tacitly assumed to be the main species of iron (II) hydroxide present in flooded soils. Further studies confirmed the validity of this assumption.

Redox potential, pH, and Fe^{++} activity of the solutions of 30 flooded soils were used to calculate the apparent standard free energy of formation of $Fe_3(OH)_8$ from its thermodynamic solubility product and the standard potentials of the $Fe(OH)_3 - Fe_3(OH)_8$ and $Fe_3(OH)_8 - Fe^{++}$ systems. Closeness of the observed values ($-$ 450.6 to $-$ 452.6) to $-$ 451.2 kcal per mole at 25 C derived from the activity product of $Fe_3(OH)_8$, determined in the laboratory, is thermodynamic proof of the presence of ferrosoferric hydroxide in flooded soils after the peak of water-soluble Fe^{++}. Agreement was closest in the soils rich in iron but low in Mn, and least in soils high in Mn. The mean value for five latosolic soils was -451.3 kcal per mole.

The presence of ferrosoferric hydroxide in reduced soils has important theoretical and practical implications. If ferrosoferric hydroxide is the dominant solid phase of reduced iron, the pH of the equilibrium solution should uniquely determine the Eh, Fe^{++} activity, and the partial pressure of CO_2 in the system as follows:

$$\begin{aligned} \mathrm{Eh} &= 0.429 - 0.059\ \mathrm{pH} \\ \log \mathrm{Fe}^{++} &= 10.60 - 2\ \mathrm{pH} \\ \log P\mathrm{co}_2 &= 18.75 - 3\ \mathrm{pH} \end{aligned}$$

In other words, a simple, rapid, and accurate electrometric determination (pH) should, theoretically, provide a measure of the content of two ecologically important components of the soil solution, viz., CO_2 and Fe^{++}, whose chemical determination is long and laborious. Practical problems are introduced by deviations from the theoretical values caused by the presence of reduced manganese, chelating agents, and organic acids; Mn tends to increase Eh and depress Fe^{++}, while chelating agents and organic acids inflate Fe^{++} and $P\mathrm{co}_2$. For these reasons, observed values of Eh and Fe^{++} deviate from the calculated figures, but Table 1 shows that they are of the right order of magnitude. Possible improvements are (a) the use of a pH meter with a precision of $\pm$ 0.001 pH unit and (b) the use of experimental values of the constants in the equations for each soil, instead of those based on a simple aqueous $Fe_3(OH)_8$ system.

Ionic strength from specific conductance

Last year (Annual Report, 1965) the applicability of the empirical relationship, μ (mole/liter) $= 16\kappa$ (mho/cm) to the solutions of flooded soils was demonstrated. This year its confidence limits were established theoretically, and its applicability extended to the solutions of aerobic soils, except strongly acid soils.

At ionic strengths not exceeding 0.02 mole/liter, a deviation of ± 2 from 16 (the μ/κ ratio) was found to cause a maximum error of only 0.44 percent in the activity coefficient of monovalent ions. Table 2 shows that, of the 10 aerobic soil solutions studied, only the three strongly acid soils gave μ/κ ratios outside these limits; they were lower apparently because of the high mobility of the H^+ ion.

The use of the empirical relation, $\mu = 16\ \kappa$, greatly simplifies the derivation of the partial pressure of CO_2 and the concentration of Fe^{++} in the solution of flooded soils because a simple, rapid, and accurate electrometric determination replaces the numerous chemical analyses required from the calculation of ionic strengths. Thus

$$\mathrm{pH} = 7.85 + \log [\mathrm{HCO_3}^-] - \log P\mathrm{co}_2 + \log \gamma_{\mathrm{HCO_3}^-}$$

becomes

$$\mathrm{pH} = 7.85 + \log [\mathrm{HCO_3}^-] - \log P\mathrm{co}_2 - 2.04\sqrt{\kappa}$$

and

$$\mathrm{pH} + \tfrac{1}{2} \log [\mathrm{Fe}^{++}] + \tfrac{1}{2} \log \gamma_{\mathrm{Fe}^{++}} = 5.30$$

becomes

$$\mathrm{pH} + \tfrac{1}{2} \log [\mathrm{Fe}^{++}] - \frac{1.02\sqrt{\kappa}}{1 + 7.88\sqrt{\kappa}} = 5.30$$

where square brackets denote concentrations and κ, specific conductance in mho cm^{-1} at 25 C. The last equation shows that the concentration of Fe^{++} in the solution of a reduced soil can be calculated from the pH and specific conductance of the solution.

Table 1. Theoretical and observed values for redox potential and concentration of Fe^{++} in the solutions of a flooded latosolic soil after the peak of water-soluble Fe^{++}.

Weeks submerged	pH	Eh (mv)		Fe^{++} (ppm)	
		calc.	obs.	calc.	obs.
2	6.55	43	37	367	360
4	6.92	21	10	52	48
6	6.80	28	40	89	74
8	6.81	27	39	85	77
10	6.79	28	40	93	74

Carbonate equilibria in flooded soils

Carbonate equilibria in pure and soil systems were studied with additional refinements and their ecological significance further clarified. The validity of the theoretical equations derived earlier (Annual Report, 1964, 1965) for pure carbonate systems was established with greater precision, and the applicability of these equations to carbonate equilibria in sodic, calcareous, and reduced soils, confirmed. Further, the simplest remedy for iron deficiency on flooded alkali and calcareous soils was found to be the incorporation of a liberal amount of organic matter.

Using a Beckman research pH meter and CO_2-N_2 mixtures calibrated with a gas chromatograph, the validity of the equation,

$$pH = 7.85 + \log [Na^+] - \log Pco_2 + \log \gamma_{HCO_3^-}$$

describing the influence of the partial pressure of CO_2 on the pH of dilute aqueous Na_2CO_3, was confirmed with greater precision (Tables 3 and 4). The deviation in the case of 0.005 *M* Na_2CO_3 equilibrated with air was expected as this lies outside the limits of the theoretical equation (Annual Report, 1965).

The applicability of this equation to sodic soils was tested by equilibrating CO_2 with an aqueous suspension of an alkali soil (pH, 10.2, $HCO_3^{--} + CO_3^{--} = 2 \times 10^{-3}$ m.e./liter, $\mu = 0.06$ m/liter) from the neighborhood of Cotabato in Mindanao, Philippines. The observed regression of pH on log Pco_2 was $pH = 6.39 - 1.00\ Pco_2$ (Fig. 1), compared with the theoretical equation for 2×10^{-3} *M*[Na^+] at an ionic strength 0.06 m/liter, viz.,

$$pH = 6.05 - 1.00 \log Pco_2$$

The higher value of "a" in the observed regression than in the theoretical equation is due to $CaCO_3$ and possibly $MgCO_3$ (Annual Report, 1965).

The relationship between pH and log Pco_2 for the alkali soil is so perfect, that if the pH of an alkali soil equilibrated with 100 percent CO_2 is known, its pH at any other Pco_2 can be predicted from the equation

$$pH = pH_0 - \log Pco_2$$

where pH_0 is the pH of the equilibrium solution at a Pco_2 of 1 atmosphere; conversely, Pco_2 at any observed pH can be predicted from the same equation.

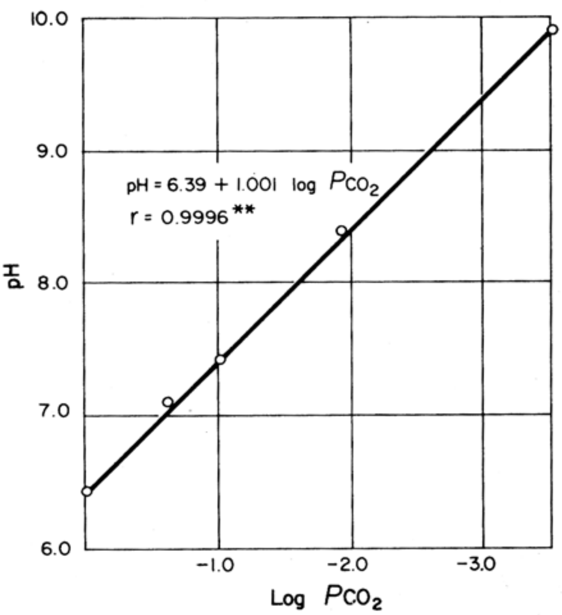

Fig. 1. Relationship between the partial pressure of CO_2 and the pH of an alkali soil.

Table 2. Influence of the ionic composition of aqueous extracts of aerobic soils on the ionic strength: specific conductance ratio and its reliability for computing activity coefficients.

Soil no.	pH	Na^+	K^+	NH_4^+	Mg^{++}	Ca^{++}	Mn^{++}	SO_4^{--}	HCO_3^-	NO_3^-	Cl^-	μ	κ mhos cm^{-1} x 10^6	$\frac{\mu}{\kappa}$	$\gamma_{HCO_3^-}$ from	
		millimoles/liter										m/l			$\frac{1}{2}\Sigma c_i z_i^2$	$16\ \kappa$
7	5.9	1.22	0.10	0.14	1.39	2.26	0.06	0.33	0.74	7.50	0.31	0.013	911	14.3	.891	.887
9	5.5	0.48	0.18	0.24	0.98	2.17	0.01	0.26	0.07	10.36	0.10	0.013	780	16.7	.891	.897
16	6.4	0.83	0.06	0.15	0.28	0.51	0.01	0.58	0.30	0.03	0.82	0.004	281	14.2	.935	.935
17	6.8	0.37	0.04	0.10	0.34	1.96	0.00	0.77	0.96	2.43	0.23	0.008	502	15.9	.912	.912
23	5.4	3.09	0.20	0.54	6.04	10.00	0.25	2.08	0.22	31.43	3.13	0.056	3790	14.8	.813	.809
26	7.1	1.22	0.02	0.04	0.58	1.37	0.00	0.27	1.06	2.64	0.58	0.007	512	13.7	.916	.912
29	5.8	1.61	0.08	0.02	0.60	0.77	0.03	1.23	0.56	0.54	0.67	0.007	436	16.1	.916	.916
39	8.1	4.04	0.06	0.06	1.39	5.04	0.00	3.75	1.80	3.93	3.05	0.027	1528	17.7	.857	.863
14	4.3	4.00	0.25	0.19	1.11	1.30	0.31	0.29	0.00	8.86	0.42	0.013	1010	12.9	.891	.883
21	4.7	1.57	0.17	1.68	0.49	1.29	0.06	0.27	0.15	5.57	1.00	0.009	833	10.8	.908	.891
28	4.2	1.83	0.23	0.63	1.03	1.21	0.40	0.06	0.00	7.00	0.14	0.010	964	10.4	.904	.887

Table 3. Influence of the partial pressure of CO_2 on the pH of aqueous 0.0005 and 0.005 *M* Na_2CO_3.

Pco_2	$-\log Pco_2$	0.0005 *M* Na_2CO_3		0.005 *M* Na_2CO_3	
atm.	corr. for v.p.	pH (theo.)	pH (obs.)	pH (theo.)	pH (obs.)
0.9999	0.014	4.85	4.85	5.82	5.82
0.3673	0.449	5.28	5.29	6.25	6.24
0.1031	1.001	5.84	5.84	6.80	6.80
0.00031 (air)	3.523	8.36	8.35	9.32	9.26

Table 4. Influence of ionic strength on the pH of 0.005 *M* Na_2CO_3 equilibrated with 0.1031 atm. Pco_2.

NaCl (m/l)	μ	$-\log \gamma_{HCO_3^-}$	pH (theo.)	pH (obs.)
0	0.001	0.015	5.84	5.84
0.005	0.006	0.036	5.81	5.81
0.010	0.011	0.047	5.80	5.80
0.025	0.026	0.068	5.78	5.78
0.050	0.051	0.089	5.76	5.74

Table 5. Influence of organic matter on the kinetics of pH of a flooded sodic soil.

O.M.	Days submerged					
	2	7	14	28	42	84
0	10.3	9.9	9.5	9.5	9.3	9.1
0.15% straw + green manure	10.0	9.4	8.6	8.6	8.1	8.3
0.1% sucrose	9.3	9.1	8.4*	6.6	7.2	8.2

* Added 0.5 g sucrose to the 50 g of soil.

The marked effect of CO_2 on the pH of aqueous sodium carbonate suggests that increasing the partial pressure of CO_2 is a simple method of accentuating the natural decrease in pH that takes place when a sodic soil is flooded. Table 5 shows the effect of two kinds of organic matter on the pH of the alkali soil from Cotabato kept submerged.

Using the equation ($pH = 6.0 - \frac{2}{3} \log Pco_2$) defining the influence of CO_2 on the pH of the $CaCO_3 - H_2O - CO_2$ system, it can be shown that the simplest remedy for iron deficiency on flooded calcareous soils is to increase the partial pressure of CO_2. A carbon dioxide pressure of 10 percent in the soil will depress its pH to about 6.7. At this pH, sufficient water-soluble iron is present in a flooded soil to preclude iron deficiency. This was dramatically confirmed when the addition of organic matter increased Pco_2, depressed pH, and prevented iron deficiency on a flooded calcareous soil (Table 6).

Redox potentials of flooded soils

In the study of flooded soils, muds, and sediments, redox potentials are widely measured *in situ* but problems in interpreting them are not recognized.

Previous studies (Annual Report, 1963, 1964) indicated that (a) duplicate potential measurements at bright platinum electrodes placed a few

Table 6. Influence of organic matter on (a) the kinetics of P_{CO_2} (atm), pH, and water-soluble Fe^{++} (ppm) and (b) the growth of rice on a flooded calcareous soil (pH 7.6, O.M. 1.5%).

Added O.M. (%)	Weeks submerged 2			4			8			Straw (g/pot)	Grain (g/pot)
	P_{CO_2}	pH	Fe^{+2}	P_{CO_2}	pH	Fe^{+2}	P_{CO_2}	pH	Fe^{+2}		
0	0.04	7.2	0.1	0.04	7.2	0.1	0.13	6.9	0.5	37.4	23.0
0.15	0.25	6.8	2.6	0.35	6.7	5.8	0.36	6.7	9.3	74.2	57.2

Table 7. Means and standard deviations of the potential of three soils measured at 16 Pt electrodes seated permanently at 10 cm below the soil surface, in each pot, at different intervals after submergence.

Days submerged	Pila clay loam pH 7.6, O.M. 1.5% Eh	σ	Maahas clay pH 6.6, O.M. 2.0% Eh	σ	Luisiana clay pH 4.7, O.M. 3.2% Eh	σ
0	385	35	409	16	508	36
7	−74	101	−108	79	62	70
14	−175	84	−7	93	−180	34
31	−187	50	−108	76	−226	16
45	−184	32	−106	72	−243	6

centimeters apart, at the same depth, in flooded soils, differed widely, and (b) soil potentials were considerably lower than the corresponding solution potentials. In further experiments it was found that (a) the soil potentials varied widely with location within the soil, (b) ΔE i.e. (solution Eh − soil Eh) was positive only after soil reduction, and (c) these phenomena were not primary bacterial effects.

In one experiment, 64 bright platinum electrodes were placed at 10, 15, 25, and 35 cm below the surface of the flooded soil in groups of 16, with the electrodes 1 cm apart. The potentials were measured against a saturated calomel electrode in contact only with the supernatant water to minimize the liquid junction potential error. The soils were: (1) Luisiana clay (pH 4.6; O.M. 3.2%); Maahas clay (pH 6.6; O.M. 2.0%); and Pila clay loam (pH 7.6; O.M. 1.5%).

There were no significant differences between the potentials at the four depths at any time of the 5-week period of submergence, for variations within a depth (Table 7) were as great as those between depths.

In a second experiment, soil potentials (means of 4 electrodes almost touching the bottom of the pot) were compared with the potentials of the solutions drawn by gravity into an electrometric cell in the strictest absence of air. Table 8 shows that ΔE was negative in the early stages of submergence but became positive after soil reduction and reached its maximum value when the soil potential was at its minimum. The minimum soil potentials were of the order of the potential of the $Fe_3(OH)_8 - Fe(OH)_2$ system, whereas the solution potentials corresponded to those of the $Fe(OH)_3 - Fe_3(OH)_8$ and $Fe_3(OH)_8 - Fe^{++}$ systems (Annual Report, 1965). This suggests that soil potentials are influenced by the active solid phase in the immediate vicinity of the electrode, while solution potentials are those of the average solution in equilibria with all the active solids.

The possible role of bacteria in soil reduction heterogeneity was next investigated. Mixtures of sand and $Fe(OH)_3$ were placed in 5-liter pots with (a) demineralized water, (b) an aqueous suspension of finely ground dry *Glyricidia maculata* leaves, (c) an aqueous extract of macerated fresh *Glyricidia maculata* filtered through cheese cloth, (d) an aqueous suspension of freshly precipitated $Fe(OH)_2$, and (e) a 0.5 percent solution of hydrazine sulfate. Sand plus a standard redox buffer (3×10^{-3} *M* $K_4Fe(CN)_6$ + 3×10^{-3} *M* $K_3Fe(CN)_6$ in 0.1 *M* KCl) was included as an additional treatment. "Soil" potentials were determined at four bright platinum electrodes seated 10 cm below the sand surface; solution potentials were measured at 2 bright platinum electrodes after drawing the solution by gravity into an electrometric cell in the strictest absence of air. Table 9 shows the mean "soil" potentials, their standard deviations, and ΔE, at intervals during a 10-week period.

These data show that (a) "soil" potentials were highly variable in all treatments in which an active solid phase, viz., $Fe(OH)_3$, was present; (b) the "soil" potentials of the $Fe(OH)_2$ and $N_2H_4 \cdot H_2SO_4$ treatments in which bacterial interference was negligible were also highly variable; (c) the "soil" potentials of the buffer, which were highly reproducible in the early stages of submergence when no active solid phase was present, became highly variable after its potential turned negative following the conversion of $K_3Fe(CN)_6$ to $Fe(OH)_3$. The data also show that all treatments (except the buffer before reduction) gave solution potentials which were strongly positive with respect to the corresponding "soil" potential.

This experiment (a) confirmed the preceding finding that variability of potentials measured *in situ* is due to heterogeneity of the reduced medium, and (b) indicated that this heterogeneity is not a primary bacterial effect.

Chemical Kinetics of Flooded Soils

Studies on the chemical kinetics of flooded soils were continued with emphasis on the implications to management of lowland rice soils.

In rice farming, fields are (a) kept submerged (by choice or not) for varying periods before transplanting, (b) drained, allowed to dry, reflooded, and organic matter incorporated with the soil, (c) drained, allowed to dry, and reflooded in midseason, and (d) kept flooded or virtually saturated continuously in year-long rice culture on the same land. The chemical and ecological significance of these practices is not sufficiently appreciated.

Laboratory and greenhouse investigations showed that (a) prolonged submergence produces a chemical environment favorable for the growth of rice, (b) mid-season drainage followed by flooding increases the concentration of CO_2 and reduction products instead of decreasing them, and (c) incorporation of dry organic matter in reduced soils does not cause a build-up of high concentrations of CO_2 or water-soluble Fe^{++}.

Influence of varying periods of soil presubmergence on the growth and yield of rice

Previous studies (Annual Report, 1964, 1965) indicated that, within 1 to 4 weeks of flooding, soils go through a period of intense chemical activity characterized by the build-up of high concentrations of CO_2, Fe^{++}, Mn^{++}, organic

Table 8. Influence of the degree of soil reduction on ΔE (i.e. solution Eh—soil Eh) in mv.

Weeks submerged	Luisiana clay pH 4.6, OM 3.2%		Maahas clay pH 6.6, OM 2.0%		Pila clay loam pH 7.6, OM 1.5%		Silo silt loam pH 8.1, OM 2.0%	
	Soil Eh	ΔE	Soil Eh	ΔE	Soil Eh	ΔE	Soil Eh	ΔE
0	621	−156	447	− 80	510	−188	460	n. d.
1	541	−179	9	153	−170	467	−149	259
2	329	−112	− 34	171	−100	267	−148	193
3	217	− 5	− 82	219	−175	315	−195	217
4	105	27	−109	276	−180	382	−215	255
6	−115	195	− 52	184	− 36	203	−185	217
8	−194	258	−119	259	−162	317	−236	303
10	−246	317	−206	348	−160	390	−257	297
13	−109	210	−127	253	−105	270	−190	239
15	−110	175	−105	220	− 85	180	−186	291

Table 9. Influence of the composition of the synthetic medium ("soil") on the mean Eh (mv) of the medium, its precision, and ΔE (solution Eh — "soil" Eh) at 7 intervals after submergence.

Treatment	Weeks submerged																				
	0			1			2			4			6			8			10		
	Eh	σ	ΔE	Eh	σ	ΔE	Eh	σ	ΔE	Eh	σ	ΔE	Eh	σ	ΔE	Eh	σ	ΔE	Eh	σ	ΔE
1. Sand + $Fe(OH)_3$ (A)	452	13	−5	−108	25	275	−124	37	218	−133	26	275	−109	95	255	− 50	100	226	46	32	159
2. A + dry green manure	316	21	59	− 61	20	285	− 37	21	262	−230	13	238	−228	3	195	−220	17	213	−211	5	216
3. A + G.M. extract	245	4	26	39	23	118	−265	40	210	−271	12	245	−256	9	220	−257	10	223	−253	3	228
4. A + $Fe(OH)_2$	−448	15	213	−315	110	412	−228	76	364	−192	46	350	−165	36	329	−219	19	421	−170	41	310
5. A + $N_2H_4 \cdot H_2SO_4$	432	9	163	300	8	140	282	55	30	155	63	307	102	16	327	110	23	426	126	6	341
6. Sand + redox buffer	415	0	8	408	3	7	402	3	3	377	3	2	310	24	3	−123	10	350	−204	33	519

acids, and organic reduction products in the soil solution. The burst of biochemical activity is followed by a lull during which these concentrations decline and get stabilized at levels that are not injurious to rice. Duration of submergence prior to transplanting should therefore markedly influence the chemical environment in which the seedling establishes itself. But most farmers and experimentalists do not appreciate sufficiently the importance of this factor.

Field studies (Annual Report, 1963) showed that delaying transplanting for 2 weeks after flooding could increase the grain yield by about 1 ton/ha even on an ideal lowland rice soil like Maahas clay, but no explanation was given in terms of the chemical kinetics of the soil. To supply this deficiency and to obtain data on other soils, the influence of 6, 4, 2, and 0 weeks pre–submergence on the growth and yield of rice on four soils was investigated in a greenhouse experiment.

The soils (Luisiana clay, pH 4.7, O.M. 3.2%; Casiguran sandy loam, pH 4.8, O.M. 4.4%; Maahas clay, pH 6.6, O.M. 2.0%; and Pila clay loam, pH 7.6, O.M. 1.5%) were mixed with 0.5% of a 1:1 mixture of ground straw and *Glyricidia maculata* (to simulate accretion of organic matter by roots, stubble and weeds), treated with 50 ppm each of N, P, K, and kept submerged in 16–liter pots for 6, 4, 2, and 0 weeks. Two Peta seedlings per pot were planted on the same day. The chemical and electrochemical kinetics of the soils were followed by analyzing the solution at frequent intervals. Growth and yield figures are in Table 10.

Pre–submergence of the soils markedly influenced the yield of straw and grain but the optimum duration varied with the soil. Four weeks' pre–submergence gave the highest yield of straw on all soils except Pila clay loam for which 6 weeks' pre–submergence was the best treatment. In regard to grain yield, 2 weeks' pre–submergence was the best treatment with Maahas clay and Casiguran sandy loam; 4 and 6 weeks were the best with Luisiana clay and Pila clay loam, respectively. Within a soil, the highest yield of grain was associated with the period of pre–submergence that brought about the highest concentrations of N, P, K, and Si in the plant.

The reasons for the poorer rice yields on the soils flooded and transplanted immediately than on the soils kept submerged varied with the soil. The chemical and electrochemical kinetics suggest that excess CO_2 and organic reduction products (oxidizable matter) were retarding factors common to all soils. Excess Fe^{++} was an additional retarding factor on Luisiana clay and excess electrolyte on Pila clay loam.

Delaying planting for at least 2 weeks after flooding provided a better environment for the growth of rice on a good soil like Maahas clay; on other soils longer periods of pre-submergence are necessary for maximum yields.

Influence of water management on the chemical kinetics of flooded soils

In a series of greenhouse experiments, the influence of: (a) prolonged submergence, (b) air-drying the soil followed by incorporation of organic matter and flooding, (c) incorporation of organic matter in the reduced soil, and (d) air-drying the soil followed by reflooding on the kinetics of such ecological important properties, ions, or substances as pH, $P\text{co}_2$, Fe^{++}, and oxidizable matter were studied. The experiments were conducted on 30 soils in 16-liter pots in the absence of rice plants. (Other studies showed that rice plants affect chiefly the nitrogen regime). The data for four representative soils are shown in Figs. 2, 3, and 4.

Prolonged submergence caused the pH values of the acid soils to increase and that of the calcareous soil to decrease to fairly stable values of 6.5 to 7.0. It depressed the partial pressure of CO_2 to less than 0.1 atmosphere in all soils except Casiguran sandy loam, a soil low in active Fe and Mn. The most dramatic effect was on the concentration of water-soluble Fe^{++}: in the acid soils it dropped from more than 300 ppm to about 50 ppm.

Prolonged submergence produced a favorable environment for rice by decreasing CO_2 toxicity on all soils and Fe^{++} toxicity in the acid soils while increasing the availability of Fe^{++} in the nearly neutral and calcareous soils (Figs. 3(a) and 4(b)).

Flooding the air-dried soil after the addition of organic matter produced pH, $P\text{co}_2$, and Fe^{++} patterns which were almost replicas of the

Table 10. Influence of the duration of soil submergence prior to transplanting on the growth and yield of rice and the mineral composition of the plant.

Soil	Weeks pre-submerged	Tillers per pot	Straw (g/pot)	Grain (g/pot)	N (% in straw)	K (% in straw)	SiO_2 (% in straw)	P (% in grain)
Luisiana	6	21.2	47	32.6	2.12	1.92	15.2	0.267
clay	4	22.5	48	35.5	2.15	1.80	15.7	0.274
pH 4.7	2	19.8	37	12.8	1.76	1.54	13.4	0.250
O.M. 3.2%	0	16.0	33	13.0	1.97	1.64	15.5	0.252
Maahas	6	36.2	103	60.0	1.12	3.05	13.4	0.391
clay	4	37.5	107	60.1	1.14	2.92	14.3	0.410
pH 6.6	2	34.8	107	75.4	1.21	2.77	14.2	0.455
O.M. 2.0%	0	37.5	104	62.6	0.89	2.79	14.1	0.428
Casiguran	6	37.0	109	45.6	1.78	1.64	9.9	0.315
sandy loam	4	43.2	129	50.0	1.76	1.60	9.2	0.334
pH 4.8	2	41.2	123	55.3	1.88	1.50	10.2	0.342
O.M. 4.4%	0	35.8	96	38.9	1.64	1.36	9.3	0.334
Pila	6	28.5	93	49.8	1.46	2.71	15.9	0.437
clay loam	4	25.2	65	44.0	1.32	2.38	15.9	0.433
pH 7.6	2	22.5	55	38.2	1.19	2.23	15.8	0.394
O.M. 1.5%	0	21.2	50	35.7	1.12	2.18	15.5	0.390
L.S.D. 0.1%		4.0	10	7.6	0.19	0.27	0.5	0.020

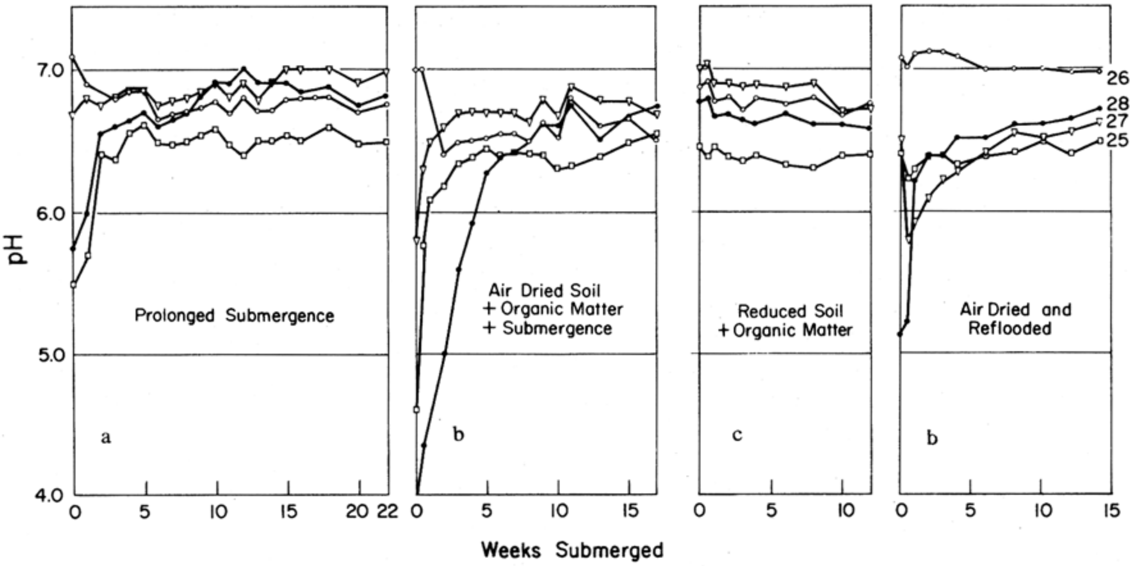

Fig. 2. pH changes in the soil solutions.

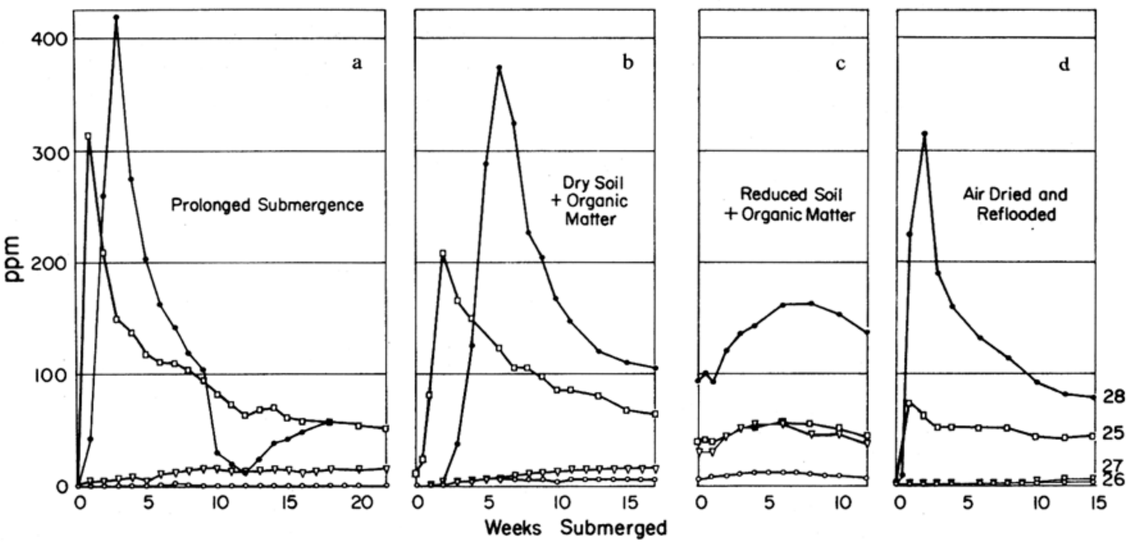

Fig. 3. Kinetics of water soluble Fe^{++}.

earlier ones (Figs. 2(b), 3(b), and 4(b)). The pH values were slightly lower, and Pco_2 higher because of the addition of organic matter.

Incorporation of 0.15 percent of a mixture of straw and dry *Glyricidia maculata* caused no appreciable change in pH, a slight increase in Pco_2, but a noticeable increase in water-soluble Fe^{++} (Figs. 2(c), 3(c), and 4(c)). Incorporation of this kind of organic matter in soils that had lost their natural oxidizing capacity did not produce toxic concentrations of CO_2 or Fe^{++} as did the addition of sucrose (Annual Report, 1965).

Air-drying the acid soils and reflooding even without the addition of organic matter produced sharper increases in Pco_2 and Fe^{++} (Figs. 3(d) and 4(d)) than incorporation of organic matter in the reduced soils.

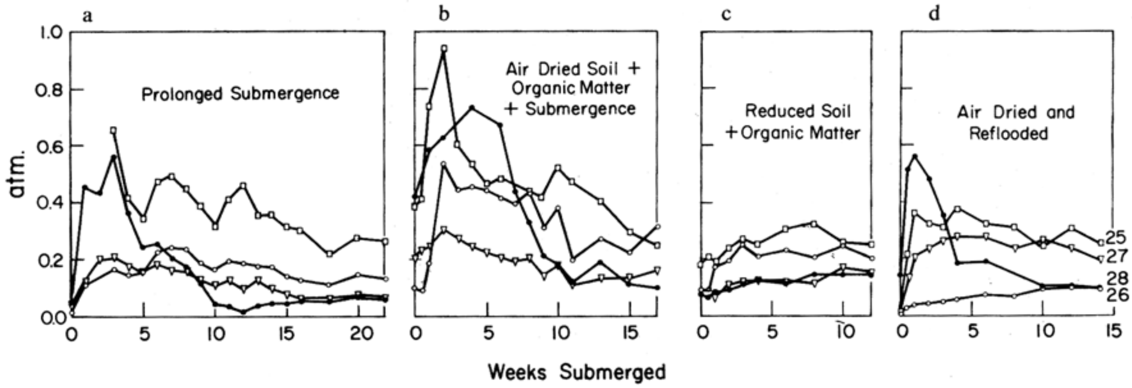

Fig. 4. Kinetics of P_{CO_2} in the soil solutions.

These kinetic studies show that a continuous submergence of the soil may be better for rice than alternate drying and flooding.

Water Regime in Rice Soils

Influence of internal drainage on the chemical kinetics of flooded soils and the growth of rice Agronomists claim that a moderate amount of percolation in flooded soils benefits rice. They have not, however, defined the soils on which internal drainage is desirable nor given a satisfactory explanation of their observation. Because the chemical implications of percolation were not clearly understood, the influence of drainage at 1 cm/day on the chemical changes and the growth of rice in four flooded soils, with and without added organic matter, was investigated in the greenhouse.

The drainage levels were 0 and 1 cm/day; the soils were Luisiana clay (pH 4.7; O.M. 3.2%), Casiguran sandy loam (pH 4.8; O.M. 4.4%), Maahas clay (pH 6.6; O.M. 2.0%) and Pila clay loam (pH 7.6, O.M. 1.5%); and the organic matter levels were 0 and 0.25 percent of a 1:1 mixture of ground straw and *Glyricidia maculata* leaves. Redox potential, pH, specific conductance, HCO_3^-, NH_4^+, K^+, Ca^{++}, Mg^{++}, Fe^{++}, Mn^{++}, $H_2PO_4^-$, SO_4^{--} and oxidizable matter were determined in the soil solutions during the first 10 weeks after planting.

Compared with the corresponding treatment without drainage, percolation at 1 cm/day: (a) increased the pH slightly in all soils except Casiguran sandy loam (a soil low in active iron and manganese), (b) decreased specific conductance in all soils, (c) increased Eh slightly in all soils except Luisiana clay, (d) markedly depressed the concentration of CO_2, Fe^{++}, Mn^{++}, and oxidizable matter, (e) lowered the concentration of NH_4^+, K^+, Ca^{++}, Mg^{++}, and SO_4^{--}, and (f) caused heavy loss of nutrients from all soils (Table 11), apart from the loss of 84 cm of water.

Some of these observations can be explained by the equations derived earlier (Annual Report, 1964, 1965) to describe redox and carbonate equilibria in flooded soils. The increase in pH is due to the decrease in partial pressure of CO_2

Table 11. Nutrient losses (expressed as kg/ha) from four submerged soils caused by drainage at 1 cm/day for 12 weeks.

Soil	NH_3-N	P	K^+	Ca^{++}	Mg^{++}	SO_4^{--}	Fe^{++}	Mn^{++}
	(kg/ha)							
Luisiana clay	218	1.2	58	198	236	321	932	135
Casiguran sandy loam	186	3.6	47	296	157	303	326	5
Maahas clay	58	2.4	66	606	693	719	126	230
Pila clay loam	32	10.2	98	771	461	736	4	18

Table 12. Influence of chemicals and water regime on the growth, yield, Fe and Mn content of the active center leaf, and foliar symptoms of Chianung 242.

Treatment	Tillers per pot	Straw (g/pot)	Grain (g/pot)	Spikelets per panicle	Sterility (%)	Fe* (ppm)	Mn† (ppm)	Foliar symptoms
Luisiana clay, pH 4.7, O.M. 3.2%								
1. Field capacity (FC)	19.7	87	21	100	57	79	7770	Fe def.*, Mn tox.†
2. FC + Fe + P + Si	35.7	132	91	128	15	109	4570	Mn toxicity†
3. FC + late flood	23.3	76	57	114	19	82	1830	Fe def.?
4. Tr. 2 + late flood	36.7	145	122	174	22	86	1720	None
5. Early flood, late FC	15.3	56	39	150	32	103	5170	None
6. Continuous flood	16.3	55	45	305	12	135	1240	None
Maahas clay, pH 6.6, O.M. 2.0%								
1. Field capacity (FC)	17.7	79	43	142	22	63	53	Fe def.*†
2. FC + Fe + P + Si	21.0	95	67	151	14	58	46	Fe def.*†
3. FC + late flood	17.3	92	71	211	21	64	1800	Fe def.*
4. Tr. 2 + late flood	20.3	97	76	204	24	97	1290	Fe def.?*
5. Early flood, late FC	36.7	161	111	164	21	94	620	None
6. Continuous flood	37.3	143	131	180	16	100	856	None
Casiguran sandy loam, pH 4.8, O.M. 4.4%								
1. Field Capacity (FC)	16.3	74	29	107	34	100	2010	Fe def.*, Mn tox.†
2. FC + Fe + P + Si	28.0	119	53	109	27	95	473	Fe def.*
3. FC + late flood	20.0	83	57	148	21	97	235	Fe def.?
4. Tr. 2 + late flood	27.3	120	77	140	18	101	177	None
5. Early flood + late FC	30.7	122	62	120	21	143	1500	None
6. Continuous flood	31.0	125	96	177	18	128	40	None

* At panicle primordia initiation. † At flowering.

caused by removal of CO_2 in the percolates as the following equations indicate:

$$pH = 6.25 - \tfrac{1}{3} \log Pco_2 \text{ (soils high in Fe)}$$
$$pH = 6.00 - \tfrac{2}{3} \log Pco_2 \text{ (calcareous soils)}$$

The decrease in Eh of Luisiana clay is a reflection of the inverse relationship between Eh and pH of the $Fe(OH)_3 - Fe_3(OH)_8$ system, viz.,

$$Eh = 0.43 - 0.059 \text{ pH}$$

The decrease in concentration of Fe^{++} and Mn^{++} caused by leaching, in spite of the presence of reduced Fe and Mn in the solid phase, is a reflection of higher pH and lower Pco_2 in the drained soils as the following equations indicate:

$$\log Fe^{++} = 10.60 - 2 \text{ pH}$$
$$\log Mn^{++} = 8.04 - 2 \text{ pH} - \log Pco_2$$

The effects of drainage on the growth and yield of rice varied with the soil and the presence or absence of added organic matter. Drainage increased vegetative growth and grain yield on the two strongly acid soils (Luisiana clay and Casiguran sandy loam) because it depressed the concentration of water-soluble CO_2, Fe^{++}, oxidizable matter and, as other studies show (Annual Report, 1965), also the concentration of organic acids. On the calcareous soil, drainage markedly depressed straw and grain yields apparently because of iron deficiency in the early stages and nitrogen deficiency later. On Maahas clay, drainage depressed the yield of straw but increased the yield of grain. The benefits of drainage were more pronounced in the presence of organic matter in the acid soil (Luisiana clay) while the adverse effects of drainage were counteracted by organic matter in the calcareous soil (Pila clay loam).

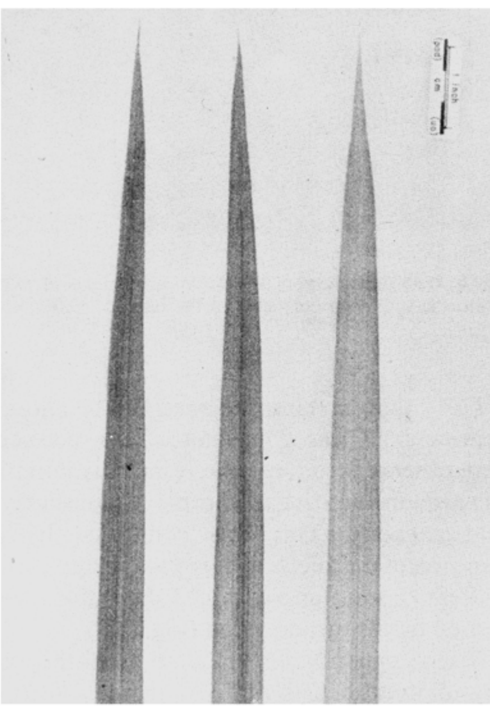

Fig. 5. Iron deficiency in Chianung 242 on Maahas clay at field capacity at panicle primordia initiation (left) was alleviated by FeEDTA (center) and avoided by continuous flooding (right).

Drainage slightly increased the concentration of P, K, and Si in the plant on all soils except Casiguran sandy loam (in which nutrient losses were heavy), reflecting a more favorable root environment for P, K, and Si uptake.

Conclusions of practical interest are that internal drainage at a moderate rate (a) removes considerable amounts of plant nutrients, (b) improves the growth of rice on acid soils and depresses it on calcareous soils, and (c) the benefits may not be commensurate with losses of plant nutrients and water.

The chemical benefits of flooding rice soils

It was shown earlier (Annual Report, 1964, 1965) that (a) rice can grow luxuriantly in a soil at field capacity if extra P, Si, and Fe are supplied, (b) but it suffers a setback in the reproductive stage because of the absence of factors associated with saturation of the soil with water, and (c) one of these factors is the availability of iron. In further greenhouse experiments, clear chemical and visual evidence was obtained that iron deficiency in all soils, along with manganese toxicity in the strongly acid soils, was the main cause of the setback suffered in the reproductive phase by rice plants in the soils at field capacity.

Some of the studies reported earlier (Annual Report, 1963, 1964, 1965) were repeated with two variations: (a) addition of an early flood, later-field-capacity treatment in one experiment, and (b) the inclusion of an early aerobic, later anaerobic, field capacity treatment in a second experiment. Table 12 shows that (a) the soils kept

Table 13. Comparison of the direct and indirect effects of flooding on the grain yield of rice on three soils.

Treatment	Luisiana clay	Casiguran sandy loam	Maahas clay
	(g/pot)		
1. Field capacity (aerobic)	2.42	4.13	5.34
2. FC + late* anaerobic	4.05	5.50	6.31
3. FC + late* flood	7.77	6.56	6.38
4. Continuous flood	7.61	7.03	7.43

* At panicle primordia initiation.

at field capacity throughout the experiment without the addition of Fe, P, and Si produced the lowest grain yield and the smallest number of spikelets per panicle, (b) these responses were associated with iron deficiency in all soils at panicle primordia initiation and, in addition, later manganese toxicity in Luisiana clay and Casiguran sandy loam, and (c) increased grain yield in the field capacity soils (with and without added Fe, P, and Si) flooded later, were associated with elimination of Mn toxicity in Luisiana clay and alleviation of Fe deficiency except in the field capacity, late flood treatment in Maahas clay. Iron deficiency symptoms were clearest in Maahas clay kept continuously at field capacity (Fig. 5) while Mn toxicity symptoms were unmistakable in the corresponding treatments with Luisiana clay.

In a second experiment, an attempt was made to separate possible direct effects on the plant of saturation of the soil with water from one of the indirect effects, viz., increased availability of iron. The treatments were: (1) continuous aerobic field capacity, (2) early aerobic field capacity, late flood, (3) early aerobic, later anaerobic, field capacity, and (4) continuous flood. The procedure was the same as for earlier experiments (Annual Report, 1963, 1964, 1965) except that the four plants in each pot in all treatments were restricted to the main culms by nipping the tiller buds as they emerged. This was done to facilitate sealing of the soil with paraffin wax to produce anaerobic soil conditions in the early aerobic, late anaerobic–field capacity pots.

Table 13 shows that late anaerobic conditions produced substantial yield increases in the soils kept at field capacity in spite of the fact that a strict anaerobic state was not achieved (this was shown by higher Eh and the lower concentration of Fe^{++} than in the submerged and late flooded treatments). Clear symptoms of iron deficiency were observed from panicle primordia initiation onwards in the case of aerobic Maahas clay at field capacity. This was confirmed by the response of the affected leaves to the application of $FeSO_4$ solution: within 3 days the $FeSO_4$ treated bands turned green (Fig. 6).

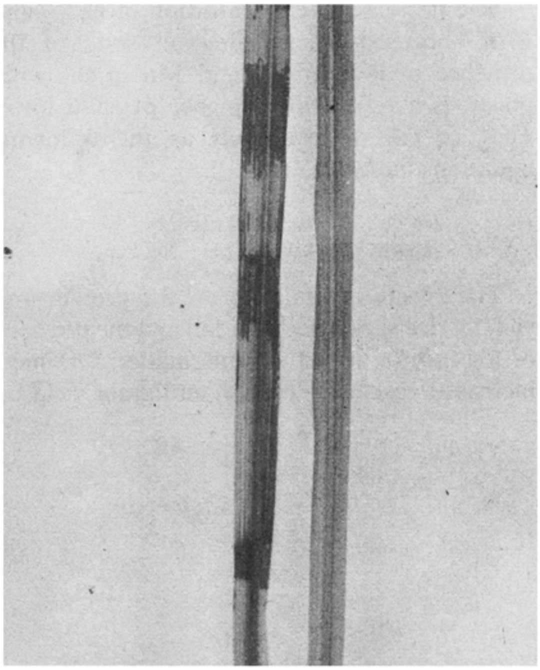

Fig. 6. Iron deficiency in the active center leaf at panicle primordia initiation corrected in the band of $FeSO_4$ application.

These experiments indicate that the chief physiological benefit of flooding rice soils is the increased availability of iron, especially in the reproductive phase of the development of the rice plant; suppression of manganese toxicity is an additional factor on strongly acid soils.

Soil Microbiology

One of the most important research findings obtained during the year was that the insecticide γ-BHC is actively degraded by the anaerobic microflora of submerged soils. Ability of γ-BHC to undergo biodegradation is a valuable property in helping to eliminate problems of residue accumulation.

The results of the two major lines of research in the department are reported as: (1) pesticide residues, and (2) nitrogen transformations in submerged soils.

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Prolonged persistence of a number of chlorinated hydrocarbon pesticides in soil and water has been reported, and attributed either to their resistance to biodegradation or the fact that the pesticide forms a complex with some component of the environment which is largely resistant to microbial attack. Accumulation of these pesticides in natural environments through repeated applications may generate situations hazardous to health and agriculture. Susceptibility to biodegradation, therefore, can be a very desirable characteristic in preventing accumulation of pesticides in natural environments. Consequently, during 1966, emphasis was placed upon determining whether γ-BHC, and several other pesticides that have been shown to be valuable in rice production, are susceptible to microbial attack.

Benzene hexachloride

Available information indicates that the γ-isomer of benzene hexachloride (γ-BHC) persists in non-flooded soils for periods ranging from $3\frac{1}{2}$ to 11 years, and for this reason, the insecticide has been classified as non-biodegradable. Information obtained by the Entomology Department, on the period of insecticidal activity following field applications, as well as evidence obtained in this department, indicates that the persistence of γ-BHC in submerged soils is much

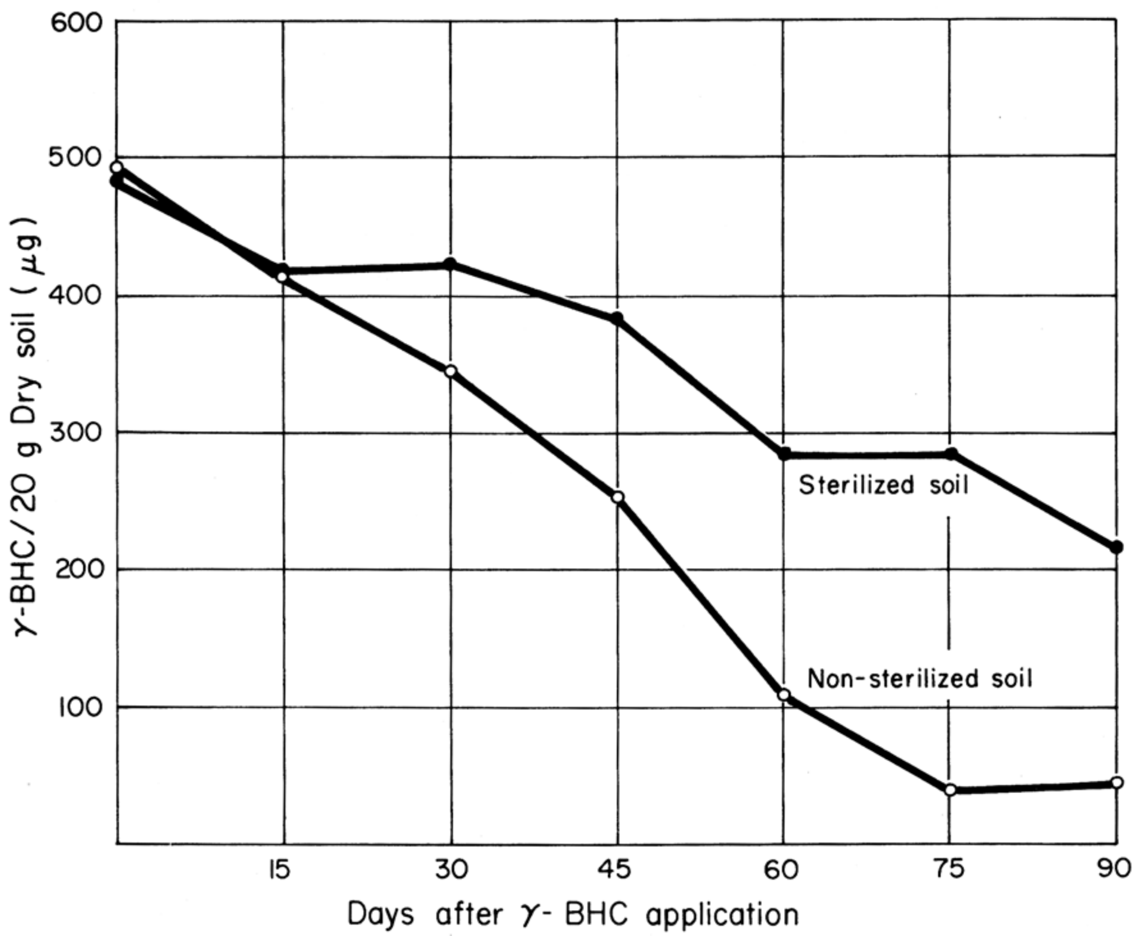


Fig. 1. Persistence of γ-BHC in flooded sterilized and non-sterilized Maahas clay.

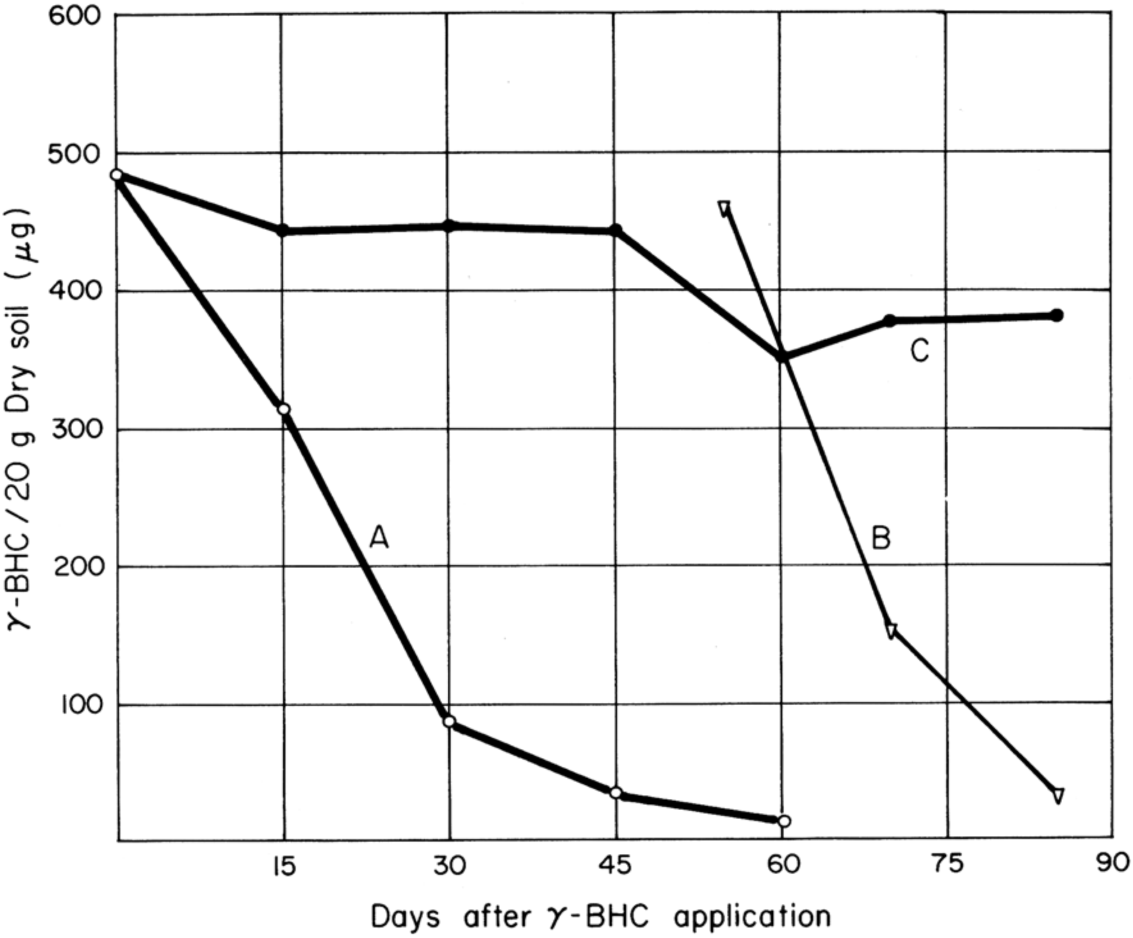


Fig. 2. Persistence of γ-BHC in flooded sterilized (C) and non-sterilized (A and B) Luisiana clay. Curve B represents results following a second application of γ-BHC at 55 days.

shorter than that cited in the literature for non-flooded soils. Preliminary results (Annual Report, 1965) gave strong evidence, although not conclusive, that γ-BHC was degraded biologically in submerged soils. The following experiments were aimed at determining the susceptibility of γ-BHC to microbial attack.

Sterilized and non-sterilized samples of soils from Luzon (Maahas clay and Luisiana clay) were flooded, treated with γ-BHC (approximately 60 kg/ha), and incubated in the greenhouse. The soils were sampled periodically, extracted, and analyzed quantitatively for γ-BHC by gas chromatography. In both soils, the γ-BHC was found to disappear more quickly from those samples which had not been sterilized (Figs. 1 and 2). More rapid loss of the insecticide from non-sterilized soils indicates a role for the soil microflora in the degradation of γ-BHC. Flooded, non-sterilized samples of Luisiana clay were subjected to a second treatment with γ-BHC, which was made 55 days after the first application. At this time, only about 4 percent of the amount of γ-BHC originally applied to the soil still remained. The rate of disappearance of the insecticide following the second application was approximately twice as fast as that obtained in the same period following the first application (Fig. 2). Active participation of the soil microflora in the degradation of γ-BHC is indicated by the shortened persistence of the insecticide in Luisiana clay which was observed after the second application. The results suggest the establishment during the 55 days after the first application of a microbial population in the soil which is active in γ-BHC degradation, and that this population can bring about the degradation of γ-BHC without any apparent lag period.

Microbial degradation of a hydrocarbon usually results in some of the carbon of the hydrocarbon molecule being released as carbon dioxide. Therefore, if C^{14} labelled pesticides are added to soil and the evolved carbon dioxide is trapped, and the amount of radioactivity of the trapped CO_2 is determined, some idea of the extent of the degradation of the pesticide can be obtained. Also, as the method is very sensitive, the susceptibility of a synthetic molecule such as γ-BHC to microbial attack can be determined.

Table 1. $C^{14}O_2$ evolution from C^{14} labelled γ-BHC applied to submerged rice soils.

Soil	Condition	C^{14} cpm/20 g soil*
Maahas clay	sterilized	90
Maahas clay	non-sterilized	10,630
Luisiana clay	sterilized	10
Luisiana clay	non-sterilized	9,830
Pila, calcareous clay loam	sterilized	100
Pila, calcareous clay loam	non-sterilized	7,220

* All counts determined after 15 days incubation and adjusted for background.

C^{14} labelled γ-BHC was added to flooded sterilized and non-sterilized samples of three soils from Luzon, viz., Maahas clay, Luisiana clay, and a calcareous clay loam pH 7.6, O.M. 1.5%. Carbon dioxide—free air was drawn over the surface of the water, the evolved carbon dioxide trapped, and the radioactivity determined. Table 1 shows the results obtained in this study after 15 days of incubation. In all cases, the radioactivity of the trapped carbon dioxide which evolved from the non-sterilized soils was far in excess of that evolved from the sterilized soils. This represents further evidence for biological degradation of γ-BHC. Also, it provides evidence that a portion of the carbon of the cyclo-hexane ring of γ-BHC was oxidized to carbon dioxide, and therefore the six-membered ring must have been ruptured.

Commercial preparations of γ-BHC marketed for use in rice stem borer control are known to contain considerable amounts of some of the other isomers of benzene hexachloride viz., α, β and δ isomers. Therefore, as these substances are also added to soil it is important to know whether they are biodegradable. Sterilized and non-sterilized samples of Maahas clay and Luisiana clay were flooded, treated with each of the four common isomers of benzene hexachloride (α, β, γ and δ) and incubated in the greenhouse. In one series of experiments a soil sample received only one isomer (approximately 32 kg/ha); in another series each soil sample was treated with all four isomers (approximately 32 kg/ha/isomer). Soil samples were removed periodically, extracted, and the amounts of each isomer of benzene hexachloride remaining in the soil determined quantitatively. The results obtained in this study for Luisiana clay (Figs. 3 and 4) showed that all four isomers disappeared more rapidly from non-sterilized soils than sterilized soils, therefore indicating biological degradation. The results obtained with Maahas clay were similar. The rates of disappearance of the isomers of benzene hexachloride from soil samples treated with all four isomers (Fig. 4) were somewhat slower than from soils treated with a single isomer (Fig. 3). However, in both treatments only traces of all four isomers could be detected in the soils 50 days after the treatments were made. As the rates of application of the isomers of BHC in this study were far in excess of the rate used in the field for stem borer control, unusually prolonged persistence of the isomers of benzene hexachloride in submerged soils therefore seems unlikely. Losses of the isomers of benzene hexachloride from sterilized soils can be attributed to volatilization, and their comparative losses were relative to their vapor pressures.

Major factors contributing to the losses of the α, γ and δ isomers of benzene hexachloride from flooded soils are therefore: (1) microbial degradation, (2) volatilization, and (3) leaching. In these studies only small losses of the β-isomer could be attributed to volatilization, so the major factors causing the loss of this isomer from flooded soils are: (1) microbial degradation, and (2) leaching.

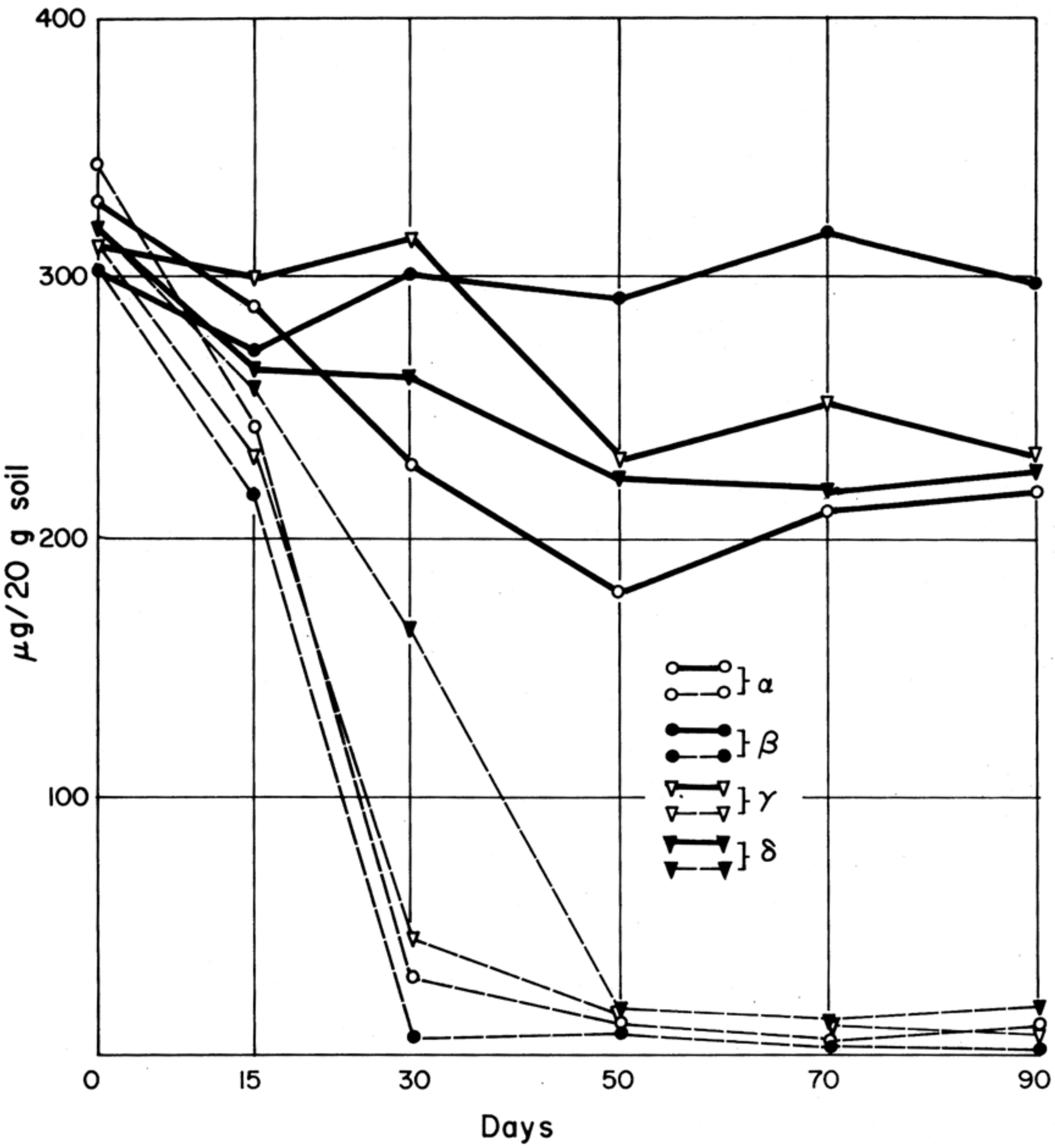


Fig. 3. Persistence of isomers of benzene hexachloride applied singly to flooded sterilized (———) and non-sterilized (– – – – –) Luisiana clay.

While the results of the foregoing experiments provide strong evidence for the biodegradability of benzene hexachloride in flooded soils, unequivocal proof of microbial degradation rests in the isolation of pure cultures of microorganisms that can metabolize the insecticide. Therefore attempts were made to isolate microorganisms that can degrade γ-BHC. The procedure used, was to treat flooded soil samples with γ-BHC, and follow its disappearance by periodically analyzing the soil for the insecticide. When approximately 90 percent of the added insecticide had disappeared from the soil, another treatment with insecticide was made. After two or three subsequent additions aimed at enriching the soil microflora with species that could degrade γ-BHC, attempts were made to isolate, in pure culture, microorganisms which

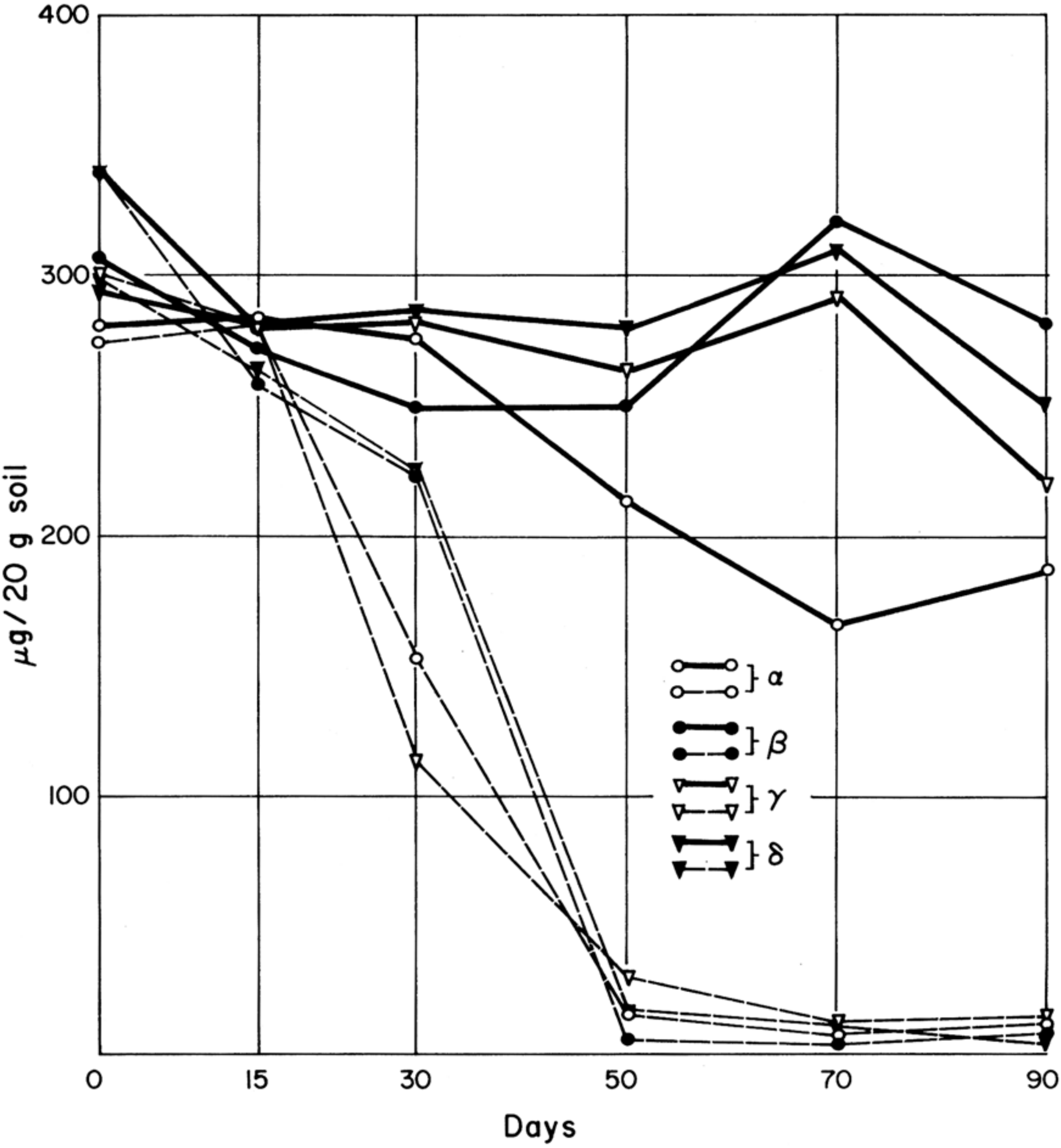


Fig. 4. Persistence of isomers of benzene hexachloride applied in combination to flooded sterilized (———) and non-sterilized (– – – – –) Luisiana clay.

could degrade γ-BHC from these treated soils. By this method, 20 aerobic and 20 anaerobic isolates were obtained which showed promise of being capable of degrading the insecticide. These cultures were subsequently tested for their ability to degrade γ-BHC in a liquid culture medium. Some of the results are shown in Table 2. Only the results obtained for the three most active anaerobic and aerobic cultures are listed. Eleven of the anaerobic isolates brought about more than 50 percent degradation of γ-BHC in the 5-week incubation period. On the other hand, very little degradation of the insecticide occurred in the aerobic cultures in the same time. These results indicate that the major microbial species involved in the degradation of γ-BHC are anaerobic, and could explain the prolonged persistence of the insecticide reported for non-

Table 2. Degradation of γ-BHC in liquid medium by anaerobic and aerobic microorganisms isolated from submerged soils.

Isolate	Cultural condition	γ-BHC remaining after 5 weeks incubation (ppm)
Control*	aerobic	8.64
12	aerobic	7.51
15	aerobic	7.35
18	aerobic	7.75
Control*	anaerobic	7.50
23	anaerobic	0.90
27	anaerobic	0.51
32	anaerobic	<0.01

* Controls represented by uninoculated medium incubated under the same conditions for the same period.

flooded "aerobic" soils in which the microbial population is predominantly aerobic.

In subsequent experiments, two levels of yeast extract (0.05 and 0.5%) were added to the culture medium, and the effect of this increased nutritive supply upon the microbial degradation of γ-BHC was examined. Representative results are shown in Table 3. Increasing the yeast extract content of the growth medium significantly increased the rate of degradation of γ-BHC. This finding is very useful because the low solubility of γ-BHC in water seriously limits the supply of carbon for growth of the microorganism in liquid media. If the organism can be supplied with supplementary carbon in the form of yeast extract without retarding its activity to degrade γ-BHC, it means that adequate quantities of microbial cells can be grown, harvested, and used in studies of the metabolism of the insecticide in chemically defined media.

While persistence studies have provided the valuable information that γ-BHC does not exhibit unusually prolonged persistence in submerged soils, and therefore does not accumulate with multiple applications, no information is available on the fate of the insecticide molecule in soil.

When cultures of microorganisms active in pesticide degradation are available, useful information can be gained by studying the degradation of the pesticide by these microorganisms in chemically defined culture media. In this way, the isolation and chemical characterization of intermediates in the degradation of the pesticide can be performed more readily, and a scheme for the pathway of degradation can be formulated. Armed with this information, the microbiologist can then transfer the study to the degradation of the pesticide in the very complex environment of the soil, thereby bringing the study of pesticide decomposition to a more practical level from the point of view of crop production. The aims of the following studies therefore are: (1) to determine the path of degradation of γ-BHC, (2) to determine the extent of γ-BHC degradation, and (3) if degradation should prove not complete, to determine the nature of the residue, and whether accumulation of the residue in soil poses any problem to crop production or health.

The most active isolate in the degradation of γ-BHC (No. 32, Table 3) was cultured, harvested, washed, concentrated to give a dense population, and finally exposed to γ-BHC in a phosphate buffer under anaerobic conditions for 6 hours. During this time, aliquots were removed

Table 3. Effect of yeast extract upon the degradation of γ-BHC by anaerobic microorganisms isolated from submerged soils.

Isolate	γ-BHC remaining after 11 days incubation (ppm)	
	0.05% yeast extract	0.5% yeast extract
Control*	3.20	3.70
22	2.40	0.11
27	2.00	0.19
32	2.50	0.03

* Control represented by uninoculated medium incubated under the same conditions for the same period.

Table 4. Degradation of γ-BHC by a washed suspension of an anaerobic microorganism isolated from submerged soils.

Time (hours)	γ-BHC remaining in reaction mixture (ppm)
0	2.87
1	2.05
2	1.61
4	1.45
6	1.50

hourly and the amount of γ-BHC remaining was determined. The chloride content of the reaction mixture was also determined hourly. The results in Table 4 show that almost half of the γ-BHC had disappeared in 6 hours.

Gamma-BHC is a chlorinated hydrocarbon and the release of chlorine from an organic combination to the inorganic chloride form is an excellent measure of the extent of degradation of such substances. During the 6-hour experiment, the chloride content of the reaction mixture increased by 1.0 ppm, which is equivalent to the theoretical amount of chloride that could be released from the amount of γ-BHC that was degraded, assuming that all six chlorine atoms of γ-BHC are released into the reaction mixture as inorganic chloride.

Provisional characterization of culture No. 32 shows it to be an anaerobic, gram negative, spore-forming rod of the genus *Clostridium*.

The results obtained in studies on benzene hexachloride may be summarized as follows:

1. The four common isomers of benzene hexachloride (α, β, γ, and δ) are all susceptible to microbial attack. This property is of distinct value in helping to eliminate problems associated with lengthy persistence of these substances in submerged soils.

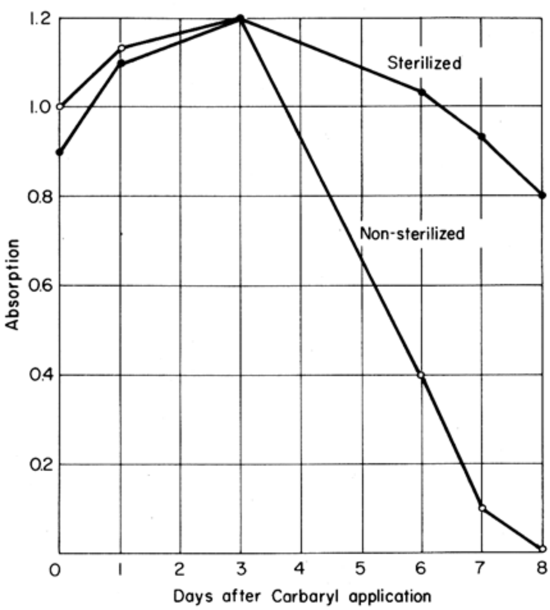


Fig. 5. Absorption of 280 mμ of supernatants from suspensions of Maahas clay treated with carbaryl.

2. Microbial degradation of the gamma isomer is predominantly due to the activities of the anaerobic species of the soil microflora of submerged soils. This suggests that where γ-BHC residues have become a problem in non-flooded soils, flood fallowing may help to reduce the levels of the insecticide in the soil.

3. Anaerobic metabolism of the γ-BHC molecule results in complete chloride release and rupture of the six-membered carbon ring.

1-napthyl-N-methyl carbamate (carbaryl)

The nucleus of the carbaryl molecule is a naphthalene ring structure, and as such, strongly absorbs light in the ultra-violet region of the spectrum giving rise to two major absorption peaks at 270 and 280 mμ. If the double aromatic ring structure of the naphthalene nucleus were ruptured as a result of microbial degradation, the absorption maxima in the ultra-violet region of the spectrum would be lost. This characteristic was used in determining the biodegradability of the insecticide, carbaryl.

Sterilized and non-sterilized suspensions of three Luzon soils (Maahas clay, Luisiana clay and a fine sandy loam from Albay) were treated with carbaryl (approximately 50 ppm) and incubated at 30 C. Periodically, samples were withdrawn, centrifuged to remove soil particles, and the absorption of the supernatants determined at 270 and 280 mμ against a soil suspension blank which had not received the insecticide. After an initial lag period of about 3 days, the absorption due to the naphthalene ring declined rapidly in the non-sterilized soil suspensions of Maahas clay, whereas the absorption of the sterilized soil suspensions remained relatively constant over the 8-day incubation period (Fig. 5). No absorption was detected in the non-sterilized Maahas clay suspensions after 8 days incubation, indicating that the naphthalene ring structure of carbaryl had been completely disrupted. More rapid loss of ultra-violet absorption in non-sterilized suspensions of the same soil is strong evidence for biological degradation.

No significant loss of absorption was found during the same incubation period for non-sterilized suspensions of Luisiana clay or the fine sandy loam from Albay. These results may

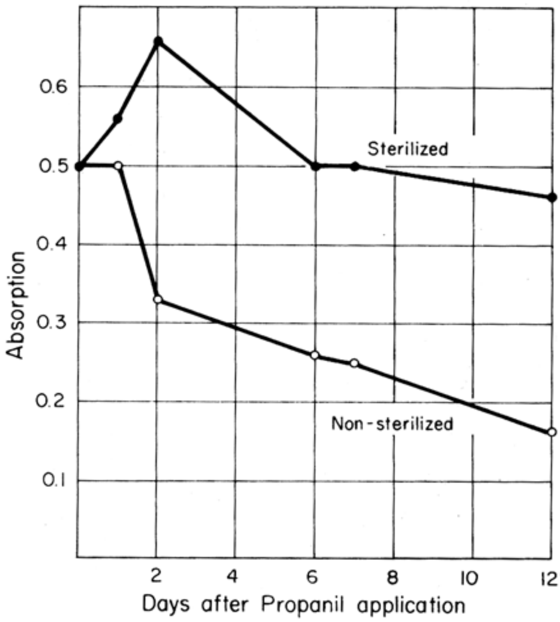


Fig. 6. Absorption of 242 mμ of supernatants from suspensions of Maahas clay treated with propanil.

indicate differences in the persistence of the insecticide among the three soils. However, as loss of ultra-violet absorption requires rather complete degradation of the insecticide molecule, the persistence of carbaryl in Luisiana clay and Albay sandy loam and similar soils should be checked using a more specific chemical technique for the assay of carbaryl.

Following enrichment culture procedures, a number of aerobic bacteria were isolated for their ability to degrade carbaryl. Two very active cultures were selected from these which were able to grow in liquid medium with carbaryl as the sole carbon source. Complete degradation of the aromatic nucleus of carbaryl was brought about in 1 week. When the cultures were supplied with yeast extract as a supplementary carbon source, growth was enhanced and complete degradation of carbaryl took only 3 days.

Unequivocal evidence for the microbial degradation of carbaryl has been obtained and therefore microbial degradation is one of the important factors governing the persistence of this insecticide in submerged soils. Further studies currently in progress are aimed at determining the pathway of degradation of carbaryl by the isolated bacteria, characterizing the bacterial species involved, and determining the fate of carbaryl and structurally related compounds in submerged soils.

3,4-dichloropropionanilide (propanil)

The herbicide, propanil, possesses an aromatic nucleus and, like carbaryl, absorbs light strongly in the ultra-violet region of the spectrum (248 mμ). Sterilized and non-sterilized soil suspensions of three Luzon soils (Maahas clay, Luisiana clay and a fine sandy loam from Albay) were treated with propanil (approximately 10 ppm) and incubated at 30 C. Periodically, samples were withdrawn and the ultra-violet absorption determined. Very little change in the ultra-violet absorption of the sterilized suspensions was detected during the 14-day incubation period (Fig. 6). However, the ultra-violet absorption of the non-sterilized Maahas clay suspensions declined rapidly, indicating rupture of the aromatic nucleus by the soil microflora. Within the first 48 hours of incubation the absorption maximum of the non-sterilized supernatants shifted from 248 mμ to 242 mμ. No such change occurred in the sterilized soil suspensions. Possibly, this slight shift of the absorption maximum may be attributed to cleavage of the propionic acid side chain from the aromatic nucleus to leave 3,4-dichloroaniline which is then degraded by the soil microflora resulting in loss of absorption of 242 mμ. The results obtained with the fine sandy loam soil were similar to those with Maahas clay. Very little degradation was detected in suspensions of Luisiana clay.

Several bacterial cultures have been isolated from the Maahas clay suspensions for their ability to degrade propanil. Current work is aimed at determining the pathway of degradation by these cultures.

Nitrogen Transformations

In 1964 and 1965 attempts were made to evaluate the significance of biological nitrogen fixation in increasing or maintaining the levels of soil nitrogen in submerged tropical soils. Also, attempts were made to trace the movement of nitrogen in and out of the pool of the soil organic nitrogen and to assess the extent of nitrogen immobilization. During the past year, a part of the research program in the department was devoted to obtaining information on several ways in which nitrogen can be lost from submerged soils, viz., (1) denitrification and (2) volatilization of ammonia.

Denitrification

Biological denitrification may be defined as the dissimilatory reduction of nitrate (or nitrite) to some gaseous forms of nitrogen, and results from the utilization of nitrate (or nitrite) as an electron acceptor in the respiration of certain facultatively anaerobic bacteria. This process is quite distinct from assimilatory nitrate reduction in which the nitrate serves as a source of nitrogen for growth of the organism.

Following harvest of the rice crop, the soil is usually allowed to dry and, depending upon the intensity of rice cultivation, remains dry for a considerable period until the next cropping season. During this time when the soils are "aerobic", nitrification of soil ammonia proceeds and a significant proportion of the soil nitrogen is converted to nitrate. When the soil is again flooded in preparation for the next planting of rice, conditions favoring denitrification are soon established as the soil oxygen is rapidly depleted.

Usually, the assumption is that all, or a very large proportion, of the nitrate nitrogen (generated during the dry phase of the rice soil) is lost from the soil after flooding through the process of denitrification. However, no information is available on the extent of assimilatory reduction of this nitrate, whereby the nitrate nitrogen is transferred to the pool of soil organic nitrogen, and is therefore not lost from the soil.

Six Philippine soils having the following characteristics were chosen for denitrification studies: Maahas clay (pH 6.6, O.M. 2.0%); Luisiana clay (pH 4.7, O.M. 3.2%); Pila calcareous clay loam (pH 7.6, O.M. 1.5%); Albay fine sandy loam (pH 5.7, O.M. 8.0%); Calabanga clay (pH 6.2, O.M. 4.8%); and Zambales fine sandy loam (pH 6.0, O.M. 4.0%). The soils were treated with $KN^{15}O_3$, flooded, and incubated in the greenhouse. Samples were removed at 0 day, 3 days, and 1, 2, 3, and 6 weeks after submergence and total nitrogen, nitrate nitrogen, KCl-extractable ammonium nitrogen, and organic nitrogen were determined. The distillates from each of these fractions were also analyzed for the N^{15} content.

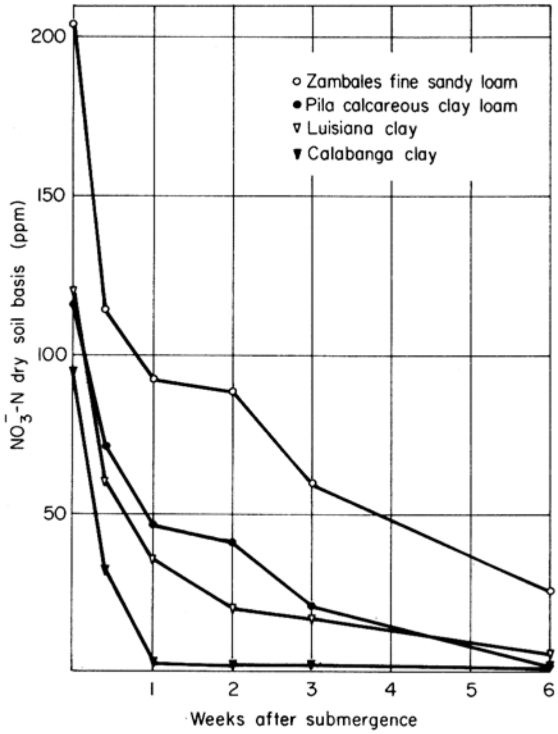


Fig. 7. Nitrate -N content of soils following submergence.

The nitrate-nitrogen content of all six soils declined rapidly following submergence. The results obtained for four of the soils are shown in Fig. 7. Almost all of the nitrate had disappeared from Albay fine sandy loam and Calabanga clay within 1 week of submergence, indicating very rapid reduction of these two soils. Determination of the N^{15} content of the distillates derived from the total soil nitrogen analyses (Fig. 8) revealed that all of the N^{15} had been lost from Albay fine sandy loam and Calabanga clay within the first 2 weeks of submergence, thereby demonstrating that all of the applied nitrate-nitrogen had been lost from these two soils by denitrification. However, even after 6 weeks of submergence, from 9 to 45 percent of the applied N^{15} was still retained by the other four soils. When the distillates from the nitrate fractions were analyzed for N^{15}, none was detected in the nitrate fractions from Albay fine sandy loam and Calabanga clay after 2 weeks of submergence. The nitrate fractions of the other four soils contained N^{15} even after 6 weeks of submergence (Fig. 9). However, not all of the N^{15} detected in the total soil nitrogen distillates could be accounted for as nitrate nitrogen.

Determination of the amount of N^{15} in the organic nitrogen fraction of these four soils showed that a considerable amount (5 to 42%) of the N^{15} from the applied nitrate had been immobilized into the organic nitrogen pool by the end of the 6 weeks of submergence (Fig. 10).

The results of these studies may be summarized as follows:

1. Considerable losses of soil nitrogen occur, when a soil is flooded, through denitrification of nitrate generated during the dry phase of soil treatment. These losses account for from 50 to 100 percent of the nitrate nitrogen present in the soil at the time of submergence.
2. The most rapid period of denitrification for the six soils studied occurred during the first week of submergence.
3. In the case of four of the soils studied, not all of the nitrate nitrogen is lost from the soil by denitrification. A significant proportion of this nitrate undergoes reduction and enters the soil organic nitrogen pool presumably through the process of assimilatory nitrate reduction.

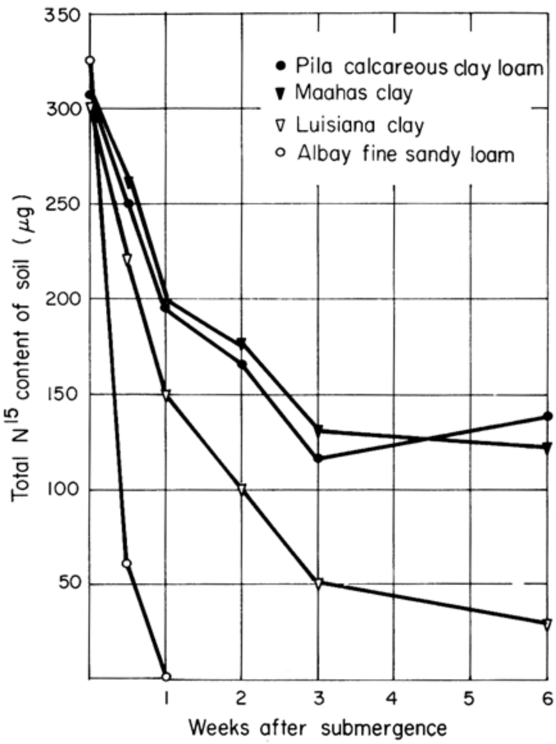


Fig. 8. Recovery of applied $KN^{15}O_3$-N^{15} in the distillates from total nitrogen determinations of submerged soils.

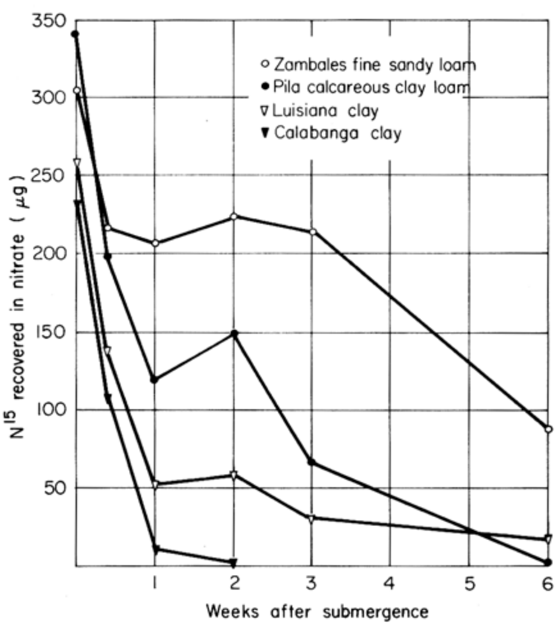


Fig. 9. Recovery of applied $KN^{15}O_3$-N^{15} in the nitrate fraction of submerged soils.

Volatilization of ammonia

Volatilization losses of nitrogen from soils in the form of ammonia have been reported, and generally occur when ammonia is formed at, or diffuses to, the soil surface, or when ammonia is applied as fertilizer to the surface of the soil. The significance of these losses of nitrogen from submerged tropical soils is not known.

To obtain information on the magnitude of these losses, four tropical soils having the following characteristics were selected: Maahas clay, pH 6.6, O.M. 2.0%; Luisiana clay, pH 4.7, O.M. 3.2%; Silo silt loam (from Taiwan) pH 8.1, O.M. 2.0%; and an acid-sulfate soil (from Vietnam) pH 3.5, O.M. 10%. The soils were placed in glass containers to provide a column of soil, approximately 15 cm in length. Nitrogen in the form of $(NH_4)_2SO_4$ was applied to the soils at levels approximating 50 and 200 kg/ha N. In one series of containers the fertilizer was applied to the surface of the soil just prior to flooding, and in another series the soil was kept saturated for 3

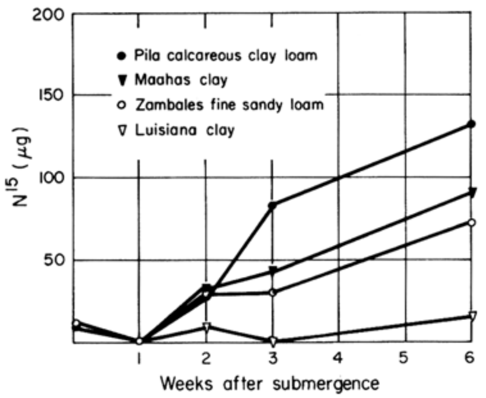


Fig. 10. Recovery of applied $KN^{15}O_3$-N^{15} in the organic nitrogen fraction of submerged soils.

days, after which the $(NH_4)_2SO_4$ was applied and mixed thoroughly with the wet soil before submergence. A third series, representing the control without additional nitrogen, was prepared. Air, freed of ammonia, was slowly drawn over the surface of the submerged soils, and any evolved ammonia was trapped and quantitatively determined at weekly intervals.

The results obtained for two of the soils up to 4 weeks after submergence are shown in Figs. 11 and 12. Small amounts of ammonia nitrogen were lost from all the unamended soils. Calculated to annual losses of ammonia nitrogen on a hectare basis these losses were: Maahas clay

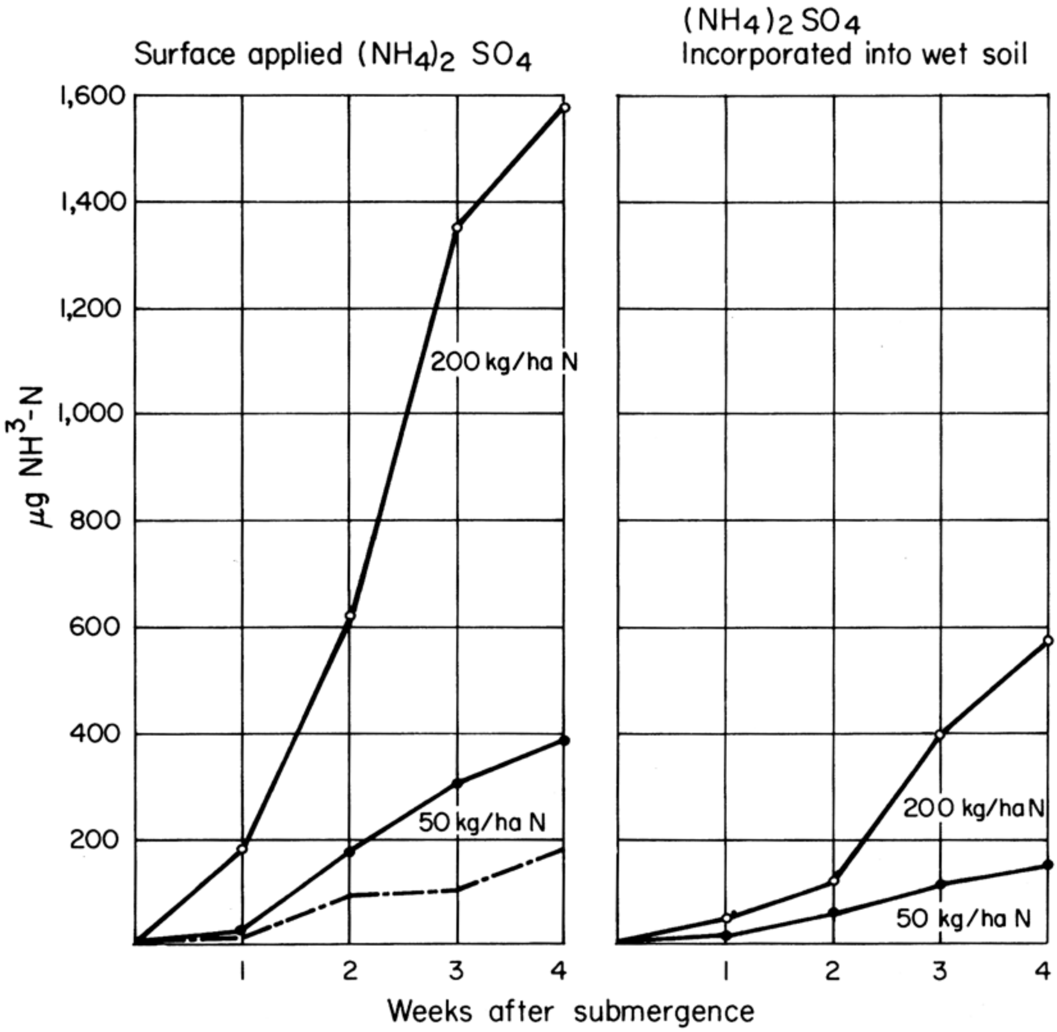


Fig. 11. Losses of ammonia by volatilization from Maahas clay following submergence. Amounts of applied nitrogen were 8.1 mg and 32.4 mg at the 50 and 200 kg/ha N levels respectively.

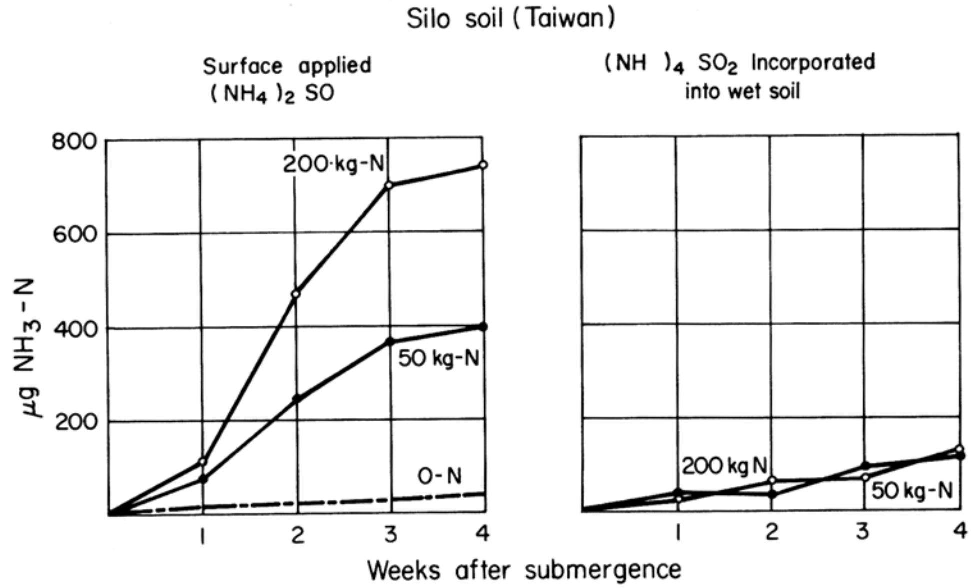


Fig. 12. Losses of ammonia by volatilization from Silo silt loam following submergence. Amounts of applied nitrogen were 7.3 mg and 29.2 mg at the 50 and 200 kg/ha N levels respectively.

10.7 kg, Luisiana clay 8.7 kg, acid-sulfate soil 4.3 kg, and Silo silt loam 3.2 kg. While these figures cannot be taken to indicate the magnitude of losses in the field, they do show that ammonia volatilization can occur even in a very acid soil such as the one from Vietnam.

When $(NH_4)_2SO_4$ was applied to the surface of the four soils the amount of ammonia lost by volatilization increased with increase in the amount applied. The amount of nitrogen lost from Maahas clay through ammonia volatilization represented 4.7 and 4.5 percent of the applied nitrogen at the 50 and 200 kg/ha N levels respectively.

Incorporation of the $(NH_4)_2SO_4$ into the soils after three days of saturation dramatically decreased the losses of nitrogen due to ammonia volatilization (Figs. 11 and 12).

The following conclusions may be drawn from these studies:

1. Losses of native soil nitrogen from flooded soils can occur through the volatilization of ammonia in spite of the low initial pH of some soils.

2. Significant losses of nitrogen through ammonia volatilization occur when fertilizer in the form of $(NH_4)_2SO_4$ is applied to the surface of soils prior to flooding, and the losses increase as the rate of application is increased.

3. While incorporation of the $(NH_4)_2SO_4$ into wet soils drastically reduces the magnitude of losses of ammonia, significant losses still occur, presumably by diffusion of the ammonia to the soil surface. The field practice of incorporation of ammonium fertilizers into the mud of a rice field therefore not only reduces losses due to nitrification, but can also reduce losses attributable to ammonia volatilization.

As loss of ammonia from soils by volatilization is believed to be controlled by a number of factors including pH, cation exchange capacity, and total nitrogen content, it was expected that the order of magnitude of losses for the four soils studied would be quite different. It is obvious that the process of ammonia volatilization from flooded soils is poorly understood and that further work is necessary.

Agronomy

Agronomy research at the Institute continued to seek answers to questions in the broad area of cultural practices. The experiments conducted fell into the same general categories as previously but with continued change in emphasis as new opportunities became apparent and as minor experiments revealed leads for further research.

New yield records established during the year for replicated trials at the Institute were for a single crop (10,130 kg/ha), two crops (16,411 kg/ha), and three crops (20,170 kg/ha). IR 8 produced the highest one-crop and double-crop totals.

Soil fertility research continued to be particularly fruitful as the newer varieties were tested in multiple-level nitrogen response tests. The practice of using at least five levels of nitrogen has led to response curves with substantially greater detail and interest than the usual nitrogen x variety experiment conducted on rice experiment stations.

In weed control research greater emphasis was placed on upland rice with a multiple factor approach and the evaluation of tillage. The discovery of selectivity in a pyridinol compound at unusually low rates was significant both for flooded and dry sown rice. Direct seeding experiments were continued and expanded along with work on minimum tillage and tillage practices. Experiments were also conducted on rotation crops, silica fertilization, herbicide screening, and water management.

An important part of the Agronomy program during the past few years has been to formulate a list of recommended cultural practices synthesized from the work of and in cooperation with the staff of the Institute. The recommendations have been made at two levels (experimental and farm) with revisions every 6 months, or more often as new practices or materials are proved superior. Different practices are recommended for dry and wet seasons.

1966 ANNUAL REPORT, The International Rice Research Institute *Mailing Address:* Manila Hotel, Manila, Philippines

Continuous-Cropping Experiment

A continuous-cropping experiment at four nitrogen levels has been conducted on the same field since 1962. The field has usually been prepared and replanted within 5 days of harvesting the previous crop and has never been allowed to dry. In June 1964 the experiment was redesigned to include planting methods, and varieties have been changed to include only those early varieties that have the best yield records in other experiments. In the March 1966 planting IR8 was included for the first time. Cultural practices which have become standard in agronomy experiments at the Institute were used.

Figure 1 shows the 10 successive crops grown since February 1963. Yields are presented as means of 4 replications from the best treatment in each crop along with the principal treatments.

The highest yields have come from harvests in April through June or early July when the main growing season is during dry, clear weather. In five out of seven cases where direct seeding treatments were included, they have produced the best yields. Optimum fertilizer nitrogen levels have usually been higher for dry-season crops and IR8 has produced the best yield in each season in which it has been grown.

The present combination is of varieties all early enough for a 3-crop annual cycle to be completed in a few days less than a year even in direct-seeded treatments. The 3-crop total yield on a best-treatment basis has exceeded 20 m ton/ha, which is probably a world record annual output of rough rice from a replicated test. In another experiment a 4-crop annual schedule is being followed but annual yields are no higher than with three crops.

Date-of-Planting Experiment

Date-of-planting experiments were continued during the year with three quite different varieties of rice planted each month at four spacings (15 x 15 cm, 25 x 25 cm, 35 x 35 cm, and 45 x 45 cm) and two fertilizer levels (30 and 90 kg/ha N).

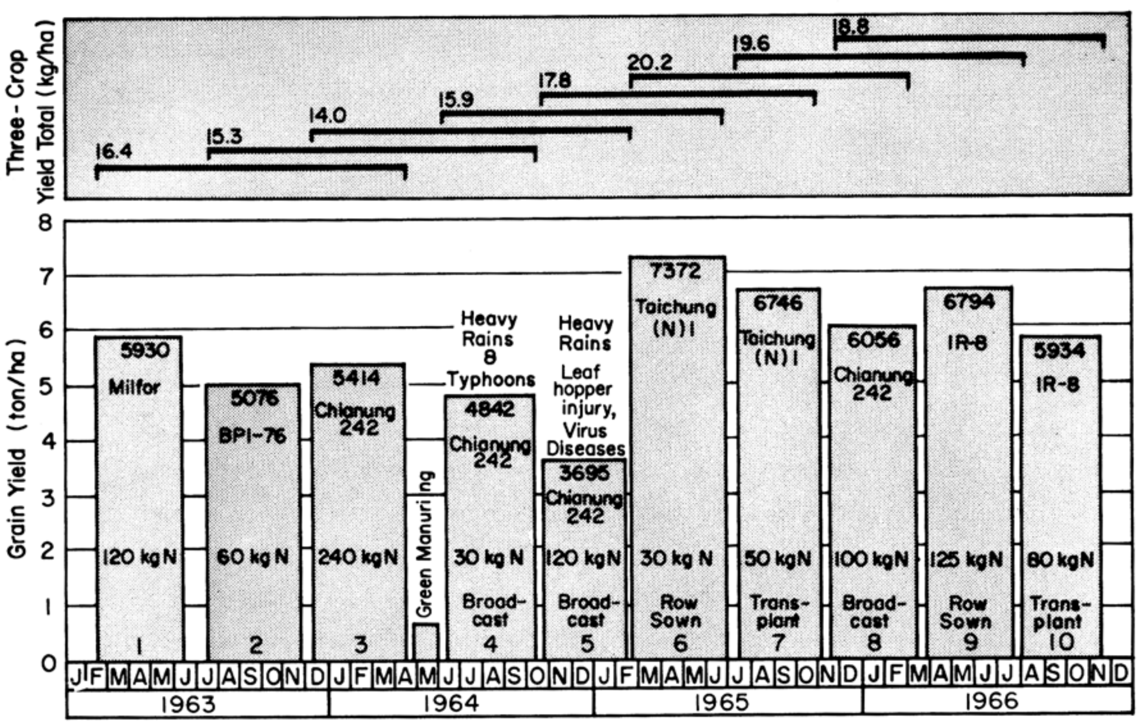


Fig. 1. A chart of the best treatment combination in a continuous cropping experiment. The 20-ton/ha yield from three successive crops obtained in 1966 is a record annual yield.

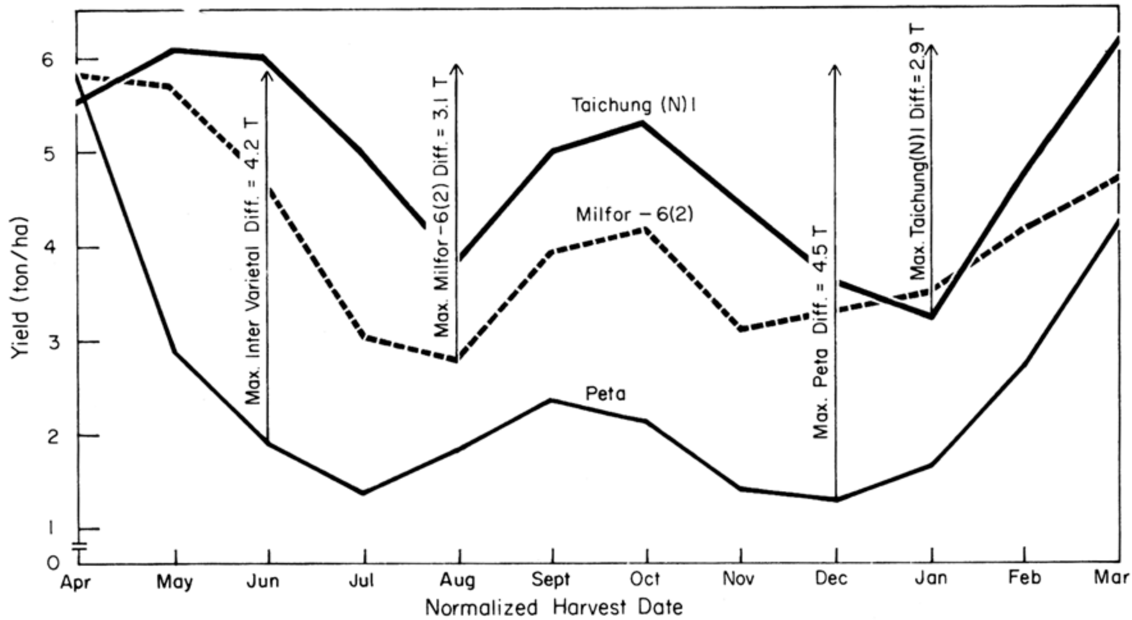


Fig. 2. Yields of Peta, Milfor-6(2) and Taichung (Native) 1 from the two closer spacings and high nitrogen levels (90 kg) plotted by dates of harvest. Peta harvests were plotted as occurring on the same date each month but the variety is somewhat photoperiod sensitive.

All three varieties had indica grain quality but were of different plant type. Peta is a typical tall (170 cm), leafy, weak-strawed tropical rice with great vigor and some disease resistance; Milfor-6(2) is an intermediate-statured (125 cm), low-tillering but moderately stiff-strawed, nitrogen-responsive variety of Philippine origin; Taichung (Native) 1 is a dwarf (100 cm), high-tillering, nitrogen-responsive but disease-susceptible indica type from Taiwan. Taichung (Native) 1 has been the standard of high yield capability in many countries where it has been grown under good management.

During 1963 and 1964, the plots were severely affected by virus disease, bacterial leaf blight, and occasionally blast, and were attacked by rats regularly during the off-season. As greater control of the biological environment was obtained, better yields resulted and the crop response more nearly represented limits of the physical environment. Virus disease was controlled with insecticides that eliminated the leafhopper vector, rat damage was moderated by a multiple factor campaign, and the stem borer was controlled with applications of γ-BHC. In making the final analysis of environment, only crops which were relatively normal in growth and undamaged by predators were used.

That the three varieties behaved differently is shown in Fig. 2 in which yield is plotted against time of harvest. In spite of large differences in plant type, leafiness, and height, the three varieties demonstrated a similar relative yield. Maximum yields were obtained when harvests were made in the months of March, April, and May which are months of highest levels of solar radiation. Lowest yields were obtained in December or January harvests which resulted from late wet-season plantings.

The tests demonstrate that environmental factors are equally important as varietal differences in determining yields. The maximum intervarietal difference occurred when harvests were made in June, and, as expected, was the difference of 4.2 ton/ha between Peta and Taichung (Native) 1. This represents the inherent varietal differences ascribable to plant type, mutual shading, disease, and lodging susceptibility, etc. The intra-varietal difference which represents the response of the same variety to changed environment or "external" shading was slightly greater for Peta, being 4.5 ton/ha.

Fig. 3. A stiff-strawed indica variety, IR8, has yielded 7 to 10 ton/ha during the dry season and 5 to 7 ton/ha during the 1966 wet season in various soil fertility experiments conducted at IRRI and elsewhere.

Taichung (Native) 1 produced a substantially lower variation (2.9 m ton) while Milfor-6(2) was intermediate (3.1 m ton).

April harvest for all three varieties produced similar yields of between 5,500 and 5,800 kg/ha for means of two spacings at 90 kg/ha N.

The experiment is being continued with changes in variety which will replace Peta and Taichung (Native) 1 with H-4 and IR8. Net radiation data are now being collected in addition to the gross figures used previously.

Soil Fertility and Fertilizer Management

During 1966 the major emphasis in soil fertility research has been on various aspects of fertilizing rice with nitrogen. Studies were made into the effect of plant types, season of growth, and soils, on the nitrogen response of existing tropical varieties in comparison with the plant types of short stature developed at the Institute. Investigations were continued on the efficient use of anhydrous ammonia, particularly with regard to the appropriate swath interval for flooded soil. Effect of time and methods of application of fertilizer nitrogen were also investigated. Other areas of research concerned management practices and nitrogen response, sources and rates of fertilizer phosphorus, effect of calcium silicate on flooded rice, and soil incorporation of insecticides for insect and disease control.

Effect of plant type and nitrogen level on the growth habit and grain yield of indica rice

Experiments were conducted during the 1966 dry and wet seasons to study the nitrogen response and the growth habits of both the traditional leafy tropical indica varieties and dwarf indicas of improved plant type selected or developed at the Institute. With the introduction of these improved varieties, substantial changes in fertilizer practices will be essential if their full potential is to be realized.

Dry season. The varieties used included tall indica varieties that are either non-sensitive to photoperiod or only weakly so. Peta, Tjeremas, Bengawan, and Binato are widely grown in the Philippines. Milfor-6(2) is a tall but fairly stiff-strawed indica variety from the Philippines, and C-18 is a selection from the University of the Philippines College of Agriculture. The two dwarf indicas used were Taichung (Native) 1 from Taiwan, and IR8, a dwarf indica variety bred at the Institute (Fig. 3). The rate of nitrogen applied varied from 0 to 120 kg/ha; it was all harrowed-in during land preparation.

Measurements made 30 days after transplanting showed that without added nitrogen, Peta, C-18, Taichung (Native) 1, and IR8 had produced more dry matter than the other varieties, indicating their greater seedling vigor. At this stage the maximum difference in plant height between the eight varieties was about 15 cm. At panicle initiation and harvest the differences between the dwarf and tall varieties ranged from 40 to 75 cm, respectively. Bengawan was the tallest variety at maturity (165 cm height).

Plant height was negatively correlated with culm strength (Fig. 4) and with the mean grain yield (Fig. 5) in the eight varieties tested; the r values were highly significant (—0.95** in both instances). The mean culm strength was significantly correlated (0.934**) with mean grain yield (Fig. 6).

These results stress the importance of short stature to culm strength and final grain yield. Most of the tall varieties lodged at some time. Varieties such as Peta, Tjeremas, Bengawan, and Binato exhibited both leaf and culm lodging (Fig. 7). The selection C-18 showed only culm lodging, and Milfor-6(2) lodged 2 days before harvest. With Binato and Bengawan leaf lodging

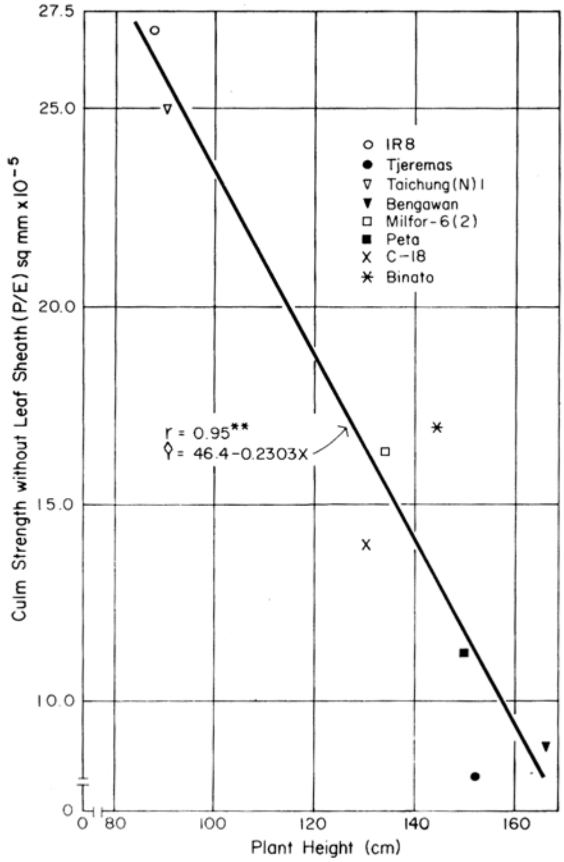


Fig. 4. Relationship between mean plant height and mean culm strength of eight indica rice varieties at maturity. IRRI, 1966 dry season.

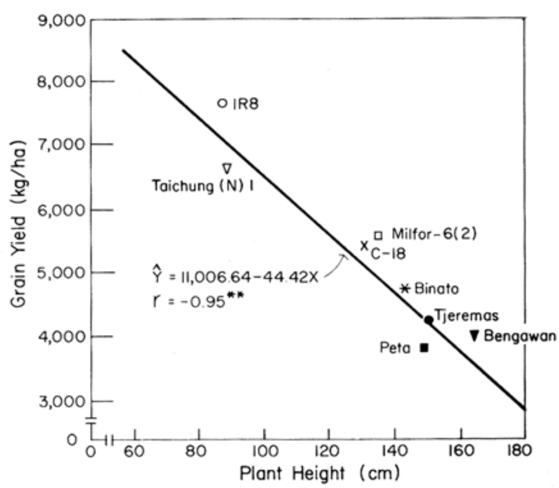


Fig. 5. Relationship between (correlation coefficient and regression factor) plant height and grain yield of eight varieties. IRRI, 1966 dry season.

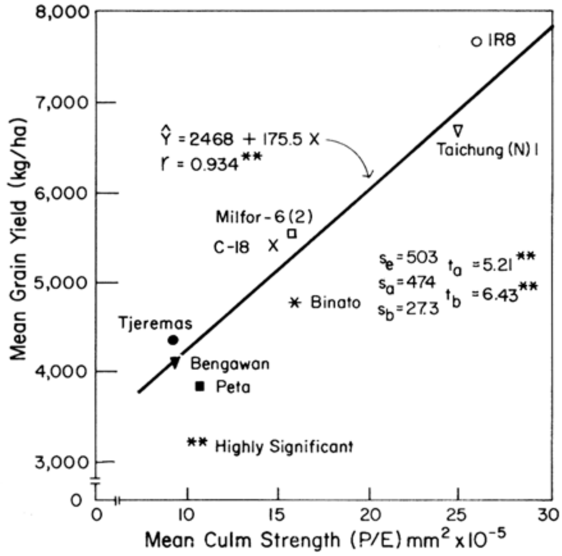


Fig. 6. Relationship between mean culm strength and mean grain yield of eight indica rice varieties. IRRI, 1966 dry season.

Tjeremas produced a significant yield response. The yields of Milfor-6(2) and C-18 were almost identical up to 90 kg/ha N, and the differences between no-nitrogen and 60 kg/ha N were significant in both varieties.

The two dwarf indica varieties, Taichung (Native) 1 and IR8, behaved very differently from the tall indicas. Taichung (Native) 1 produced highest yield at 90 kg/ha N; the difference in grain yields between 90 kg/ha and no-nitrogen was significant, but not between any two levels of applied nitrogen (30-120 kg/ha N). IR8 produced progressively higher yields up to 120 kg/ha N. There was a significant increase of 2 m ton/ha of grain yield with the first 30 kg/ha N applied.

The efficiency of nitrogen utilization as measured by kg rough rice/kg N applied was 69 between 30 and 0 kg/ha N for IR8. Even at 120 kg/ha N, IR8 produced about 30 kg rough rice/kg N. This is certainly a substantial return even at 120 kg/ha N, since, in the Philippines, the cost of 1 kg of nitrogen is 3.2 times more than that of 1 kg of rough rice.

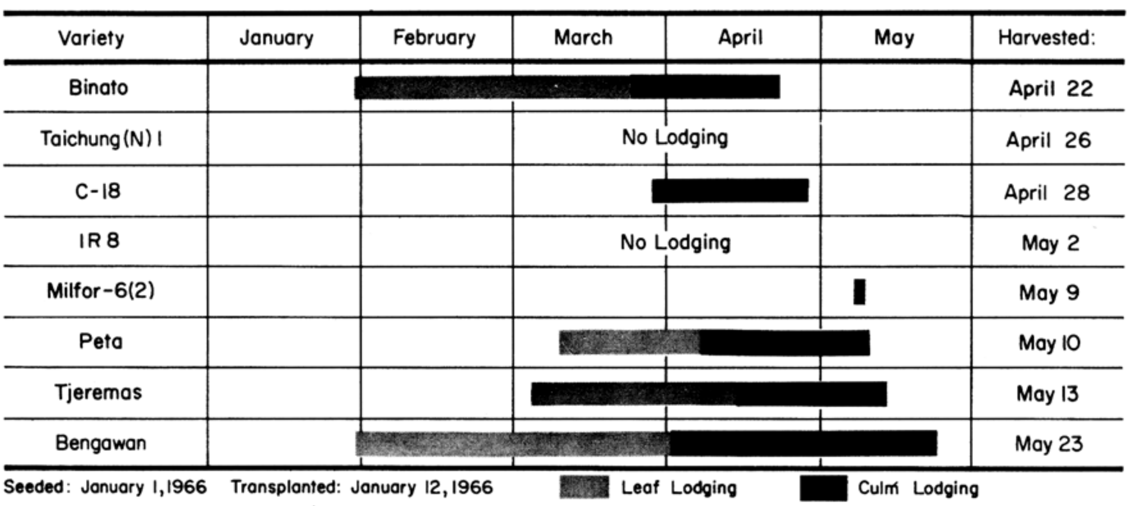


Fig. 7. Differences in the sequence and kind of lodging of eight indica varieties. IRRI, 1966 dry season.

commenced even at the initial tillering stage. Peta and Tjeremas exhibited leaf lodging when nearing panicle initiation stage. Most of the leaf lodging at early stages of growth was observed early in the morning. The two dwarfs, Taichung (Native) 1 and IR8, showed no signs of lodging even at 120 kg/ha N.

Except for Milfor-6(2), all the typical, tall indica varieties yielded most where from 30 to 60 kg/ha N was applied (Fig. 8), and of these only

The productivity of IR8 based on field duration was 86.2 kg/ha/day. The grain yields of IR8 or Taichung (Native) 1 did not decrease even at high levels of applied nitrogen. By contrast, there was a reduction in grain yield with all tall varieties except Milfor-6(2).

At 30 days after transplanting, the dry matter production (DMP) of most varieties was similar at equivalent levels of nitrogen. With greater amount of dry matter produced at later stages of growth, such as at panicle initiation and at harvest, the light transmission ratio (LTR) values decreased but the relationship seems to be log normal rather than negative linear.

The relationships of DMP and LTR at three stages of plant growth are summarized together in Fig. 9. There does not seem to be a clear optimum LTR at panicle initiation to produce a maximum dry matter increase from panicle initiation to harvest (Fig. 10). Up to the panicle initiation, the dry matter produced by Peta and IR8 were similar (Fig. 11); thereafter, IR8 increased steadily whereas the rate of increase in Peta was more gradual. Taichung (Native) 1 behaved similarly to IR8 but the dry matter produced was lower beyond 30 days after transplanting. These results show that IR8 is more efficient than Taichung (Native) 1 or Peta, not only in grain production but also in total dry matter production (Fig. 11). The increase in dry matter from panicle initiation to harvest was significantly correlated with the grain yield of eight varieties (Fig. 12).

At harvest, IR8 produced most dry matter, followed by Milfor-6(2) > Taichung (Native) 1 > Bengawan > C-18 > Binato > Tjeremas > Peta (average of all nitrogen levels). The difference in dry matter produced by IR8 and Peta was about 3 m ton/ha at harvest compared with only 36 kg/ha a month after transplanting. This is explained by the data on lodging. The tall, weak-strawed variety, Peta, may be capable, if it does not lodge, of producing dry matter similar in amount to that produced by a stiff-strawed variety such as IR8. However, when the plants lodge, particularly at early stages of growth, they will produce not only low grain yield but also low straw yield and hence low total dry matter at harvest. Furthermore, even when total dry matter yields at harvest are similar, a tall variety such as Peta will produce more straw than grain, in contrast to the equal grain and straw production for a dwarf variety such as IR8.

Wet season. In addition to the varieties used in the dry season, BPI-76 and several photosensitive Philippine varieties were included in the wet-season test. The nitrogen applied varied from 0 to 80 kg/ha N with 20-kg increments. IR8 produced a modest increase of 861 kg/ha of rough rice with 60 kg/ha N (Fig. 13). However, at all nitrogen levels IR8 produced the highest yield of the varieties tested. The difference in grain yield between IR8 and Taichung (Native) 1 was 1,631 kg/ha and between IR8 and Peta, 3,474 kg/ha (average of all N levels). The highest yields of IR8, Taichung (Native) 1 and Peta were 15,507, 11,708, and 7,998 kg/ha rough/rice/2 crops respectively (dry and wet seasons). These results demonstrate the superiority of IR8 over Taichung (Native) 1 not only during the sunny dry season but also in the cloudy wet season and hence in annual production under a 2-crop culture.

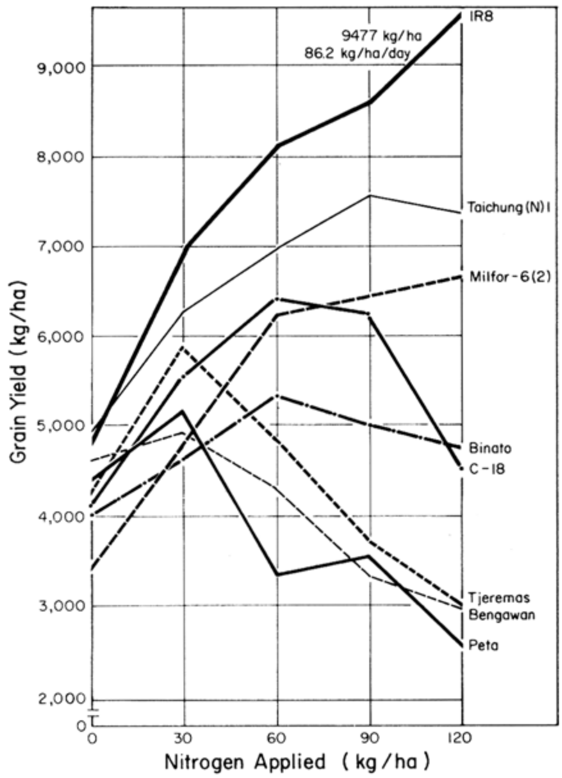


Fig. 8. Effect of levels of nitrogen on the grain yield of indica rice. IRRI, 1966 dry season.

The sequence of leaf and culm lodging is summarized in Fig. 14. Peta, Tjeremas, and Bengawan started exhibiting leaf lodging at maximum tillering stage, and severe culm lodging at booting stage at most levels of added

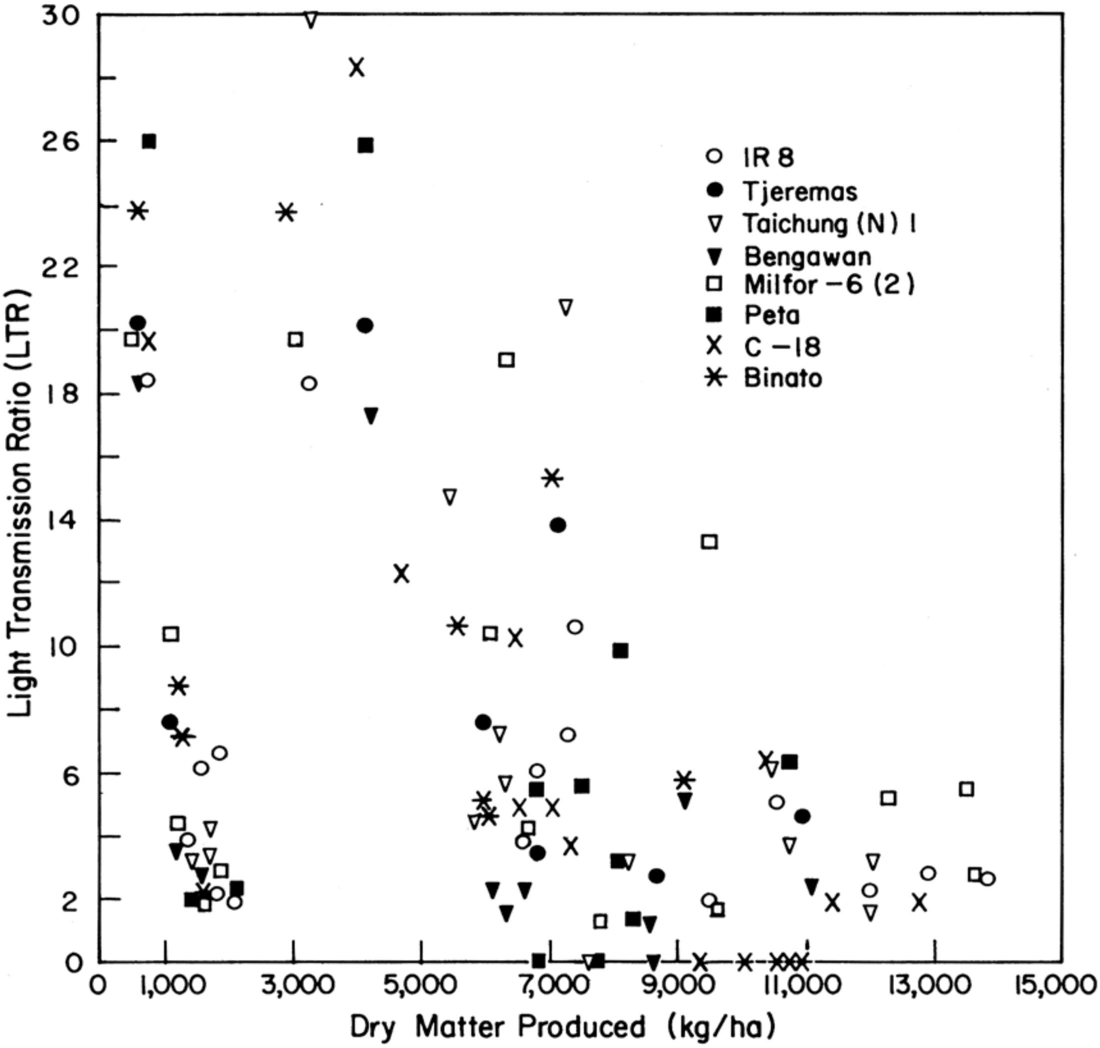


Fig. 9. Relationship between dry matter produced by eight indica rice varieties at three stages of growth and corresponding light transmission ratio. IRRI, 1966 dry season.

nitrogen. At harvest, Peta, Tjeremas, and Bengawas lodged 100 percent at all levels of nitrogen, including no-nitrogen plots. C-18 lodged 95 to 100 percent with any level of added nitrogen and 50 percent in the no-nitrogen plots. When Peta, Bengawan, and C-18 were completely lodged without added nitrogen, the short stiff-strawed variety, IR8, stood erect even with 80 kg/ha N during the wet season (Fig. 15).

The dry matter production of Peta increased progressively up to heading and then, as a result of lodging, decreased rapidly from heading to harvest (Fig. 16), whereas that of stiff-strawed varieties, such as Taichung (Native) 1 and IR8, increased steadily up to maturity. At harvest, IR8 produced more dry matter than either Taichung (Native) 1 or Peta.

The difference in dry matter produced at maturity by IR8 and Taichung (Native) 1 was primarily due to the incidence of bacterial leaf blight on Taichung (Native) 1, particularly at higher levels of added nitrogen.

As in the dry season, the increase in dry matter from panicle initiation to harvest was significantly correlated with grain yield (Fig. 17). Results also indicate that during the wet season the increase in dry matter from panicle initiation to harvest was primarily dependent on the resist-

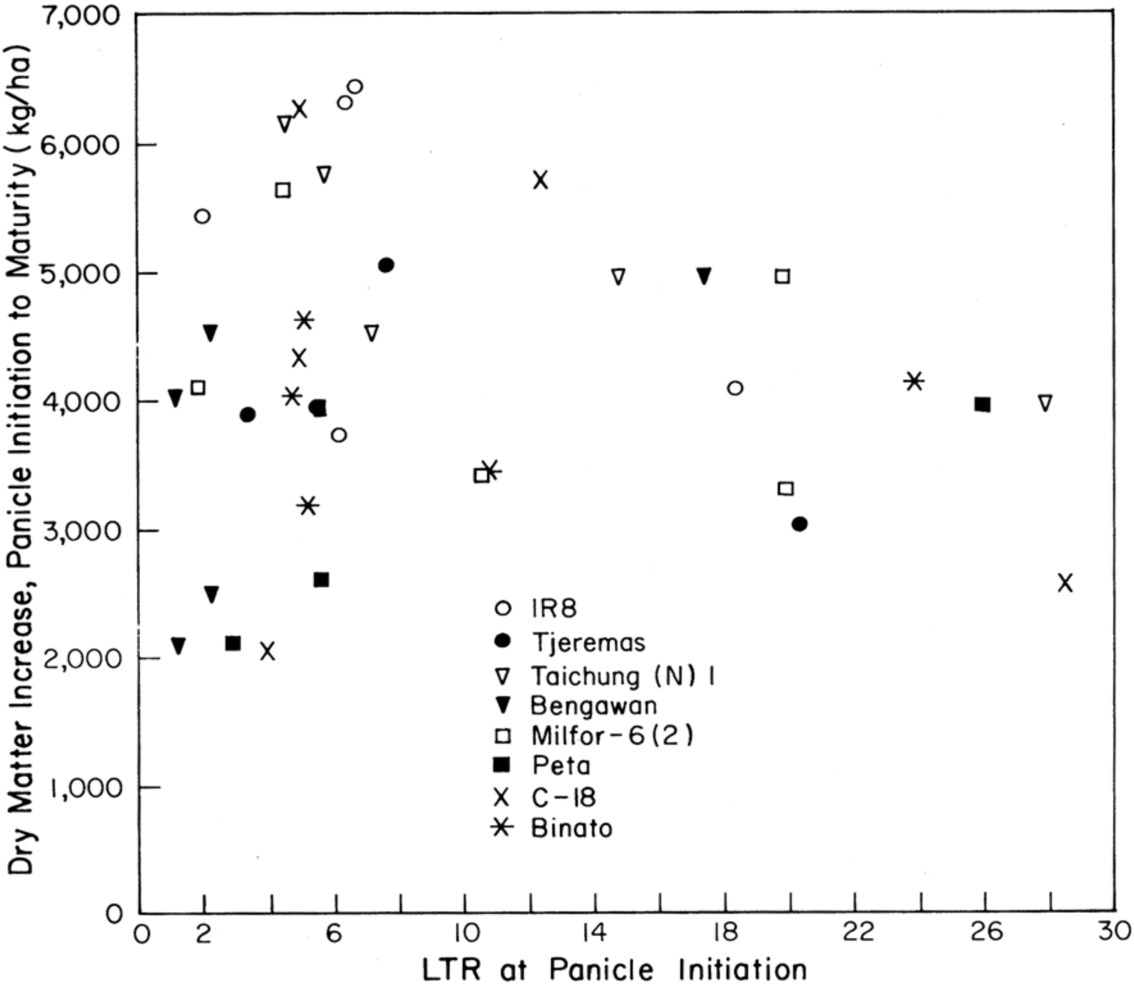


Fig. 10. Relationship between light transmission ratio at panicle initiation of eight indica varieties and increase in dry matter from panicle initiation to maturity. IRRI, 1966 dry season.

ance to lodging. The total dry matter produced during the wet season, and corresponding LTR at three stages of growth, are summarized in Fig. 18.

Adaptation to heavy fertilization of indica rice

An experiment was conducted on Maahas clay soil to study the ability of varieties and selections of short stature to withstand heavy dressings of nitrogen fertilizer without being affected by disease or lodging. A tall, weak-strawed indica variety, H-4 from Ceylon, was included as a check. An indication of the high native fertility of certain locations on the Institute farm (Maahas clay) is that the grain yields ranged from 5,000 to 7,000 kg/ha without nitrogen. Analyses of wet soil samples collected from the experimental site showed that the net release of NH_4^+-N over the period of the experiment amounted to 45 kg/ha. The experiment was also, of course, conducted with stringent insect, disease, and weed control and with continuous and adequate water supply (Table 1).

Highest yield was obtained with IR8 at 120 kg/ha N which corresponded to the results obtained in the experiment on nitrogen response of indica rice. The other dwarfs yielded from 7,000 to 8,000 kg/ha, mostly with 60 kg/ha N.

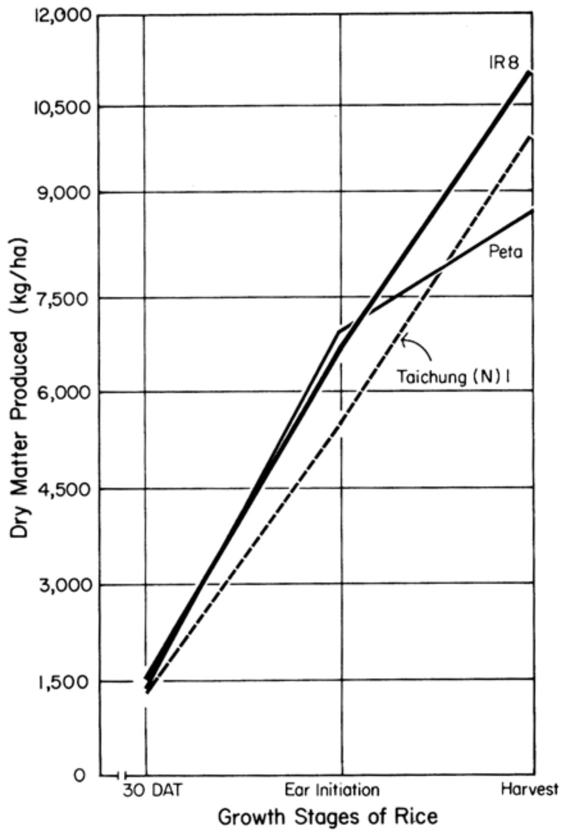


Fig. 11. Total dry matter produced by different rice plant types at three stages of plant growth. IRRI, 1966 dry season.

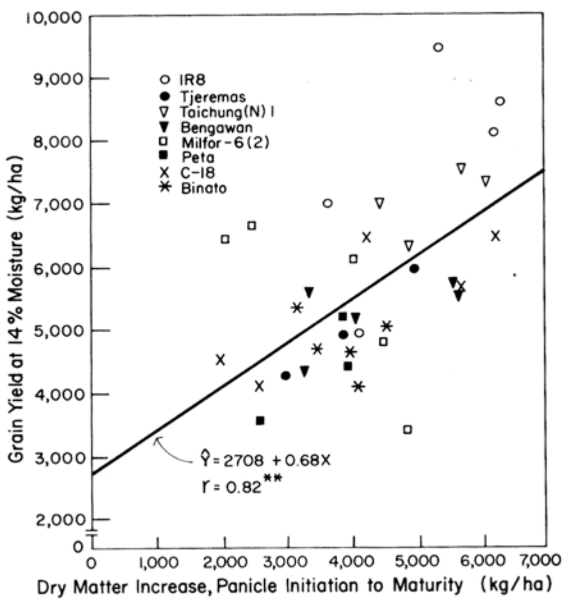


Fig. 12. Relationship between grain yield at 14% moisture and increase in dry matter from panicle initiation to maturity. IRRI, 1966 dry season.

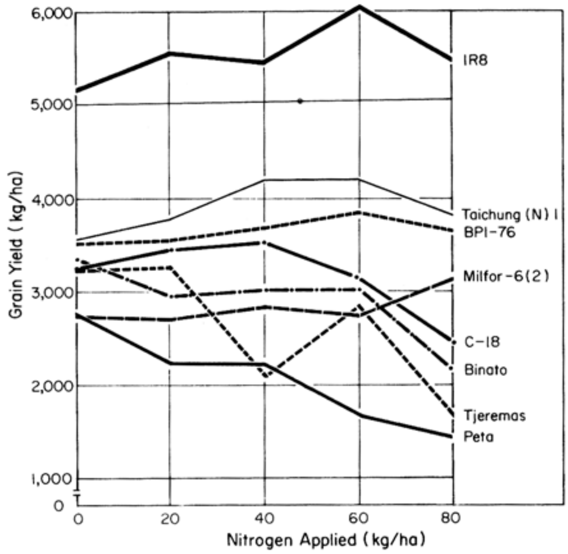


Fig. 13. Effect of levels of nitrogen on the grain yield of indica rice. IRRI, 1966 wet season.

Taichung (Native) 1 was affected by blast *(Piricularia oryzae)*, particularly at 180 and 240 kg/ha N, and suffered a significant reduction in grain yield. In this experiment, Acc. 6993, IR9-60, and IR8 usually did not lodge. IR8 lodged at 240 kg/ha N shortly before harvest. IR8-246, IR8-36, and Taichung (Native) 1 lodged at the higher levels of nitrogen. The tall, typical leafy variety, H-4, produced most grain with no fertilizer and lodged with added nitrogen since the native fertility was already high.

Nitrogen response and varietal type

The objectives of this experiment were not only to examine varietal types and nitrogen response of tall and dwarf indica varieties, but also to compare these indicas with the japonicas from Taiwan and with varieties, such as ADT-27 from India, developed from indica x japonica parents. Although japonicas from Taiwan are widely adapted in the tropics and, compared to tall indicas, produce a high stable yield in most seasons, they have certain characters which limit their suitability for extensive cultivation in tropical Asia.

Nitrogen as ammonium sulfate was harrowed into Maahas clay soil, mostly before transplanting, at rates that varied from 0 to 210 kg/ha in 30-kg increments.

Table 1. Effect of levels of nitrogen on the grain yield of seven varieties. IRRI, 1966 dry season.

Grain yield at 14% moisture (average, 3 replications)

Nitrogen applied	Variety or selection							Mean (N-level)
	Acc. 6993	Taichung (N) 1	IR9-60	IR8-36	IR8-246	IR8	H-4	
(kg/ha)			(kg/ha)				(check)	(kg/ha)
0	5184	6218	5534	6243	6844	7210	6062	6185
40+20	7431	8199	7410	7940	8089	8607	5855	7647
100+20	7187	7674	6566	6552	7498	9340	4787	7086
160+20	7273	3712†	7838	5848	5405	9179	4453	6244
220+20	7333	3592†	6725	3502	4526	8636	3319	5376
Mean (variety)	6881	5879	6815	6017	6472	8594	4895	
Duration (days)	113	114	117	122	118	122	124	

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
N levels (N)$^{n.s.}$	453	—	7	
Variety (V)**	233	657	4	14
N X V**	521	1469	8	

† Seriously affected by blast *(Piricularia oryzae)*.

Dry season. On the fertile Maahas clay soil, with stringent insect, disease and weed control, and under continuous and assured water supply, the mean grain yield without added nitrogen was 5,877 kg/ha for all varieties; IR8 produced 7,896 kg/ha rough rice without added nitrogen (Fig. 19). This is explained by an earlier study showing that during 110 days of submergence substantial amounts of ammonium nitrogen are released from the Maahas clay. The dry season was normal with respect to solar energy.

In this experiment IR8 produced its highest yield of 10,130 kg/ha rough rice (average of 4 replicates)—the highest so far reported from

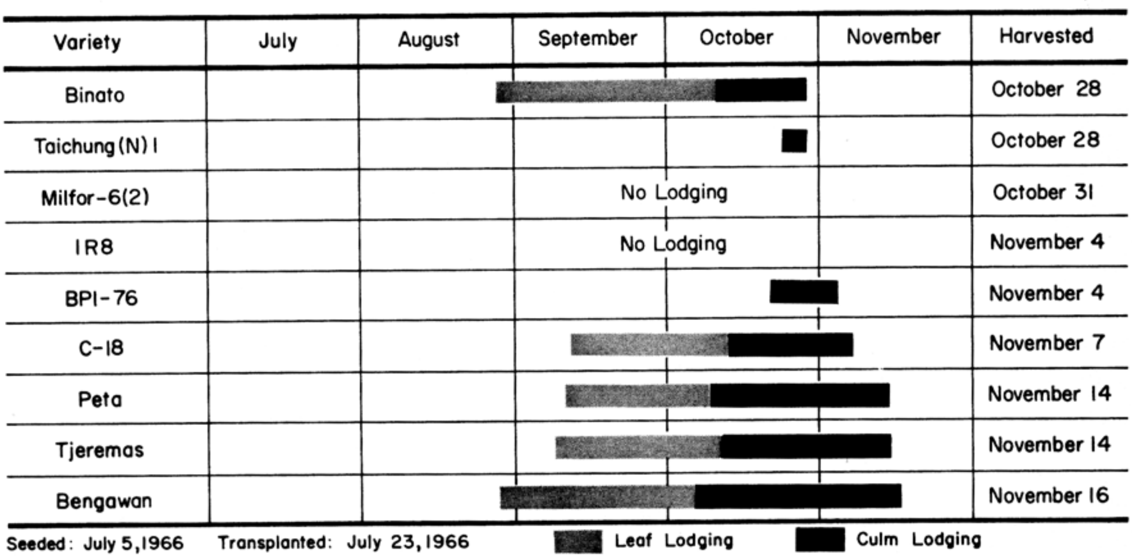


Fig. 14. Differences in the sequence and kind of lodging of indica varieties. IRRI, 1966 wet season.

Fig. 15. While tall and weak strawed varieties, Peta and Bengawan, and a selection, C-18, lodged heavily close to maturity, growing on fertile Maahas clay, a stiff-strawed variety, IR8, did not lodge even with 80 kg/ha N. IRRI, 1966 wet season.

replicated Institute experiments. The productivity of IR8 based on field duration was 92 kg/ha/day rough rice, the highest value reported anywhere for an indica rice.

Most varieties and selections yielded best at 60 kg/ha N. The efficiency of fertilizer nitrogen at this rate of four varieties was:

IR8 — 39.8 (kg rough rice/kg N)
IR9-60 — 21.2 (kg rough rice/kg N)
Tainan 1 — 21.8 (kg rough rice/kg N)
ADT-27 — 1.2 (kg rough rice/kg N)

The results thus demonstrate that by using a suitable variety the efficiency of fertilizer nitrogen can be substantially improved.

Another interesting aspect of this experiment was that the reduction in grain yield, even at high levels of added nitrogen, was not as drastic for dwarf indicas (IR8 and IR9-60) as for the ponlai variety, Tainan 1, or the relatively weak-strawed varieties or selections, such as ADT-27 and C-18. Taichung (Native) 1 was affected by blast *(Piricularia oryzae)* at higher levels of added nitrogen; the incidence was severe beyond 120 kg/ha N, causing substantial reduction in grain yield.

The results show the yield advantage and potential of dwarf indicas over the ponlai varieties and certainly over the tall, weak-strawed indicas. Furthermore, the results demonstrate the superiority of IR8 over closely related varieties and selections with a similar plant type.

Wet season. Six of the eight varieties used during the dry season were retained in the wet-season experiment but Fujisaka 5 and B5711 were omitted and replaced by IR5-47-2 (Peta x Tangkai Rotan) and a traditional tall, weak-strawed variety, Mashuri from Malaysia.

Once again IR8 outyielded any other variety or selection (Table 2). The top yield of 6,281 kg/ha, however, was comparatively low for the variety. This can be ascribed to seasonal conditions; as pointed out in a previous section, during September and October, solar radiation was about 20 percent below normal. The 2-crop total, 16,411 kg/ha rough rice, obtained with IR8 in this experiment, is the highest annual production for this number of crops reported from experiments at the Institute.

From the dry- and wet-season experiments, the following general observations can be made:

(1) Tall, weak-strawed tropical varieties are lower yielding in any season than either ponlai or dwarf indicas.

(2) Ponlai varieties have good plant type, are high yielding and adapted to most tropical environments, but they are 20 cm taller than the dwarf indicas and the straw strength is lower. The ponlais invariably lodge close to harvest, particularly at high nitrogen levels and under adverse climatic conditions. They do not have the seedling vigor necessary to insure an early stand establishment under poor water control during the monsoon season.

(3) Many dwarf indicas will provide consistently high yields in both seasons and in most normal planting situations. Because of their short stature, the dwarfs lodge only under extremely high fertility or when affected by diseases and/or storms.

(4) The yields of IR8 are consistently higher than those of the dwarf indicas Taichung (Native) 1, IR9-60, and Acc. 6993.

Nitrogen response experiments in farmer's fields

Studies were conducted on farmers' fields under economically feasible management practices into varietal effects on nitrogen response. These experiments were conducted in cooperation with the superintendent of the Institute Experimental Farm.

Dry season. Experiments were conducted in two locations at Biñan and one at Los Baños, Philippines. The nitrogen levels varied from 0 to 150 kg/ha N. The varieties used at Biñan were Binato, IR8, Taichung (Native) 1 and a selection, IR9-60. Taichung (Native) 1 was not included in the Los Baños experiment. Pest control measures in these experiments were less elaborate than those used at the Institute farm and should be within the capacity of many Asian farmers.

Table 2. Effect of levels of nitrogen on the grain yield of different varietal types of rice. IRRI, 1966 wet season.

Grain yield at 14% moisture (average, 4 replications)

Nitrogen applied	Variety or selection								Mean (N-rates)
	IR8	ADT-27†	Taichung (N) 1	Tainan 1	IR9-60	C-18	IR5-47-2	Mashuri	
(kg/ha)					(kg/ha)				
0	5566	2850	4094	3532	4643	4375	5231	3007	4162
5+10	5545	3317	4601	4081	4854	3596	5433	3789	4402
20+10	5737	3163	3648	3706	4900	3292	4980	3451	4166
35+10	6192	2425	4873	4151	4648	1496	3927	3182	3849
50+10	6281	2470	4442	4287	4734	2594	4155	1933	3862
65+10	5252	2025	3924	4241	4857	1684	3547	2132	3458
80+10	4268	1709	3275	3853	4332	1643	3303	1683	3009
95+10	4900	2200	4124	3513	4498	1019	2385	1606	3031
Mean (variety)		2420	4123	3920	4683	2462	4120	2598	

	Without ADT-27				With ADT-27			
Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Nitrogen levels (N)**	142	394	3.6					
Variety (V)**	306	909	7.8	19 **	200	568	5.4	15
N X V**	377	1045	9.6					

† Average of 2 replications.

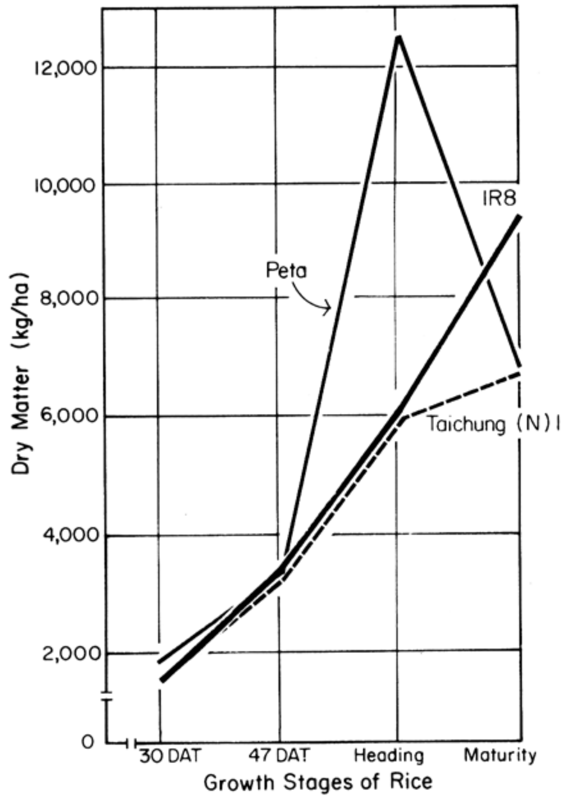


Fig. 16. Total dry matter produced by different rice plant types at four stages of plant growth. IRRI, 1966 wet season.

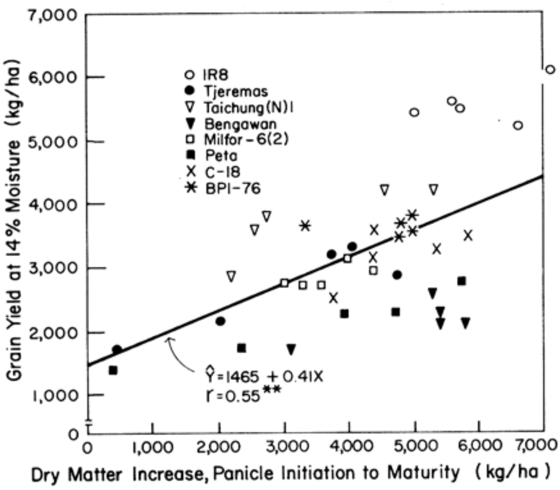


Fig. 17. Relationship between increase in dry matter from panicle initiation to maturity and grain yield at 14% moisture. IRRI, 1966 wet season.

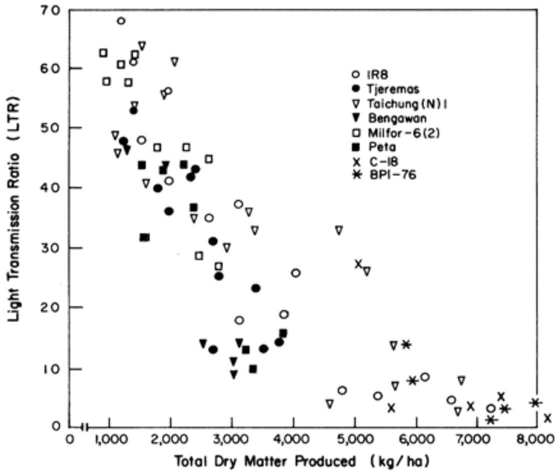


Fig. 18. Relationship between total dry matter produced by eight indica rice varieties and corresponding light transmission ratio at three stages of growth. IRRI, 1966 wet season.

In all three experiments the highest yields were obtained with IR8 and ranged from over 7 tons to 8.5 m ton/ha (Tables 3, 4, and 5). The highest grain yields from Taichung (Native) 1 were 5.8 and 6.4 m ton/ha. In the Los Baños experiment, the highest yield from Binato was 5.6 m ton/ha, whereas in the same experiment IR8 yielded 8.5 m ton/ha. The relative resistances to lodging of these two varieties are shown in Fig. 20.

Wet season. An experiment was conducted in a farmer's field at Calamba using a local variety, Peta, and, as examples of improved varieties, IR8, IR5-47-2, and Taichung (Native) 1.

The grain yield difference with IR8 between 80 kg/ha N and no nitrogen was highly significant (Fig. 21). None of the other varieties responded significantly in terms of grain yield to added nitrogen. The highest yield of IR8 was 7,476 kg/ha at 80 kg/ha N. This was the highest yield obtained during the wet season in any soil fertility experiment conducted either at the Institute or on outside plots. IR5-47-2, about 30 cm taller than IR8, yielded 6.8 m ton/ha (Fig. 21). Compared with Taichung (Native) 1, which had a maximum yield of 6 ton/ha in this experiment, IR5-47-2 appears to be a promising selection and should perform reasonably well if it does not lodge at an early stage of growth. IR5-47-2 is undoubtedly superior to Peta but

Table 3. Effect of levels of nitrogen on the grain yield of indica rice. Nitrogen response experiment in farmer's field, Biñan I, Philippines, 1966 dry season.

Grain yield at 14% moisture

Nitrogen applied	Variety or selection			Mean (N-rate).
	IR9-60	IR8	Taichung (N) 1	
(kg/ha)		(kg/ha)		
0	4004	4945	4796	4582
40+20	5395	6938	6201	6178
80+20	5221	7280	6406	6302
120+20	5792	7285	6095	6390
Mean (variety)	5103	6612	5874	

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
N-rate**	123	392	3.1	
Variety**	86	252	1.5	5.9
N X V*	173	504	3.0	

Table 4. Effect of levels of nitrogen on the grain yield of indica rice. Nitrogen response experiment in farmer's field, Biñan II, Philippines, 1966 dry season.

Grain yield at 14% moisture

Nitrogen applied	Variety or selection				Mean (N-rate)
	Binato	IR9-60	IR8	Taichung (N) 1	
(kg/ha)		(kg/ha)			
0	3033	3383	4854	3729	3750
30+20	3426	3907	4602	4507	4110
80+20	3156	4523	6663	5450	4948
130+20	3056	3879	7232	5883	5012
Mean (variety)	3168	3923	5838	4892	

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Nitrogen rate	344	—	7.7	
Variety**	196	604	4.4	12.4
N X V*	392	1208	8.8	

Table 5. Effect of levels of nitrogen on the grain yield of indica rice. Nitrogen response experiment in farmer's field, Los Baños, 1966 dry season.

Grain yield at 14% moisture

Nitrogen applied	Variety or selection			Mean (N-rate)
	Binato	IR9-60	IR8	
(kg/ha)		(kg/ha)		
0	4771	4344	5400	4838
30+20	4756	5431	7216	5801
80+20	5659	6239	8534	6811
130+20	4538	7240	8501	6750
Mean (variety)	4931	5814	7413	

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
N level (N)$^{n.s.}$	197	—	3.3	
Variety (V)**	123	401	2.0	5.8
N X V**	246	802	4.1	

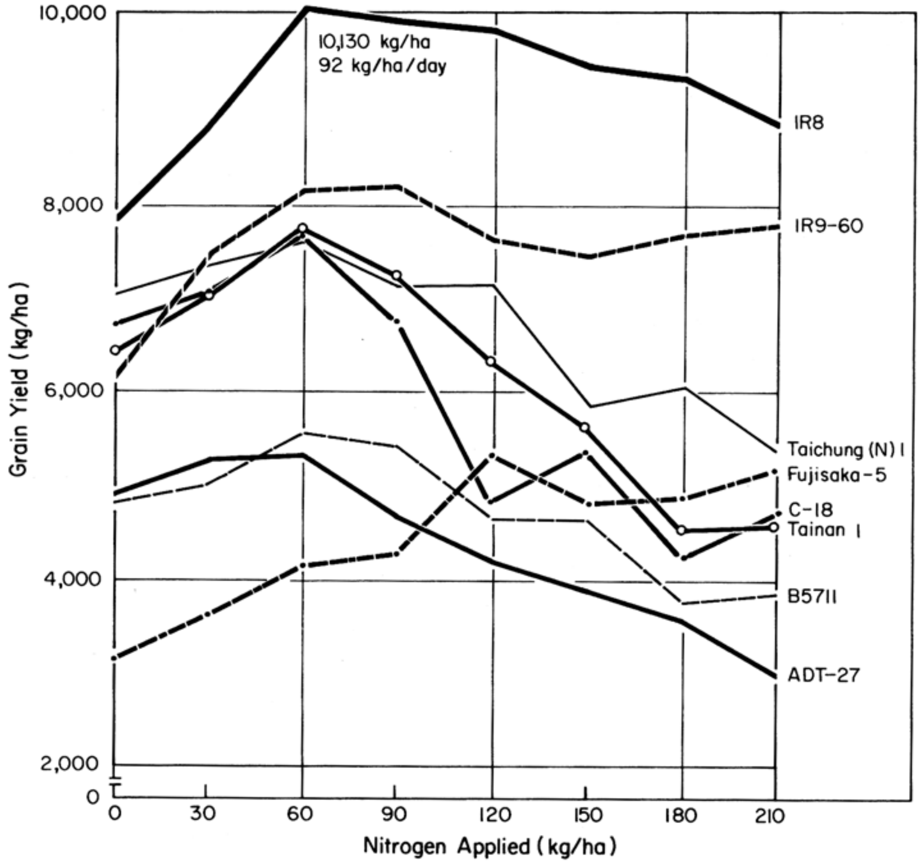


Fig. 19. Effect of levels of nitrogen on the grain yield of different varietal types of rice. IRRI, 1966 dry season.

Fig. 20. While a tall, weak-strawed indica variety, Binato, lodged without any fertilizer, a stiff-strawed indica variety, IR8, was erect and standing even at 150 kg/ha N. Nitrogen response experiment in farmer's field. Los Baños, Laguna, Philippines, 1966 dry season.

does not appear to be as consistently high yielding as IR8.

In contrast to the dry-season experiments, the pest control practices were similar to those used in experiments at the Institute farm, but the grain yields from the Calamba experiment were higher than those at the Institute. This suggests that the pest and disease problems were less serious in the farmer's field than at the Institute where the difficulties are possibly accentuated by continuous rice growing.

Nitrogen response in relation to varieties and management level

The nitrogen response and the profitability of fertilizer use vary with varieties, the soil-climatic complex, and the perfection attained in other management practices such as insect, disease, and weed control, and water supply. The profitability of fertilizer application with a specific variety or varietal type is closely associated with fertilizer prices, grain yield, and price of rice. Finally, to decide the quantity of fertilizer to use, the cost of other management practices, particularly those needing cash inputs, must also be taken into consideration.

Experiments were conducted at the Institute farm during the 1966 crop seasons to: (1) determine the nitrogen response and yield potential of 2 or 3 varietal types under three management practices, (2) evaluate the profitability of nitrogen fertilizer application under three management practices, and (3) determine the cost of production under experimental conditions. Three levels of management were employed but the degree of insect control and fertilizer application differed between the wet and dry seasons.

Dry season. The varieties used were Chianung 242, a high-yielding japonica variety from Taiwan, Sigadis, a tall, leafy, weak-strawed variety from Indonesia, and IR8. Nitrogen as ammonium sulfate was harrowed into Maahas clay at rates of 30, 60, 90, and 120 kg/ha. Except for a no-nitrogen check, all varieties received an additional 20 kg/ha N at panicle initiation. The yields obtained are shown in Table 6 and details of the management practices and their cost are presented in Table 7.

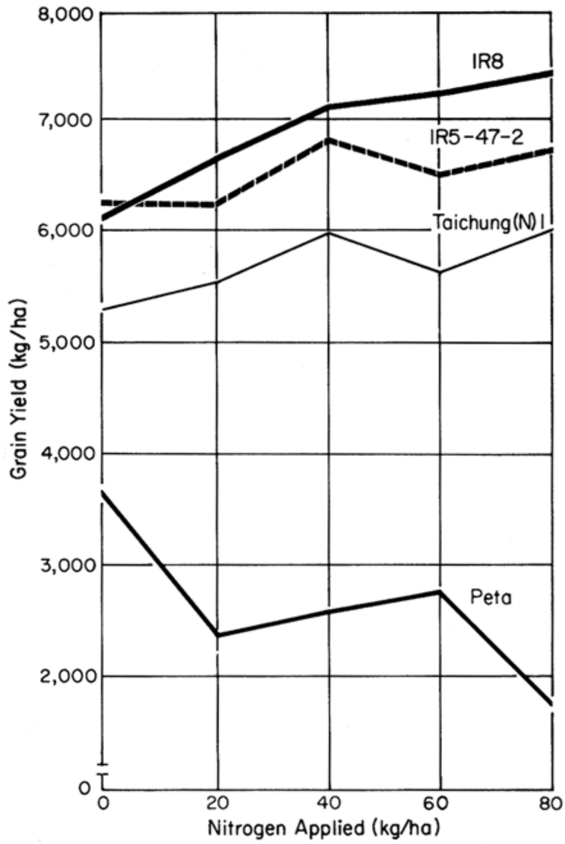


Fig. 21. Effect of levels of nitrogen on the grain yield of indica rice; nitrogen response experiment in farmer's field. Calamba, Laguna, Philippines, 1966 wet season.

Chianung 242, which lodged 3 to 4 weeks before harvest in one replicate of each of the 110 and 140 kg/ha N treatments, matured 117 days after seeding. The variety IR8 did not lodge at any stage of growth even at 140 kg/ha N and matured 135 days after seeding. The variety Sigadis exhibited leaf lodging at all levels of added nitrogen about 2 months before harvest. No leaf lodging was observed on non-fertilized plots. However, 39 days before harvest, Sigadis lodged completely at all levels of added nitrogen or management levels and matured 145 days after seeding.

The grain yield differences between the three varieties were 1,269 kg/ha between Chianung 242 and Sigadis, 1,744 kg/ha between IR8 and Chianung 242, and 3,013 between IR8 and Sigadis. It is notable that the highest yield of Sigadis, obtained with 80 kg/ha N, was lower than those obtained from IR8 and Chianung 242 with no applied nitrogen (Table 6).

Table 6. Effect of varietal types, nitrogen levels, and management practices on the grain yield of rice. IRRI, 1966 dry season.

Grain yield at 14% moisture (average, 3 replications)

Nitrogen applied	Management practice	Variety: Chianung 242	Variety: IR8	Variety: Sigadis	Mean (management practice)	Mean (N-level)
(kg/ha)				(kg/ha)		
0	I	5346	5378	3897	4874	
	II	4712	6496	4317	5175	5385
	III	5431	7560	5325	6105	
50	I	5922	6781	4232	5645	
	II	5815	7817	4576	6069	6220
	III	6312	9045	5483	6947	
80	I	5980	7933	5226	6380	
	II	6500	8567	5732	6933	6996
	III	7286	9191	6546	7674	
110	I	6252	7453	4650	6118	
	II	7004	8625	5447	7025	6937
	III	7518	9251	6236	7668	
140	I	6776	8618	4062	6485	
	II	7084	9399	5200	7228	7234
	III	8005	9989	5972	7989	
Mean (variety)		6396	8140	5127		
(Average, all rates)	I	6055	7233	4414		
	II	6223	8180	5054		
	III	6910	9007	5912		

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Nitrogen level (N)**	143.6	468	2.2	8.8
Management practice (M)**	76.3	225	1.2	
M X N n.s.	170.6	—	2.6	
Variety (V)**	85.8	243	1.3	
N X V**	192.0	543	2.9	
M X V*	148.7	420	2.3	
N X M X V n.s.	332.5	—	5.1	

Under management practice III, Chianung 242 and Sigadis produced similar grain yields in the no-nitrogen treatment. IR8 produced 7.5 m ton/ha without added fertilizer nitrogen and a maximum yield, with fertilizer, of 9,989 kg/ha (Table 6).

Cost of operation under three management practices. The least expensive item was protection against insect pests in the seedbed, followed by weeding and fertilizer application in the field. The most expensive item was the cost of insecticides for application in the field, particularly carbaryl. The cash input necessary for the three management levels varied from ₱594*/ha (Table 7) to ₱1,561/ha at 140 kg/ha N. For Chianung 242 the highest return over the cash inputs (gross income—cash input) was obtained at 140 kg/ha N under management level I. IR8 also gave the highest return at these nitrogen and management levels, but the return over the cash input was higher than for Chianung 242. For

* 1 P = about US $0.26.

Sigadis the highest return was obtained from management level I at 80 kg/ha N.

From these results it seems that beyond management level I, the additional cash input necessary to obtain higher grain yield does not raise the net return. When the values of production and farm expenses, including operator's labor, are calculated for the grain yield data (8,618 kg/ha), and the cash inputs necessary to obtain such grain yields with 140 kg/ha N under management practice I (Table 7), it can be shown that a net return of about ₱1,000/ha (US $260) can be obtained if a high-yielding variety such as IR8 is grown under appropriate management.

Wet season. The experiment was repeated with varieties IR8 and Sigadis and nitrogen levels from 0 to 100 kg/ha with 25-kg increments. The degree of insect control used was less intense in the wet than in the dry season; fewer applications of insecticide were made. Weed control was similar to that of the dry season. There were significant increases in grain yield with IR8 up to 100 kg/ha added N, with a maximum yield of 6,029 kg/ha at management practice III. If the average of the three management levels are taken, the highest yield for Sigadis was without added nitrogen. But the highest yield for an individual treatment was with 25 kg/ha N at management level III. The differences in grain

Table 7. Details and costs (Philippine pesos)* of three systems of management and five levels of nitrogen fertilizer†. IRRI, 1966 dry season.

Operation	Management practice		
	I	II	III
1. Seedbed spray (0.2% endrin)			
No. of treatments	1	2	3
Cost of material	0.7	1.4	2.1
2. Carbaryl field spray			
No. of treatments	2	4	8
Total a.i.‡ used (kg/ha)	6	12	24
Cost of spray and application	230.9	461.8	923.5
3. Gamma-BHC			
No. of treatments	2	3	5
Total a.i. used (kg/ha)	5	8	14
Cost of material	117.5	188.0	329.0
4. Handweeding			
No. of treatments	1	1	1.5§
Cost	80	80	120
5. Weedicide (MCPA)			
No. of treatments	—	1	1
Cost of material and application	—	22.0	22.0
Total cost	429	753	1,397

* 1 Philippine peso = about US $0.26.

†

Nitrogen applied (kg/ha)	Cost of nitrogen (as urea) (₱/ha)
0	0
50	59.0
80	94.4
110	129.8
140	165.2

‡ Active ingredient.

§ 1 complete and 1 light.

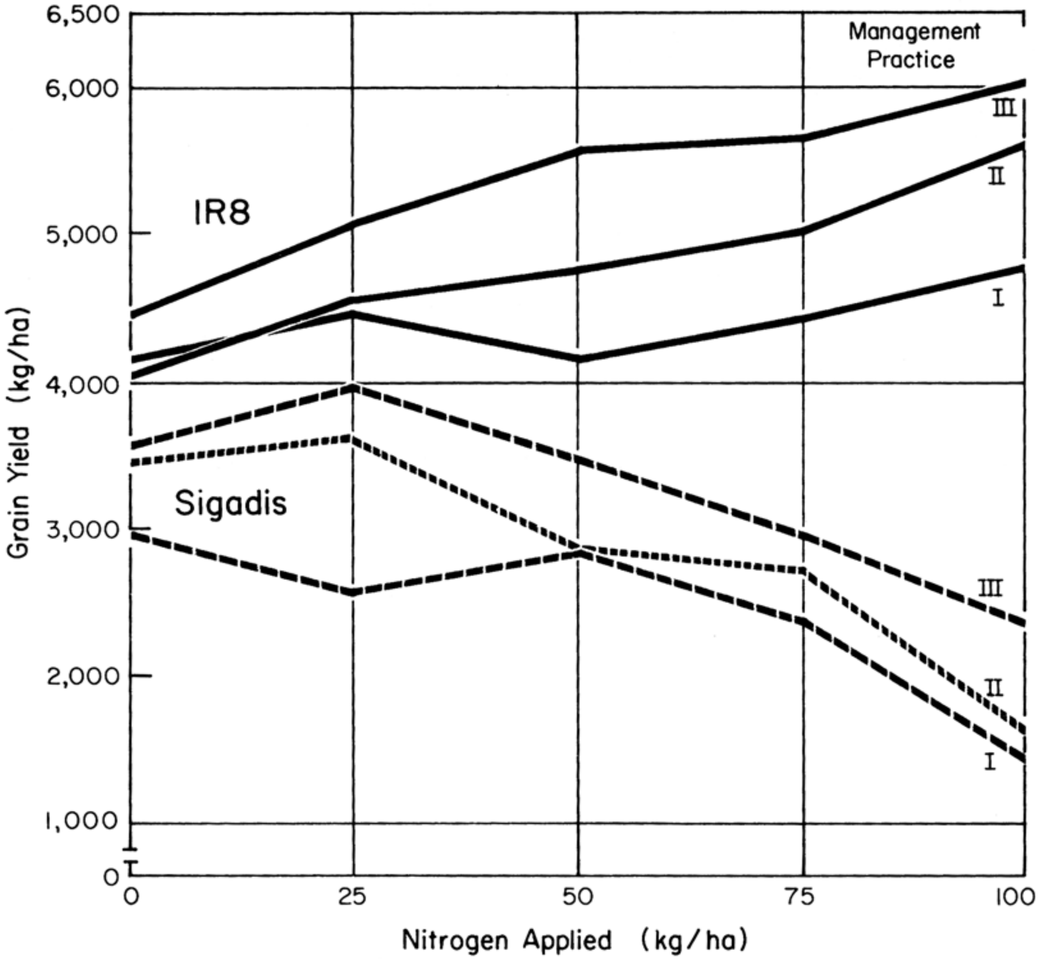


Fig. 22. Effect of varietal types, levels of nitrogen, and management practices on the grain yield of rice. IRRI, 1966 wet season.

yield between management levels were highly significant. IR8 yielded 4,384 in management practice I and 5,353 with management practice III, an increase of 1 m ton/ha (Table 8). The differences in grain yield between the two varieties were also significant; IR8 produced almost twice as much grain as Sigadis (Fig. 22). On an annual basis IR8 produced 16 m ton/ha/2 crops compared with 10.5 m ton/ha/2 crops for Sigadis. The results demonstrate that whether the management level is high or low, a stiff-strawed variety will outyield a tall, weak-strawed variety by a substantial margin.

To summarize the results of these experiments:

(1) IR8 has consistently outyielded a highly productive Taiwanese japonica in the dry season and, by a greater margin, a tall, weak-strawed indica variety from Indonesia in both seasons.

(2) The grain yields of rice varieties presently grown in the tropics can be improved substantially if appropriate management practices are followed. However, the increase in grain yield from improved practices is higher with a short, stiff-strawed variety than with existing tall, weak-strawed, indica varieties.

(3) With IR8 the grain yield was increased substantially as the level of management was raised in both seasons.

(4) In this experiment the net return for any variety in the dry season was greatest with management practice I. Further increase in input increased the cost twofold to threefold and net return was correspondingly reduced. There were,

however, some extremely high yields obtained with the management practice III.

Effect of anhydrous ammonia on soil nitrogen mineralization

Analyses of an uncropped Maahas clay soil treated with either anhydrous ammonia or ammonium sulfate at 30 and 90 days after submergence have shown that the mineral nitrogen content is markedly higher in the soil treated with anhydrous ammonia. The amount of mineral nitrogen ($NH_4^+ + NO_3^- - N$) present in the unfertilized control plot after 99 days of submergence was 160 kg/ha (139 kg/ha NH_4^+ — N). Where 50 kg/ha N was applied the total available nitrogen present (i.e. released from soil organic matter + fertilizer) should be 160 + 50 or 210 kg/ha. With the addition of 50 kg/ha N as anhydrous ammonia the amount of recovered mineral nitrogen was 11 to 64 kg/ha higher than the calculated possible. When the same rate of nitrogen was applied as ammonium

Table 8. Effect of varietal types, nitrogen levels, and management practices on the grain yield of rice. IRRI, 1966 wet season.

Grain yield at 14% moisture (average, 3 replications)

Nitrogen applied	Management practice	Variety: IR8	Variety: Sigadis	Mean (management practice)	Mean (N-level)
(kg/ha)			(kg/ha)		
0	I	4138	2986	3562	
	II	4068	3458	3763	3775
	III	4444	3556	4000	
25	I	4465	2597	3531	
	II	4577	3630	4104	4052
	III	5089	3955	4522	
50	I	4127	2863	3495	
	II	4777	2879	3828	3947
	III	5570	3465	4518	
75	I	4405	2391	3398	
	II	5019	2706	3862	3852
	III	5632	2959	4296	
100	I	4786	1401	3094	
	II	5613	1601	3607	3628
	III	6029	2340	4184	
Mean (variety)		4849	2852	3850	
(Average, all rates)	I	4384	2448		
	II	4810	2851		
	III	5353	3255		
Duration (days)		126	136		

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Nitrogen level (N)$^{n.s.}$	94	—	2	11
Management practice (M)**	58	171	2	
M X N$^{n.s.}$	129	—	3	
Variety (V)**	65	187	2	
N X V**	146	420	4	
M X V$^{n.s.}$	113	—	3	
N X M X V$^{n.s.}$	252	—	7	

sulfate (broadcast and incorporated) the mineral nitrogen recovered was 26 kg/ha lower than the calculated possible. From the above results it seems evident that addition of anhydrous ammonia, irrespective of depths of placement, stimulated mineralization of organic nitrogen in the soil, while a loss of applied nitrogen equivalent to 52 percent occurred in the ammonium sulfate (broadcast and incorporated) treatments.

tion. The mean efficiency of nitrogen (kg rough rice/kg N) for each method was 53, 44 and 28 in the 20, 5, and 0 cm placements of anhydrous ammonia respectively, while ammonium sulfate broadcast and incorporated gave 38 kg rough rice/kg N. The efficiency of anhydrous ammonia placed at 20 cm was 89 and 12 percent greater than that placed at 0 and 5 cm respectively, and 39 percent greater than the ammonium sulfate

Table 9. Effect of levels of nitrogen and depths of application of anhydrous ammonia on the grain yield of IR8. IRRI, 1966 dry season.

Grain yield (kg/ha) at 14% moisture (average, 4 replications)

Nitrogen applied (kg/ha)	Fertilizer material: Ammonium sulfate — Broadcast and incorporated	Anhydrous ammonia — Placement depth (cm): 0	5	20	Mean (rate) (kg/ha)
0	4752	4739	5230	5019	4935
25	6506	6119	6964	7125	6679
50	6582	6371	7114	7630	6924
75	7265	6541	7209	7850	7216
100	7673	6564	7227	8090	7389
Mean (placement)	6556	6067	6749	7143	
Mean (material)	6556		6653		

Analysis of variance:	L.S.D.	cv(x) %	CV(X) %
Method & Fert. Material (M)**	491	2.3	
N-rate (N)**	331	1.8	7.0
M X N$^{n.s.}$			

Rate and depth of placement of anhydrous ammonia

Experiments conducted during the 1966 dry season demonstrated anhydrous ammonia to be as efficient as ammonium sulfate in increasing the grain yield of IR8 (Table 9). The first 25 kg/ha N increased grain yield by 70 kg rough rice/kg N. Placement of anhydrous ammonia at 20 cm gave significantly higher grain yield than that obtained from application at 5 cm or 0 cm or from the ammonium sulfate (broadcast and incorporated) treatment. Soil surface application of anhydrous ammonia was significantly less effective than the other methods of applica-

treatment. An application of 25 kg/ha N as anhydrous ammonia injected at 5 or 20 cm resulted in grain yields equivalent to those to be expected from applying about 70 kg/ha N as ammonium sulfate, broadcast and incorporated. These results demonstrate the possibility of obtaining high grain yields by applying a low rate of fertilizer at an appropriate depth in the soil.

Swath interval for anhydrous ammonia

From the 1965 crop seasons data, it is certain that anhydrous ammonia is as good a source of nitrogen as any other ammonium-containing standard fertilizer. Experiments were conducted during the 1966 dry and wet seasons to determine the swath interval necessary for applying anhydrous ammonia to flooded Maahas clay to insure uniform fertilizer distribution.

Dry season. Results show that the grain yield differences from the application of anhydrous ammonia at 40-, 60-, 80- and 100-cm swath intervals were not significant (Table 10). To obtain more precise information, samples of 10 hills each were collected at 10, 30, and 50 cm from the line of application. Measurements on these samples showed that the grain yield did decrease with increasing distance from the line of application where the swath interval was 60, 80, or 100 cm, but again the differences were not significant. The lack of significant differences between swath interval treatments can presumably be explained by a high yield near the line of application being sufficient to counterbalance the low yields in the row farthest from the line of application.

Wet season. The experiment was repeated with swath intervals differing by 20 cm from 40 to 140 cm. Nitrogen rates were 0, 30 and 60 kg/ha. The variety IR8 was planted at 20 x 20 cm spacing. There were no significant differences between the grain yields at 30 and 60 kg/ha N, between swath intervals, or nitrogen levels x swath intervals. There was a significant response only to 30 kg/ha of applied nitrogen.

Table 10. Effect of levels of nitrogen and swath intervals for anhydrous ammonia application to an indica selection, IR8-246. IRRI, 1966 dry season.

Grain yield at 14% moisture (average, 3 replications)

Swath width (cm)	Nitrogen applied (kg/ha) 0	60	90	Mean (swath)
40, BT*	5639	6801	6885	6843
40, AT†		7229	7548	7389
60, AT		6973	7398	7186
80, AT		6867	7244	7056
100, AT		6755	7110	6933
Mean (rate)		6925	7237	

Duration (days) 125

Analysis of variance:	L.S.D.	$cv(\bar{x})$ %	CV(X) %
N-rate$^{n.s.}$	—	7.4	
Swath width$^{n.s.}$	—	1.8	5.4
N X Swath$^{n.s.}$			

* BT=Anhydrous ammonia applied before transplanting.
† AT=Anhydrous ammonia applied 2 weeks after transplanting.

Table 11. Effect of split application of nitrogen on the grain yield of a tall indica rice. IRRI, 1966 dry season.

Grain yield at 14% moisture (average, 3 replications)

Time of N application: Planting	50% tillering	Panicle initiation	Variety: H-4
	(kg/ha)		(kg/ha)
0	0	0	5947
90	0	0	5478
0	30	60	4201
0	60	30	3795
0	0	90	6674
30	30	30	3511

Duration (days) 135

Note: H-4 lodged in all treatments close to harvest including the check.

Analysis of variance:	s.e.	L.S.D.	$cv(\bar{x})$ %	CV(X) %
Time of N application$^{n.s.}$	847	—	17.2	30

Time of nitrogen application for flooded rice

In a weak-strawed variety, split application of nitrogen is sometimes recommended to prevent lodging and increase the grain yield. Experiments were conducted during the 1966 crop season to record the lodging sequence and response to nitrogen as affected by time of application.

Dry season. A weak-strawed Ceylonese variety, H-4, failed to respond to nitrogen when a total of 90 kg/ha was applied in three split applications (Table 11). The highest yield, 6,674 kg/ha, was obtained where 90 kg/ha N was all applied at panicle initiation, but none of the treatment differences was statistically significant because the variability (30% CV) was high due to lodging. The variety lodged in all treatments, with earlier application of nitrogen resulting in earlier lodging.

Table 12. Effect of split applications of nitrogen on the grain yield of two varietal types of rice. IRRI, 1966 wet season.

Grain yield at 14% moisture (average, 3 replications)

Treatment number	Nitrogen application (kg/ha) 1†	2‡	3§	4‖	5¶	Variety H-4	Variety IR8	Mean (treatment)
						(kg/ha)		(kg/ha)
1	0	0	0	0	0	4123	3597	3860
2	60	0	0	0	0	1120	4160	2640
3	0	30	30	0	0	2227	4600	3414
4	0	0	30	30	0	4195	4555	4375
5	0	0	0	30	30	4483	3502	3992
6	0	20	20	20	0	4228	4313	4270
7	0	0	20	20	20	4285	4239	4262
8	0	20	20	0	20	3219	4557	3888
9	0	15	15	15	15	3537	3875	3706
10	12.5	12.5	12.5	12.5	12.5	3837	4246	4042
		Mean (variety)				3525	4164	
Duration (days)						132	124	

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Time of N application**	220	631	5.7	14
Variety$^{n.s.}$	245	—	6.4	
V x T**	311	892	8.1	

	H-4	IR8
† Last harrowing	July 11	July 11
‡ Maximum tillering	Aug. 13	Aug. 13
§ Panicle initiation	Sept. 6	Sept. 6
‖ Booting	Sept. 23	Sept. 23
¶ Heading	Oct. 4	Oct. 4

Wet season. Nitrogen was applied at five stages: at last harrowing, maximum tillering, panicle initiation, booting, and heading. H-4 and IR8 were used in the test. For H-4, there was no significant increase in grain yield with added nitrogen. However, highest yield was obtained where 60 kg/ha N was applied at booting and heading, and the lowest where the entire nitrogen dose was applied during land preparation. The difference in grain yields between these two treatments was highly significant (Table 12).

On the other hand, with IR8, the grain yield differences were not significant between times of nitrogen application, although there was a modest increase in grain yield with added fertilizer. Treatment 5 resulted in the lowest yield with IR8 but the highest with H-4. These results can be explained by the lodging behavior of H-4. With early application of nitrogen (treatment 2), H-4 exhibited leaf lodging as early as maximum tillering stage, and culm lodging at an early heading stage (Table 13). H-4 lodged completely (100%) at harvest in all nitrogen application treatments with the exception of treatment 5 in which it lodged 40 percent only 2 weeks before harvest, and 68 percent at harvest (Table 13). IR8 did not lodge at any stage of growth. The relative height difference between H-4 and IR8 without added nitrogen is shown in Fig. 23. These results indicate that, with a weak-strawed, lodging-susceptible variety grown during the wet season in a fertile soil such as Maahas clay, fertilizer nitrogen is not to be recommended. Possibly a modest increase in grain yield may be obtained with weak-strawed varieties if a small quantity of nitrogen (30 kg/ha) is applied either at booting or heading. For a stiff-strawed variety all the nitrogen can be applied in a clayey soil during land preparation; nothing is to be gained by split-applications. IR8 produced a low yield compared with other experiments because the amount of nitrogen applied was insufficient for the shallow soil of the experimental site.

Early application of 60 kg/ha N to H-4 resulted in 46 percent sterile grains and also a lower grain: straw ratio (0.28), whereas with late application the sterility was only 10 to 20 percent and the grain: straw ratio 0.7.

A total of 60 kg/ha N applied in two applications between booting and heading significantly increased the protein (Kjeldahl N x 5.95) content of the grain for both varieties over those recorded from other times of nitrogen application (Table 14). The differences in the protein content between nitrogen applied all at planting (treatment 2) and split applications at two later stages of growth (treatment 5) were about 1.5 and 2 percent for H-4 and IR8 respectively (Table 14).

These data indicate that the split application of nitrogen, particularly after the booting stage, is desirable for increasing both grain yields and protein content of H-4. For IR8 there was no increase in yields when nitrogen was applied at later stages, but there was a substantial increase in the protein content of the grain.

Time of nitrogen application for upland rice

When ammonium nitrogen fertilizer is added to an upland soil, the ammonium nitrogen is rapidly converted to nitrate which can be taken up by the rice crop or lost through various processes. It may be desirable to split the nitrogen application, particularly at high levels of added nitrogen. It may not be desirable to apply too much nitrogen at early stages of growth since competition from weeds may be stimulated and the rice plant may suffer from nitrogen deficiency at later stages of growth.

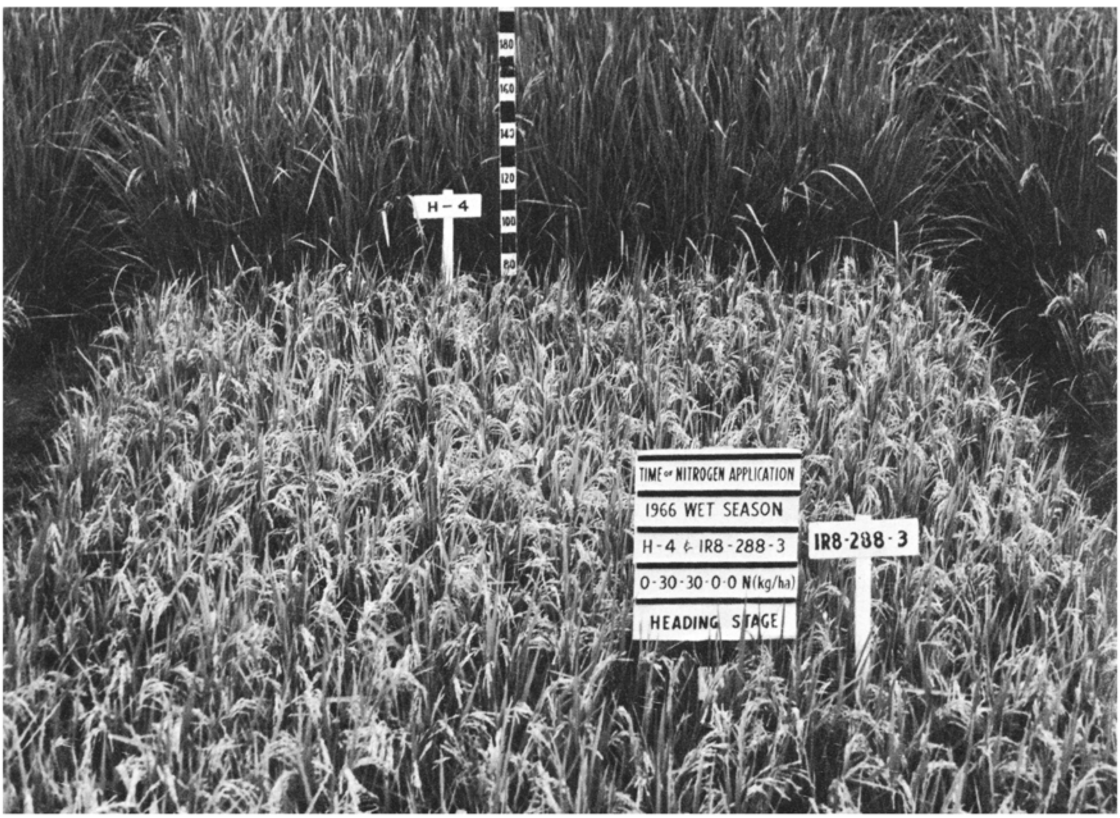


Fig. 23. The heights of IR8 (front) and H-4 (rear) growing on Maahas clay soil without added nitrogen. IRRI, 1966 wet season.

Table 13. Effect of split application of nitrogen on the sequence and percentage lodging of a weak-strawed indica variety H-4. IRRI, 1966 wet season.

Treatment number	Nitrogen application (kg/ha)					Leaf lodging (%)		Culm lodging (%)					
						Maximum tillering stage	Ear initiation stage	Heading stage					Harvest
	1*	2†	3‡	4§	5‖	Aug. 23	Sept. 13	Oct. 8	Oct. 11	Oct. 15	Oct. 18	Oct. 19	Nov. 3
1	0	0	0	0	0	0	0	0	23.3	23.3	26.7	40	80
2	60	0	0	0	0	23.3	43.3	30	90	90	90	91.7	100
3	0	30	30	0	0	3.3	10	23.3	76.7	76.7	76.7	90	100
4	0	0	30	30	0	0	0	23.3	28.3	33.3	43.3	86.7	100
5	0	0	0	30	30	0	0	0	0	0	20	40	68.3
6	0	20	20	20	0	0	0	0	20	23.3	43.3	86.7	100
7	0	0	20	20	20	0	0	13.3	33.3	33.3	53.3	88.3	100
8	0	20	20	0	20	0	0	26.7	73.3	73.3	73.3	90	100
9	0	15	15	15	15	0	0	23.3	28.3	28.3	36.7	90	100
10	12.5	12.5	12.5	12.5	12.5	0	0	26.7	40	40	40	83.3	100

* Last harrowing.
† Maximum tillering.
‡ Panicle initiation.
§ Booting.
‖ Heading.

An experiment was conducted during the 1966 wet season to study the rate and time of nitrogen application on upland rice. The varieties were Palawan, a tall standard upland variety from the Philippines, IR52-18-2, a selection developed from indica x japonica crosses, and IR8. The levels of applied nitrogen varied from 0 to 120 kg/ha, and the time of application was at planting, at 50 percent tillering, and at panicle initiation. The plots were protected against insect attack, and weeds were controlled by a combination of herbicide treatment and hand-weeding.

A severe drought during the later half of August and early September, resulted in wilting at the time of panicle primordium initiation (August 15). The plants were also affected by bacterial leaf blight, particularly when fertilized heavily at an early stage. The incidence of sheath blight was also heavy. These influences resulted in low grain yields with all three varieties tested. The highest grain yield of 2,519 kg/ha was obtained with IR52-18-2 where 60 kg/ha N was applied between 50 percent tillering and panicle initiation (Table 15).

Each variety produced significantly higher yield with added nitrogen; the grain yield in the best treatment was almost double that of the no-nitrogen control. Delaying the application of nitrogen to IR8 reduced the grain yield significantly, particularly at higher rates. By contrast, with IR52-18-2 the highest yield at each rate was obtained when the nitrogen was applied between 50 percent tillering and at panicle initiation. With the upland variety Palawan, no consistent trend in grain yield was obtained but higher yield was usually obtained when nitrogen was applied in a split dose after planting. There was no significant difference in average yield between the three varieties, nor were the yields for different times of application significantly different in themselves.

From these results it seems that, for some short-strawed varieties, such as IR8, growing in a clayey soil, early application of nitrogen is desirable, whereas in others nitrogen should be applied in two or three dressings.

Long-term fertility experiment

The experiment was started during the 1964 wet season and continued with two crops a year during 1965 and 1966. The treatments in 1966 were the same as in previous years but the varieties were changed. Those used this year were Chianung 242, IR8, and H-4.

Dry season. The dwarf indica variety, IR8, outyielded a high-yielding ponlai variety, Chianung 242, by a margin of 2 m ton/ha and outyielded a tall indica variety, H-4, by 4 m ton/ha (Table 16). The productivity of IR8 based on field duration was 88 kg/ha/day, a high value for tropical rice. The highest yield of 9,411 kg/ha was about eightfold the average yield of many Southeast Asian countries. The efficiency of fertilizer nitrogen with IR8 was 28.6 kg rough rice/kg N where 140 kg N was applied, which was twice the rate obtained from Chianung 242 (14.0 kg rough rice/kg N). Chianung 242 lodged 8 days before harvest at 140 kg/ha N, but IR8 did not lodge at any stage, even at 140 kg/ha applied N. On the other hand, H-4, treated with 140 kg/ha N, lodged completely about 3 weeks before harvest after a rain of 0.45 inches. This treatment resulted in a negative response to nitrogen. None of the three varieties showed any response to phosphorus and/or potassium.

Wet season. During the wet season, response to either nitrogen or phosphorus was not significant. The variety H-4 showed a negative response to 60 kg/ha applied N. However, without added nitrogen, H-4 produced just as much grain as IR8 (Table 17). Compared with IR8, Chianung 242 was severely affected by virus disease. H-4 was not affected by virus disease, but early lodging, particularly with

Table 14. Effect of time of nitrogen application on the protein content of grains of IR8 and H-4. IRRI, 1966 wet season.

Treatment	Nitrogen application (kg/ha)					Variety		Mean
number	1*	2†	3‡	4§	5‖	H-4	IR8	(treatment)
							(%)	
1	0	0	0	0	0	5.18	4.88	5.03
2	60	0	0	0	0	6.31	5.47	5.89
3	0	30	30	0	0	6.37	5.71	6.04
4	0	0	30	30	0	6.12	6.84	6.48
5	0	0	0	30	30	7.79	7.50	7.64
6	0	20	20	20	0	6.24	6.37	6.30
7	0	0	20	20	20	6.72	7.08	6.90
8	0	20	20	0	20	6.96	6.07	6.52
9	0	15	15	15	15	6.66	6.72	6.69
10	12.5	12.5	12.5	12.5	12.5	6.48	6.43	6.46
		Mean (variety)				6.48	6.43	
Duration (days)						132	124	

Analysis of variance:		s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
	Variety (V)$^{n.s.}$	0.12	—	2	7
	N treatments (N)**	0.18	0.54	3	
	V x N$^{n.s.}$	0.30	—	5	

* Last harrowing.
† Maximum tillering.
‡ Panicle initiation.
§ Booting.
‖ Heading.

added nitrogen, caused a substantial reduction in grain yield.

IRRI-BPI cooperative fertility experiments

During the 1966 crop seasons, experiments were conducted on nitrogen response of different varietal types in collaboration with the Philippine Bureau of Plant Industry at the Maligaya Rice Research and Training Center. As indicated in the 1965 Annual Report, the soil at Maligaya is similar to the Maahas clay at the Institute farm but has a lower organic matter, and hence nitrogen content.

Dry season. The dry-season nitrogen applications varied from 0 to 210 kg/ha. Apart from 20 kg top-dressed during panicle initiation, the nitrogen was all harrowed-in during land preparation. Without added nitrogen, the mean grain yield for seven varieties and selections was 3,190 kg/ha (Table 18), whereas in a similar experiment conducted on Maahas clay soil at the Institute farm, the mean grain yield for eight varieties without added nitrogen was 5,877 kg/ha. Of the six varieties and selections grown, IR8 produced the highest grain yield of 7,472 kg/ha with 150 kg/ha N. This yield was significantly greater than from any treatment receiving less than 150 kg/ha N. Based on the average value for all varieties (Table 18), most varieties or selections responded significantly to as much as 90 kg/ha N.

Wet season. During the wet season, IR5-47-2 and BPI-76 (photoperiod sensitive) were included in the test, and B5711 was excluded as it did not show any promise during the dry season. The highest grain yield (7,306 kg/ha)

Table 15. Effect of varietal types, nitrogen levels, and times of nitrogen application on the grain yield of upland rice. IRRI, 1966 wet season.

Grain yield at 14% moisture

Nitrogen applied	Time of application: At planting	50% tillering	Panicle initiation	Variety or selection: IR8	IR52-18-2	Palawan	Mean (treatment)
(kg/ha)		(%)			(kg/ha)		
0	—	—	—	1276	1071	1149	1165
60	100	—	—	1868	975	1420	1421
	50	50	—	1740	1177	1410	1442
	33	33	33	1825	1674	1421	1640
	50	—	50	1586	1191	1801	1526
	—	50	50	1564	2519	1552	1878
90	100	—	—	2060	1200	990	1417
	50	50	—	2010	1754	998	1587
	33	33	33	1545	1168	1676	1463
	50	—	50	2235	1153	1932	1773
	—	50	50	1527	1985	1345	1619
120	100	—	—	2430	1770	871	1690
	50	50	—	2073	1106	881	1353
	33	33	33	1974	1379	1321	1558
	50	—	50	1893	1619	1140	1551
	—	50	50	1077	2010	1188	1425

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Variety (V)$^{n.s.}$	173	—	11	34
Treatment (T)$^{n.s.}$	175	—	11	
V x T*	303	851	20	
Timing$^{n.s.}$				
Control vs. rest*	62	174	4	

Table 16. Effect of NPK fertilization on the grain yield of H-4, IR8, and Chianung 242. Long-term fertility experiment, IRRI, 1966 dry season.

Grain yield at 14% moisture (average, 4 replications)

Fertilizer treatment			Variety			Mean
N	P_2O_5	K_2O	H-4	IR8	Chianung 242	(treatment)
	(kg/ha)			(kg/ha)		
0	0	0	5403	5111	4765	5093
100 + 40	0	0	5006	8979	6418	6801
0	30	0	4778	5233	4741	4917
0	0	30	5466	5097	4335	4966
100 + 40	30	0	4150	8939	7376	6822
100 + 40	0	30	3972	9280	6161	6471
100 + 40	30	30	3090	9411	6668	6390
100 + 40*	30	30	3044	9166	6635	6282
Mean (variety)			4364	7652	5887	
Duration (days)			120	118	118	

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Treatment combinations**	347	978	5.8	11.5
Variety (V)**	123	346	2.0	
Treatment (T)**	200	565	3.3	
V x T**				

* Compost + inorganic (23.4 + 116.4 kg N).

was obtained with IR5-47-2, followed by IR8, 6,184 kg/ha (Fig. 24). This is the only 1966 soil fertility experiment in which IR8 was outyielded.

Taichung (Native) 1 produced significantly lower grain yield than all other varieties or selections tested (average of all N levels) as it was severely affected by bacterial leaf blight, particularly beyond 60 kg/ha applied N. Tainan 1 was affected by virus disease but all other varieties and selections were relatively free from any major diseases. MIFB253-3 was irregular in heading and height.

Grain yields of Peta and IR8 without added nitrogen were identical (7,019 and 7,088 kg/ha/2 crops); with added nitrogen, the grain yields for Peta and IR8 were 8,907 and 13,656 kg/ha/2 crops, respectively, or a difference of 4,749 kg/ha/2 crops. These results suggest that at low fertility a tall, weak-strawed variety may produce yields similar to those of a short, lodging-resistant variety but certainly will yield substantially less at high fertility. The results also demonstrate that the improved varieties and

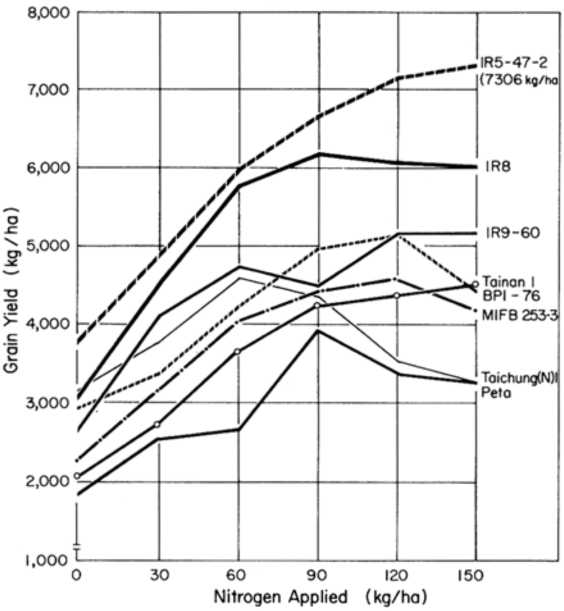


Fig. 24. Effect of levels of nitrogen on the grain yield of different varietal types of rice. IRRI-BPI cooperative fertility experiment. Maligaya, Rice Research and Training Center, Philippines, 1966 wet season.

Table 17. Effect of NPK fertilization on the grain yield of H-4, IR8 and Chianung 242. Long-term fertility experiment, IRRI, 1966 wet season.

Grain yield at 14% moisture (average, 4 replications)

Fertilizer treatment			Variety			Mean
N	P_2O_5	K_2O	Chianung 242	H-4	IR8	(treatment)
	(kg/ha)			(kg/ha)		
0	0	0	2652	4146	4284	3694
60	0	0	2521	1390	4756	2889
0	30	0	2752	4050	3885	3562
0	0	30	2516	3666	3925	3369
60	30	0	2587	1416	4940	2981
60	0	30	2718	1490	4462	2890
60	30	30	2840	1678	4749	3089
60*	30	30	3027	1442	4830	3100
Mean (variety)			2702	2410	4479	
Duration (days)			119	132	125	

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Treatment combination**	242	683	7.6	
Variety (V)**	86	243	2.7	15
Treatment (T)**	140	395	4.4	
V x T**				

* Compost + inorganic (24.6 + 35.4 kg N).

Table 18. Effect of levels of nitrogen on the grain yield of different varietal types of rice. IRRI-BPI cooperative fertility experiment, Maligaya Rice Research and Training Center, Philippines, 1966 dry season.

Grain yield at 14% moisture (average, 3 replications)

Nitrogen applied	Variety or selection							Mean (N-level)
	Acc. 6966	Tainan 1	Taichung (N) 1	IR9-60	IR8	MIFB 253-3	Peta	
(kg/ha)				(kg/ha)				(kg/ha)
0	2940	2046	3157	3671	4033	2582	3898	3190
10 + 20	2383	3161	3683	3999	4555	3548	3819	3592
40 + 20	3386	3265	4189	4914	5773	4843	3892	4323
70 + 20	3173	5773	4567	5801	5760	5218	4344	4948
100 + 20	3528	5060	5641	6038	5869	5107	3817	5008
130 + 20	3987	4869	5524	6481	7472	5790	3559	5383
160 + 20	4902	4454	5981	6849	7340	4688	3122	5334
190 + 20	4774	5200	4896	6697	6468	5293	2866	5170
Mean (value)	3634	4228	4705	5556	5909	4634	3665	4618
Duration (days)	116	116	116	135	135	147	147-161	

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Nitrogen rates (N)**	163	457	3.5	
Variety (V)**	282	870	6.1	16
N x V**	434	1218	9.3	

Table 19. Effect of sources and rates of fertilizer phosphorus on the grain yield of IR8 growing in Buenavista clay* in Bulacan, Philippines, 1966 wet season.

Grain yield (kg/ha) at 14% moisture (average, 3 replications)

Treatment			Source I	Source II	Mean
N	P_2O_5	K_2O	Phosphorus 29-29-0† (TVA material)	Triphos 0-40-0	(treatment)
	(kg/ha)				
0	0	0	3726	3726	3726
116	0	60	5246	5792	5519
116	29	60	5901	5674	5788
116	58	60	6584	6269	6426
116	87	60	5873	6440	6156
116	116	60	6277	6570	6424
116	116	0	—	6189	6189
Duration (days)			128		

Analysis of variance:

	Source I	Source II
Treatments	**	**
s.e.	236	312
L.S.D. (kg)	745	961
cv($\bar{x}$) %	4.2	5.4
CV(X) %	7.3	9.4

* Soil analysis of surface horizon pH 6.0 (moist soil); O.M. 0.81%; total N 0.05%; 0.02 *N* H_2SO_4 Ext. P 22 ppm.
† Urea-ammonium-phosphate.

selections, which have performed so well at the Institute farm, will give equally good performances in an area typical of large rice acreages in the Philippines.

Sources and rates of fertilizer phosphorus for flooded rice

Superphosphate is commonly used as the source of phosphorus in rice soils but there are indications that other sources are equally effective and may be cheaper or more available. The objectives of this experiment were: (1) to determine the best source of P for a specific deficient soil, and (2) to determine the phosphorus response of rice grown on this soil.

The field experiment was conducted during the 1966 wet season in Bulacan, Philippines. The soil is classified as Buenavista clay (pH 6.0, O.M. 0.81%, total N 0.05%, 0.02 *N* H_2SO_4 ext. P 22 ppm).

Three urea-ammonium phosphate fertilizer materials (29-29-0, 25-35-0, and 34-17-0) from the Tennessee Valley Authority, U.S.A., and triple superphosphate (40% P_2O_5) were used in the experiment. Fertilizers were incorporated during land preparation. IR8 was the variety grown.

Before panicle primordium initiation, the growth differences between no-phosphorus and phosphorus-treated plants were dramatic. Subsequently, response to added nitrogen was apparent. At harvest, there was at least 1.5 m ton/ha increase in grain yield due to added nitrogen. Addition of phosphorus also increased grain yield significantly. The highest grain yield was 6,584 kg/ha (Table 19). The mean yield differences between phosphorus sources were not significant (Table 20). Most of the phosphorus-treated plants matured a few days earlier than those without phosphorus treatment. Evidence strongly indicates that the soil in Bulacan is not deficient in potassium. The soil is extremely low in organic matter, and hence total nitrogen, but contains as much 0.02 *N* H_2SO_4

extractable P as the Maahas clay at the Institute farm where phosphorus responses are not obtained, suggesting that the release of phosphorus on flooding the Buenavista soil is inadequate.

Silica fertilization in flooded soils

Two field experiments were conducted during the 1966 dry season (January through May) at the Institute farm (Maahas clay) and in a farmer's field in Luisiana (Luisiana clay, pH 5.1, O.M. 3.1, Total N 0.19%, CEC 44 m.e./100 g soil. Great soil group, humic latosol).

The objectives of these experiments were: (1) to determine the silica response of two varieties, a japonica and an indica, in flooded Maahas clay, and (2) to determine the silica response of a dwarf indica with or without P fertilization in the flooded Luisiana clay.

Maahas clay soil (Institute farm). The varieties CI 9504 and IR8 were used and the rates of SiO_2 applied varied from 0 to 1,600 kg/ha. There was no significant difference in grain yields between the silica and no-silica treatments with either variety. The variety IR8 produced an average yield of 9,181 kg/ha, compared with 4,924 from CI 9504.

Luisiana clay. The soil was kept submerged for about 2 months prior to transplanting and the pH was about neutral before treatments were imposed. There was no significant increase in grain yield in response to either nitrogen or phosphorus (Table 21). With added silica, however, grain yield was significantly greater

Table 20. Effect of sources and rates of fertilizer phosphorus on the grain yield of IR8 growing in Buenavista clay in Bulacan, Philippines, 1966 wet season.

Grain yield at 14% moisture (average, 3 replications)

Treatment			Source III	Treatment			Source IV
N	P_2O_5	K_2O	Phosphorus 25-35-0*	N	P_2O_5	K_2O	Phosphorus 34-17-0*
	(kg/ha)		(kg/ha)		(kg/ha)		(kg/ha)
0	0	0	3726	0	0	0	3726
100	0	60	5270	102	0	0	5319
100	35	60	5966	102	0	60	5088
100	70	60	6062	102	17	60	5951
100	105	60	6257	102	34	60	5658
100	140	60	5805	102	51	60	5543
100	140	0	6405				

Analysis of variance:

	Source III	Source IV
Treatment	**	**
s.e.	223	210
L.S.D. (kg)	687	662
cv($\bar{x}$) %	4.0	4.0
CV(X) %	6.9	7.0

Average grain yield for four sources (kg/ha) (all rates of applied P)

I	II	III	IV	Mean of (100-116)-0-60
6159	6228	6099	5717	5299

Analysis of variance for 4 sources (mean):

Phosphorus source	n.s.
s.e.	225
cv($\bar{x}$) %	4.0
CV(X) %	18.0

* Urea-ammonium phosphate.

than that from the treatments receiving only nitrogen. Even where silica had been applied, however, phosphorus produced no yield response. IR8 yielded 8.5 ton/ha in one of the treatments receiving silica (Table 21).

Application of calcium silicate increased tiller number, panicle number, panicle weight, and panicle length, and it reduced sterility. Plant height, weight of 100 grains, and grain:straw ratio remained unaltered by applications of the silicate slag fertilizer (Table 22).

Detailed chemical analyses for all major and most minor, and trace elements in grain, straw, and root did not reveal any benefit from the

Table 21. Effect of levels of silica with or without P, on the grain yield of IR8 growing in a humic latosol (Luisiana clay), 1966 dry season.

Grain yield at 14% moisture (average, 3 replications)

Treatment number	Treatment SiO_2*	N	P	Grain yield	Mean (SiO_2 rate)
		(kg/ha)		(kg/ha)	(kg/ha)
1	0	0	0	5642	
2	0	0	87.2†	5801	
3	0	60	0	6506	6506 (check)
4	250	60	0	7189	7441
5	250	60	87.2	7693	
6	500	60	0	7311	7482
7	500	60	87.2	7653	
8	750	60	0	8369	8246
9	750	60	87.2	8122	
10	1000	60	0	7483	7719
11	1000	60	87.2	7955	
12	1500	60	0	7494	7570
13	1500	60	87.2	7645	
14	2000	60	0	7867	8204
15	2000	60	87.2	8540	
Mean — Grain yield: $SiO_2 + N$				7619	7777 kg/ha
Mean — Grain yield: $SiO_2 + N + P$				7935	
Duration (days): 123					
Analysis of variance:		s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Treatment**		338	978	4.6	7.9

* As calcium silicate (40% SiO_2).
† Equivalent to 200 kg P_2O_5/ha.

application of calcium silicate in either nutrition or translocation of any element. It seems that the substantial increase in grain yield in response to silica application was a reflection of some non-nutritional factor.

Table 22. Effect of silica fertilization on the plant characters of IR8 grown in a humic latosol (Luisiana clay), 1966 wet season.

Plant character at harvest	60 kg/ha N (check)	60 kg N + SiO_2 (average of 250-2000 kg/ha)
Plant height (cm)	77	77
Tiller no./hill	16.4	17.3
Panicle no./hill	15.9	17.0
Panicle weight (g)	1.8	2.3
Panicle length (cm)	18.6	19.4
Wt. of 100 grains (g)	2.9	3.0
Sterility (%)	16.5	10.3
Grain: straw ratio	1.1	1.0

Soil incorporation of insecticides

As a possible alternative to the recommended practice of applying gamma-BHC and carbaryl to the irrigation water, an experiment was conducted during the dry season of 1966 to study the effect of soil incorporation of carbaryl on insect pest control, prevention of virus spread, and the grain yield of flooded rice.

The highest grain yield was obtained with 20 kg/ha carbaryl incorporated into the flooded Maahas clay soil without any γ-BHC treatments or carbaryl spray (Table 23). Most of the grain yield increase with 20 kg/ha carbaryl incorporated into the soil was due to better stem borer control and a significant reduction in the number of virus hills (Table 24). These data strongly suggest that incorporation of carbaryl into the flooded soils during land preparation is a reasonable alternative method of insecticide application.

Table 23. Effect of soil application of insecticides on the grain yield of Tainan 1 and IR9-60. IRRI, 1966 dry season.

Grain yield at 14% moisture (average, 4 replications)

Treatment number	Insecticide treatment: Soil applied carbaryl (active ingredient)		Insecticide treatment: γ-BHC in irrigation water (active ingredient)	Variety or selection: Tainan 1	Variety or selection: IR9-60	Mean (treatment)
	(kg/ha)				(kg/ha)	
1	No insecticide			3928	5628	4778
2	0	+	2 + 3 + 3	4418	6243	5331
3	5	+	2 + 3 + 3	4166	6273	5220
4	10	+	2 + 3 + 3	4392	6394	5393
5	20	+	2 + 3 + 3	4417	6959	5688
6	30	+	2 + 3 + 3	3791	6974	5382
7	20	+	(No γ-BHC)	4098	7233	5666
8	Standard practice*			4989	7227	6108
Mean (variety)				4275	6616	
Duration (days)				137	120	

Analysis of variance:	s.e.	L.S.D.	cv($\bar{x}$) %	CV(X) %
Treatment combination**	282	804	5.2	10.4
Variety (V)**	100	284	1.8	
Treatment (T)**	200	569	3.7	
V x T n.s.	—	—	—	

*7 kg γ-BHC 2 + 2 + 3 kg) + 13 kg carbaryl (3 + 3 + 3 + 1 + 3 kg).

Table 24. Effects of soil application of insecticides on the leafhopper, virus hill, dead hearts, and white head counts of Tainan 1 and IR9-60. IRRI, 1966 dry season.

Treatment number	Insecticide treatment: Soil-applied carbaryl	Insecticide treatment: γ-BHC in irrigation water	Leafhopper count/9.6 sq m 5 sweeps		Virus hill count/19.16 sq m				Dead heart count/19.15 sq m		White head count/5 sq m	
	active ingredient (kg/ha)		Days after transplanting: 29		28	61	28	61	28		At harvest: 107	109
			Tainan 1	IR9-60	Tainan 1	Tainan 1	IR9-60	IR9-60	Tainan 1	IR9-60	Tainan 1	IR9-60
									(%)	(%)	(%)	(%)
1	No insecticide		28	9	3.5	14.5	16.7	13.7	1.06	0.910	4.2	10.4
2	0	+ 2+3+2	7	3	2.7	1.0	1.0	9.0	0.35	0.092	2.0	5.5
3	5	+ 2+3+2	2	3	0.8	2.7	2.5	2.0	0.21	0.062	2.1	3.9
4	10	+ 2+3+2	2	2	0.2	1.0	3.5	1.2	0.08	0.012	1.6	2.1
5	20	+ 2+3+2	2	2	0.2	0.8	0.8	1.2	0.03	0.002	1.0	1.0
6	30	+ 2+3+2	2	4	0.8	2.0	0.8	1.5	0.02	0.012	1.2	2.9
7	20	+ (No γ-BHC)	5	2	0.5	2.2	0.8	2.8	0.12	0.0093	4.5	1.7
8	Standard practice†		3	2	0.2	0	2.2	0.8	0.05	0.015	1.8	1.2

	Leafhopper count		Virus hill count (61 days after transplanting)			White head count		
Analysis of variance:	s.e.	L.S.D.		s.e.	L.S.D.		s.e.	L.S.D.
Treatment combination**	2.8	7.9	n.s.	1.8	—	**	0.4	1.0
Variety (V)*	1.0	2.8	n.s.	0.6	—	**	0.1	0.4
Treatment (T)**	2.0	5.6	**	1.3	3.7	**	0.2	0.7
V x T*	2.8	7.9	n.s.	1.8	—	**	0.4	1.0

†7 kg γ-BHC + 13 kg carbaryl (3 applications + 5 applications).

Weed Control

The research program in weed control was concentrated on four topics: (1) evaluation of hand and mechanical weeding methods in comparison with chemicals; (2) investigation of herbicides for water application; (3) tests of tillage and planting methods in relation to weed control; and (4) combinations of techniques for upland rice weed control.

Screening of herbicides

Screening of herbicides for rice crops was continued with four testing conditions as described in previous annual reports. Table 25 presents the summary of results as a rank order listing as the chemicals were evaluated for yield or weed control in each of the four categories. Only the 20 best treatments are listed.

Several new chemicals appear on the list for the first time, while others had been used in new combinations as submitted by the manufacturers. About 70 materials were tested. Because of the low replication (2) of the test, little significance is attached to differences in rank of less than 10 places.

Substantial interest has been generated in three or four of the new herbicides. A pyridinol compound (Daxtron; Dow Chemical International) has been effective in water application at remarkably low rates while some granular combinations with 2, 4-D (Knox weed, Stauffer Chemical Co., and Roundup, Monsanto Company) have also proved effective when applied either to the water or drained paddy. The behavior and management of the more promising of these materials will be tested further.

Only the molinate granule, pyridinol, and the EPTC+ 2, 4-D combination were superior or equal to the handweeding control or to the recommended practice of using 2, 4-D (or MCPA) before handweeding.

Weed control in direct-seeded rice

Water-applied chemicals have been tested for several years in screening and management experiments with transplanted rice, but one of the principal advantages of chemical weed control is the control of weeds in direct-seeded rice.

In July 1966, an experiment was begun, using the best water-applied herbicides from screening tests on transplanted rice, to test their utility in direct-seeded rice. Three rates and four times of application were used in a split-plot design in which IR8 was sown at 100 kg/ha in rows on the soil surface with a two-row, hand-pulled mechanical drill (Annual Report, 1964). Seed was soaked in water 24 hours and drained for 24 hours before being drilled on the puddled soil 3 days after final harrowing. A total of 90 kg/ha N was applied in a split dose, and standard insecticide practices were used. Seeds of the grassy weed, *Echinochloa crusgalli,* were broadcast the day following sowing the rice. All plots were sprayed with 1 kg/ha of MCPA 35 days after planting for control of broadleaved weeds.

The experimental chemicals were molinate (S-ethyl hexahydro-IH-azepine-1-carbothioate) applied at 2, 3 and 4 kg/ha; NPE (2, 4-dichlorophenyl-4-nitrophenyl ether) at 0.5, 1.0 and 2.0 kg/ha; Dichlobenil (2, 6-dichlorobenzonitrile) at 0.5, 1 and 2 kg/ha; and pyridinol (2, 3, 5-trichloro-4-pyridinol) at .05, .075 and 0.1 kg/ha. They were applied 3 days after sowing (preemergence to grass weeds), 1 day after emergence (5 days after sowing), 3 days after emergence (7 days after sowing) and 7 days after emergence (11 days after sowing). At the weed preemergence date, the plumule of the rice seedlings had emerged about 1 cm.

Treatments were evaluated in terms of seedling survival, weed weight, number of *Echinochloa crusgalli* panicles per plot, and yield of grain. Figure 25 shows yields and *E. crusgalli* panicles in comparison with the non-weeded and hand-weeded controls.

E. crusgalli was adequately controlled by each of the two earlier pyridinol applications, the preemergence treatment with NPE, and all the molinate applications except the lowest rate. Yields that were significantly better than in handweeding treatments were produced with the higher rates of pyridinol when applied preemergence and with 3 kg of molinate early post-emergence.

Dichlobenil was somewhat toxic to direct-seeded rice although it has controlled weeds well in transplanted rice. Both germination and

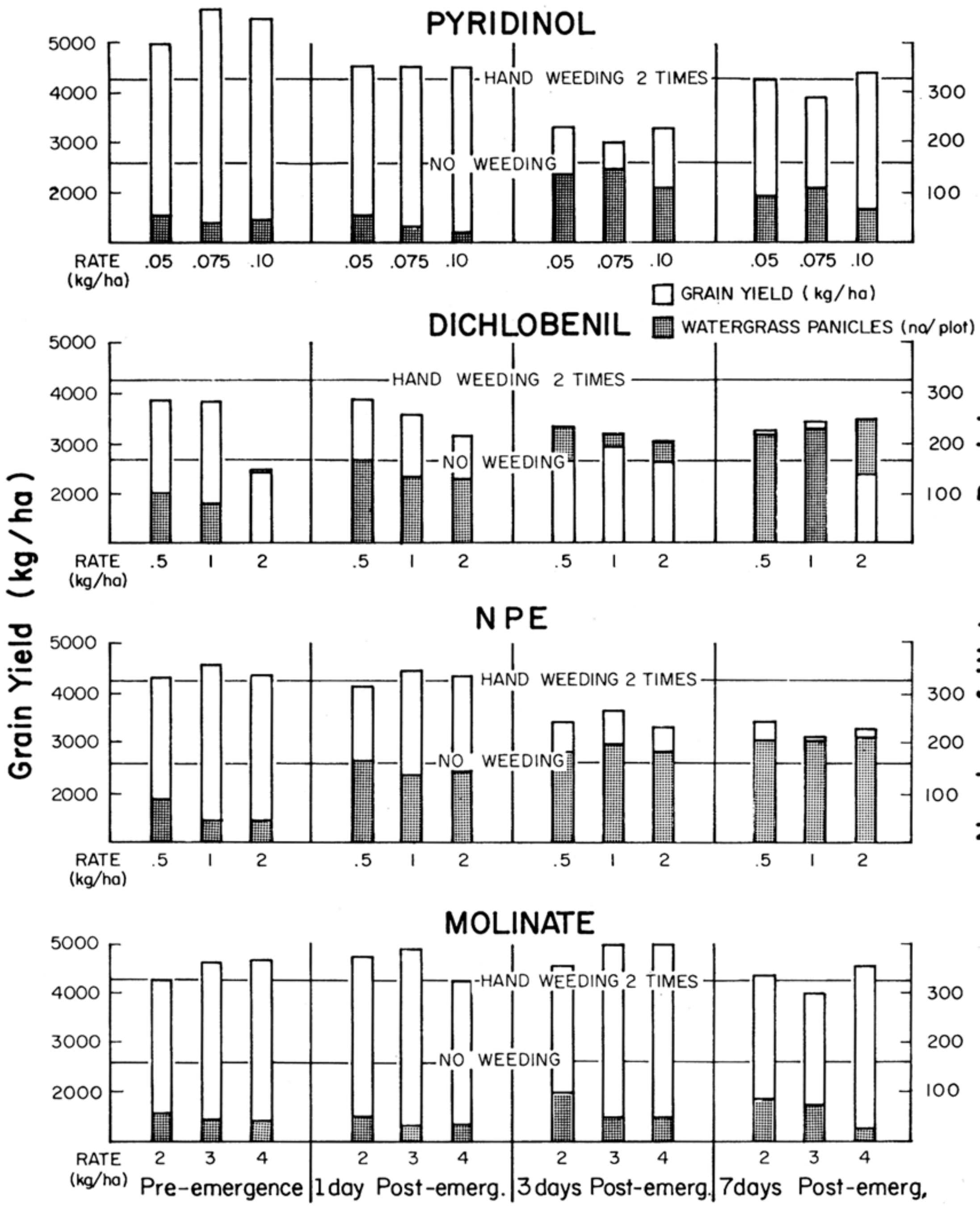


Fig. 25. Grain yield and grass control (counts) for chemicals applied to shallow water (2 cm) at three rates and four times after sowing soaked rice on the surface of puddled soil. 1966 wet season.

Table 25. Rank of herbicides in a screening test evaluating yield and weed control under four conditions of testing. 1966 wet season.

Treatment (common chemical or trade name)	Rate (kg/ha)	Rank order in evaluation for							
		Early application (4 DAT)*				Late application (16 DAT)*			
		Drained		Flooded		Drained		Flooded	
		Yield	Weed weight	Yield	Weed weight	Yield	Weed weight	Yield	Weed weight
Handweeding twice (25 & 45 DAT)		1	2	11	2	1	1	2	2
2,4-D ester (0.8) ff HW		7	1	4	1	2	2	1	1
Molinate G	(3.0)			21	9	3	3	3	3
Pyridinol	(0.2)	12	22	1	8	4	6	10	5
EPTC + 2,4-D G	(3.0)	3	4	2	12				
Dichlobenil	(2.0)	5	16	8	16			8	9
Molinate EC	(3.0)	20 +	20	5	3			20 +	7
MCPA + 2,4-D	(1.0)	13	15					4	6
CP 31393 + 2,4-D G	(4.0)	n.t.	n.t.†	n.t.	n.t.			5	10
CP 50144 G	(1.0)	n.t.	n.t.	n.t.	n.t.			7	17
CDAA	(5.0)	4	23	7	20			6	12
CP 45592	(4.0)	2	10	13	17	5	7		
IHARA-CHLOS	(10.0)	6	6	20 +	14				
Trifluralin	(1.0)	8	8	20	16				
NPE G	(2.0)	11	11						
KN_3 G	(4.0)	16	7					20 +	16
KN_3 WP		19	5						
EPTC G	(2.0)			3	6				
EPTC EC	(2.0)			10	4				
Propanil EC	(3.0)					?	10		

* Days after transplanting.
† Not tested.

tiller production were inhibited. Weed control with NPE deteriorated rapidly with delayed applications and yields consequently declined with post-emergence timing. Pyridinol lost the yield advantage with later applications and grass control was not maintained. Molinate displayed a greater latitude in timing than other chemicals in the test.

Upland weed control

Experiments on upland weed control using commercially available chemicals and conventional tillage sequences have been generally unsuccessful. The 1966 crop year did not favor high upland rice yields but experiments were evaluated on the basis of weed control, and were considered indicative of performance of chemicals except for the yield results.

Much research in Europe, Japan and U.S.A. in recent years has been directed toward minimum tillage practices for a number of crops but little success has been reported for rice. The potential for low-cost weed control hinges on utility of cheap chemicals and the judicious use of mechanical or traditional tillage techniques.

A rate and timing experiment was conducted with four rates each of PCP (Na) (5, 10, 15 and 20 kg/ha), PCP-oil (2.5, 5, 7.5 and 10 kg/ha), DNPB (1, 2, 4, and 8 kg/ha), diquat (0.5, 1, 2, and 4 kg/ha), paraquat (0.25, 0.5, 1 and 2 kg/ha). Controls of propanil (4 kg/ha), propanil (4 kg/ha) followed by 2, 4, 5-T (1 kg/ha) at two times of application (preplant and preemergence), along with handweeded and non-weeded treatments, were used.

The "stale seedbed" technique was used in this experiment in which the seedbed was prepared 16 days before seeding. On the day following final tillage, a sprinkler irrigation was applied to wet the soil to a 10-cm depth to enhance the germination of weeds. A japonica variety from Taiwan, PI 215936, was drilled on February 2, 1965, in the weedy field 16 days after tillage in 25-cm rows at 80 kg/ha with a Planet Jr. seed drill.

Preplanting and preemergence applications of herbicides were made at 12 and 18 days after tillage, or 3 days before and after seeding when the weeds were at 2- to 3- and 4- to 5-leaf stages, respectively. The application of 2, 4, 5-T (1 kg/ha) was made 30 days after drilling in propanil-treated plots. Handweeding was done 30 days after seeding.

A mixed fertilizer (50-50-0 kg/ha) was applied 40 days after seeding and the field was irrigated by sprinkler and furrow irrigation whenever required.

Weed control rating and the weed samples for dry weight were obtained 60 days after tillage.

The major weed species found in the experimental area in a decreasing order of density (population) were *Cyperus rotundas* L., *Eleusine indica* (L.) Gaertn., *Echinochloa colonum* (L.) Link, *Digitaria* spp., *Dactyloctanium aegypticum* (L.) P. Beauv, *Portulaca oleracea* L., *Ipomoea triloba* L., *Calapogonium muconoides* Desv., *Celosia argentea* L., *Amaranthus spinosus* L., *Commelina benghalensis* L., *Gynandropsis gynandra* (L.) Merr. and *Heliotropium indicum* (L.). *Cyperus rotundus* and grassy weeds germinated earlier than the broadleaved weeds and were more difficult to control.

On some grassy weeds, herbicides killed only exposed leaves, and new leaves and tillers developed later. Broadleaved species were well controlled in plots treated with 2, 4, 5-T but *Portulaca oleracea* was resistant to 2, 4, 5-T spray.

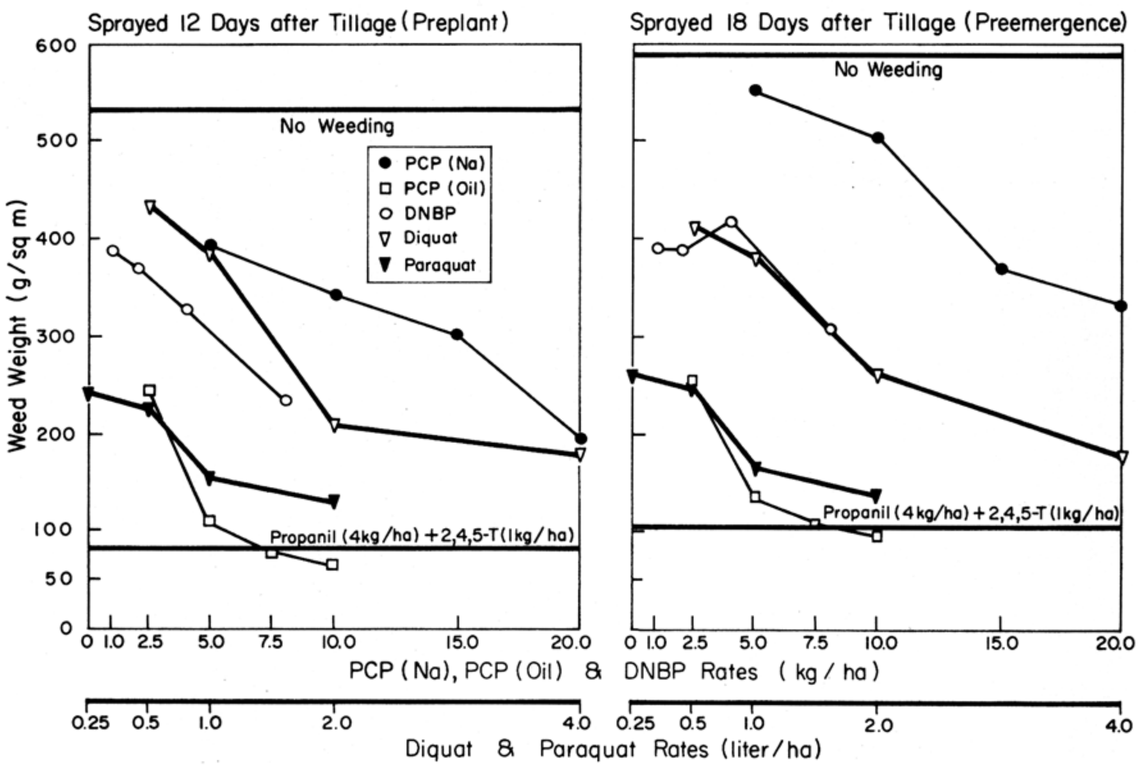


Fig. 26. Relative weed control with different chemicals and rates in delayed planting tests with upland rice. 1965 dry season.

The degree of weed control, measured in terms of weed weight 60 days after tillage, is presented in Fig. 26. Preplant application of herbicides 12 days after tillage reduced weed weight slightly more than the preemergence application at 18 days after tillage. With the later application, some of the newly germinated weed seedlings were protected by leaves of larger weeds and thus escaped the herbicide spray. Moreover, the late application caused only defoliation of grassy weeds larger than the 4- to 5-leaf stage so that new leaves and tillers developed from the basal parts.

Increased rates of all herbicides consistently reduced weed weights. Satisfactory weed control was obtained with PCP (oil) at 5, 7.5 and 10 kg/ha, paraquat at 2 liter/ha, propanil at 4 kg/ha and propanil at 4 kg/ha followed by 2, 4, 5-T at 1 kg/ha. The average weed weights were 112, 93, 80, 134, 118 and 98 g/sq m respectively. The difference between the mean weed weight of these promising treatments and the non-weeded con-

Fig. 27. IR8 sown on the puddled surface of a sloping bed to test effects of water depth on germination and emergence. IRRI, 1965 dry season.

trol was about 456 g/sq m. PCP (oil) applied at rates exceeding 5 kg/ha did not result in additional reduction in weed weight. The lowest rates of PCP (oil) (2.5 kg/ha) and paraquat (0.25 liter/ha) were as good as, or better than, the highest rates of diquat (4 liter/ha), DNPB (8 kg/ha) and PCP (Na) (20 kg/ha). The weed control rating (visual score) provided information similar to that obtained from weed weights for evaluating the degree of weed control. For a single hand-weeding at 30 days after seeding the average labor requirement was 720 man-hour/ha, indicating the high cost of weed control by hand-weeding.

Visual toxicity ratings showed that the herbicides were not toxic to the rice plant except for PCP (oil) at 10 kg/ha and DNBP at 8 kg/ha for which slight toxicity, particularly in preemergence application, was observed. PCP (oil), paraquat, and propanil showed promising results and were selected and studied in upland rice weed control in other experiments.

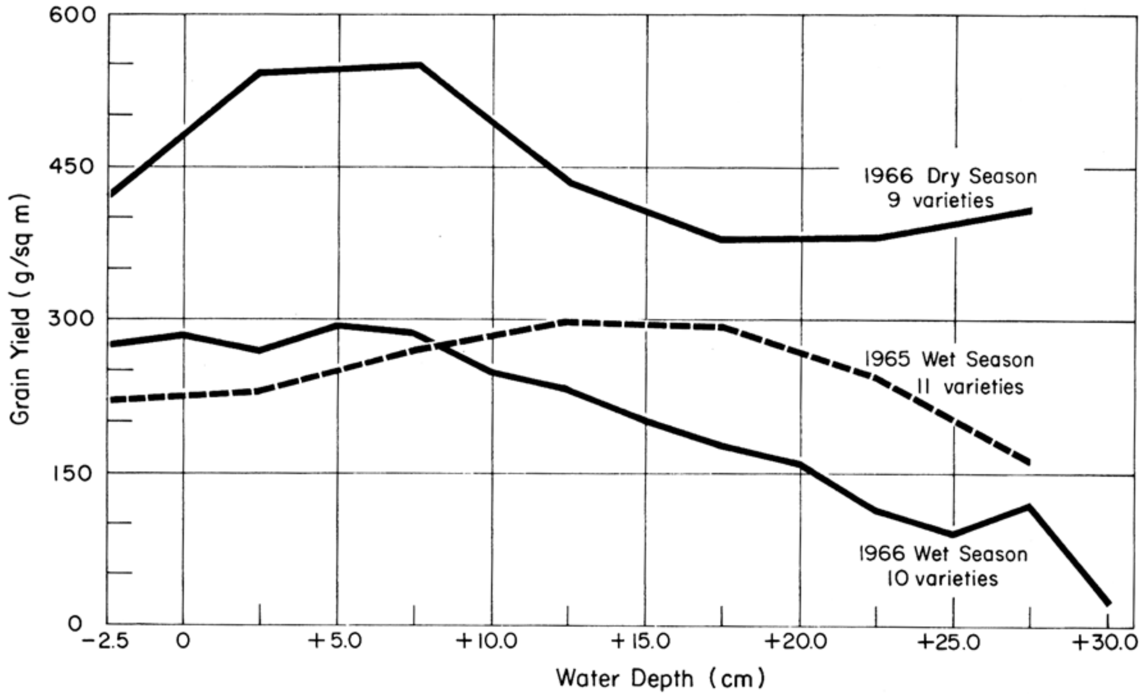


Fig. 28. Relationship of mean grain yield in three seasons to water depth of rice varieties seeded directly on the surface of puddled soil followed by continuous submergence. IRRI, 1965-66.

Studies of Other Cultural Practices

Direct seeding studies

To test the effect of water depth on establishment and yield of traditional and improved varieties, 10 varieties were sown directly on the surface of puddled soil on a sloping bed (Fig. 27). The slope of the bed was 1 cm/m and the soaked, incubated seeds were sown in rows on the bed the day before flooding. The water was maintained as a continuous flood throughout the growth of the crop. Standard cultural practices were applied but herbicides were not used until the plants were 30 days old.

Information on stand establishment, seedling survival, tillering, growth, and weed production was collected. The experiment was conducted for three seasons.

Figure 28 shows the yield of grain plotted against depth of water for the three seasons. Differences between varieties, water depths, and seasons were marked but general success and high yields were obtained from direct seeding and continuous flooding. In the 1965 wet season, the best mean yields were obtained with 12.5 cm depth of water. Selections IR9-106 and IR3-66 produced the best yields at water depths between 7.5 and 12.5 cm. The poorest yields resulted from some of the American indicas which were bred under direct seeding conditions (Acc. 9795, and Acc. 6993).

In the 1966 dry season, IR8 proved to be superior to other varieties and selections in the test by a wide margin. The best yield was produced at 2.5 cm of water and was equivalent to 8.8 ton/ha, but the best average yield for all varieties occurred between the 2.5 to 7.5 cm depths. Yields were higher than in the wet season for all varieties (650 g/sq m) and above-average yields were obtained with IR9-60, Milfor-6 (2), and Taichung (Native) 1.

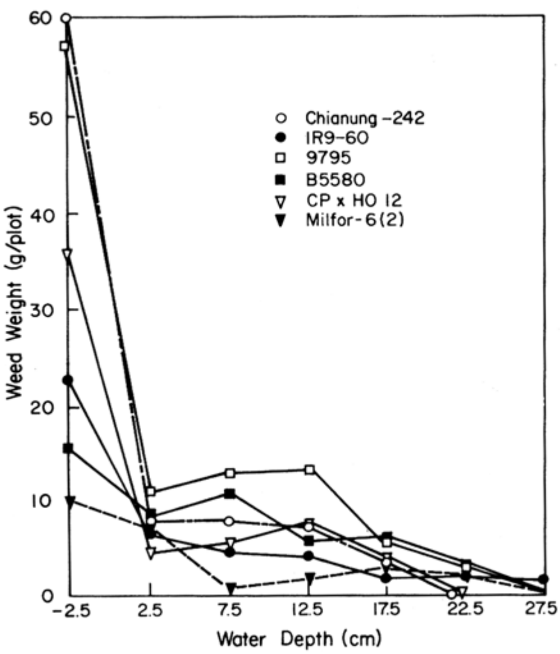


Fig. 29. Weed weight (g/plot) at first weeding as affected by water depth in six directly seeded varieties. IRRI, 1965 wet season.

The 1966 wet season test produced generally lower yields, the maximum being the 470 g/sq m for IR8 at the 5-cm depth. IR8 was again the best variety but was not significantly better than MIFB-322 at shallow depths. The best depth for the average of all varieties in the test was between 0 and 10 cm of water, and most varieties declined in yield with greater depths. Taichung (Native) 1 and C-18 produced some unusually high yields at the 27.5-cm depth. Most varieties were seriously affected by sheath blight.

Representative data are presented (Fig. 29) for weed control effects of water depth. In the 1965 wet season, weed weights were taken from the first weeding for six varieties and are plotted against depth of water. It is readily seen that the principal weed control effect was obtained from the first 2.5 cm of flood water. Beyond 2.5 cm the weed weight at first weeding continued to decline but at a reduced rate. Weeds were completely controlled at about 25 cm of water but rice emergence was also greatly reduced. Varietal differences were not pronounced but, in general, the lower tillering ponlai or U.S. varieties permitted greater weed growth.

The components of yield are plotted against water depth in Fig. 30. Tiller (panicle) number declines markedly beyond 7.5 cm depth of water (mean of 10 varieties and selections). While the weight per panicle increases moderately, the grain weight remains essentially constant with a net effect of decline in yield with increasing water depth. Data on seedling establishment and survival have been presented (Annual Report, 1965).

From this series of experiments it is clear that adequate stands of rice can be established by water seeding in either season. Normal yields have been produced when water has been maintained continuously at shallow depths (2.5-10 cm). When weeds are controlled and soil fertility is adequate, yields of about 4.5 ton/ha in the wet season and 8 ton/ha in the dry season have been obtained with the better varieties.

Minimum tillage experiments

Several crops are being grown in technically advanced agricultural areas with tillage and planting techniques that are variously called "minimum tillage", "plow-plant", "stale seedbed" and other names. These usually involve reduced mechanical tillage and the addition of a chemical treatment to substitute for the weed control effects of tillage. In spite of the cost and technical difficulty of applying chemical sprays, the difficulties of timely and efficient land preparation with either animals or machines in many rice-growing areas make this approach seem a fruitful one for research.

During the 1965 crop year and previously, preliminary experiments had identified three

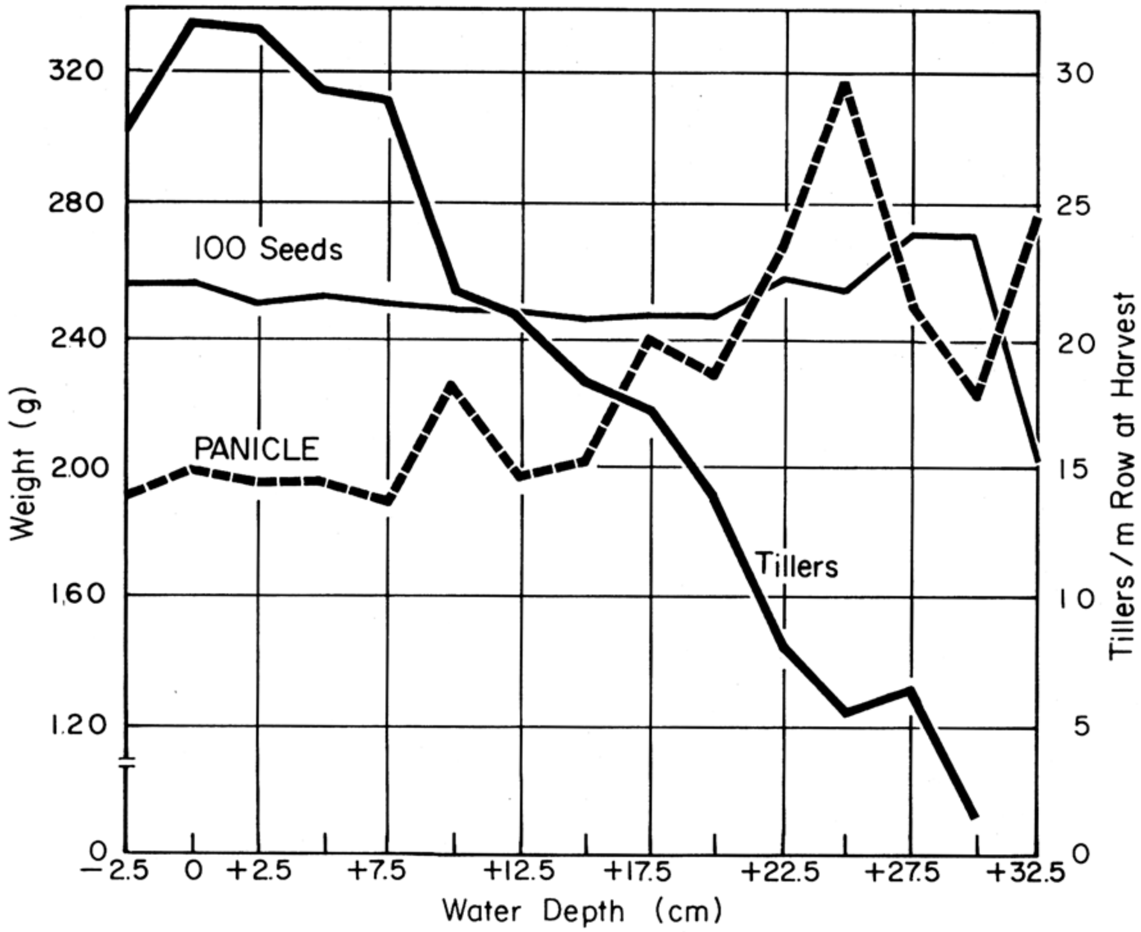


Fig. 30. Influence of water depth on yield components (mean of 10 varieties) sown directly on puddled soil. IRRI, 1966 wet season.

particularly promising chemicals for this technique: PCP, paraquat, and an experimental pyridinol herbicide. Previous experiments had also shown, as is well known, that some varieties yield well when transplanted while others perform relatively better when broadcast or row-sown. Problems with weed control were relatively more serious with poor land preparation and low yields were obtained, particularly in combinations of direct seeding and rough seedbed preparation.

During the 1965 wet season an experiment was conducted in which four tillage methods were tested utilizing chemical weed control sprays following a single rotovator pass. Control plots were harrowed twice. BPI-76 and PI 215936 were tested with broadcast, drilled, and transplanted methods of stand establishment. The results, shown in Table 26, indicated that transplanted rice was significantly better than direct-seeded rice and that 6 kg/ha of PCP in diesel oil sprayed after rotovation gave yields equal to standard tillage techniques. The paraquat rate used in the test was too low to control weeds well and yields were equivalent to the non-treated control. The difference in hand-weeding time required was about the same for the two high-yielding treatments.

During the dry season, a similar experiment without the planting methods variable or the rotovator treatment was conducted in which the paraquat rate was raised and another chemical was used to substitute for tillage (Table 27). Plots were flooded with water, and seedlings were transplanted directly in the wet soil. If weeded, the three chemical treatments gave yields equivalent to the standard plow and harrow method, indicating that weed control

Table 26. Results from a tillage and planting method experiment with two varieties. IRRI, 1965 wet season.

Tillage and planting method	Time to weed (man-hr/ha)			Yield (kg/ha)		
	BPI-76	PI-215936	Mean	BPI-76	PI-215936	Mean
Rotovated, no preplanting treatment						
A. Broadcast 100 kg/ha	507	623	565	3521	2803	3162
B. Drilled in 25 cm rows, 100 kg/ha	491	529	510	3632	2633	3132
C. Transplanted 25 x 25	457	584	520	4249	3312	3780
Mean	485	579	532	3801	2916	3358
Rotovated, PCP (oil) sprayed at 6 kg/ha						
A. Broadcast	161	222	191	4074	4238	4156
B. Drilled	158	198	178	4404	3754	4079
C. Transplanted	129	164	147	5070	4884	4977
Mean	149	195	172	4516	4292	4404
Rotovated, paraquat 0.4 kg/ha						
A. Broadcast	376	391	383	3729	2203	2971
B. Drilled	351	323	337	4384	2739	3561
C. Transplanted	289	336	313	4247	2703	3475
Mean	339	350	344	4123	2548	3335
Standard tillage (rotovated and harrowed twice)						
A. Broadcast	196	238	217	4504	4005	4254
B. Drilled	188	231	209	4700	4711	4705
C. Transplanted	161	180	171	5540	5256	5398
Mean	182	216	199	4915	4657	4786

Fertilizer: 60-30-30 kg/ha
MCPA: 1.0 kg ai/ha 25 DAT

Time to weed: $L.S.D._{.05}$ Variety=42; Tillage=68; Planting method=24

Yield: $L.S.D._{.05}$ Variety=236; Tillage=669; Planting method=180

is the principal function of tillage (Fig. 31). None of the chemical treatments, however, effected a degree of weed control as great as did normal tillage.

Water management

Water management experiments were conducted during the wet and dry seasons in 1966. Water use and efficiency were measured as described in previous reports.

During the dry season, eight irrigation treatments were applied to IR9-60 planted in replicated metal tanks. No statistical significance was obtained between yields but water consumptive use was increased by about 50 percent in deep continuous flooding treatments compared with plots maintained at saturation (soil surface irrigation).

During the wet season, four treatments, including rainfed irrigation, were installed using IR8 as the test variety. Yields and water use data (Table 28) showed no differences in yields between water treatments with IR8 but a significant reduction in yield of H-4 was recorded with deep continuous flooding when grown in concurrent trials in ordinary paddies. The amount of rainfall during the growing season was normal and the 458 mm falling in 86 days was sufficient to grow a crop of 5,200 kg/ha when other management practices were adequate and a high-yielding variety was used. The reduced yield with the deep water treatment for

Table 27. A minimum tillage experiment with transplanted rice in which chemical weed control was substituted for land preparation. IRRI, 1966 dry season.

Treatment	Panicle	Productive tillers	Panicle weight	Missing hills	Weeding time	Yield
	(no/sq m)	(%)	(g)	(no/plot)	(man-hr/ha)	(kg/ha)
Unplowed, PCP (0) 5.0 kg/ha	400	97.2	3.11	4.25	308	5996
Unplowed, Paraquat 0.8 kg/ha	400	97.1	3.47	2.62	361	6359
Unplowed, Pyridinol (1.0) + Picloram (0.2)	420	96.6	2.66	6.12	363	6409
Unplowed, no preplant treatment	390	94.6	2.82	18.37	581	3637
Standard plow and harrow	370	98.8	2.59	1.37	94	5882
					Time	Yield
L.S.D.$_{.05}$					177	603

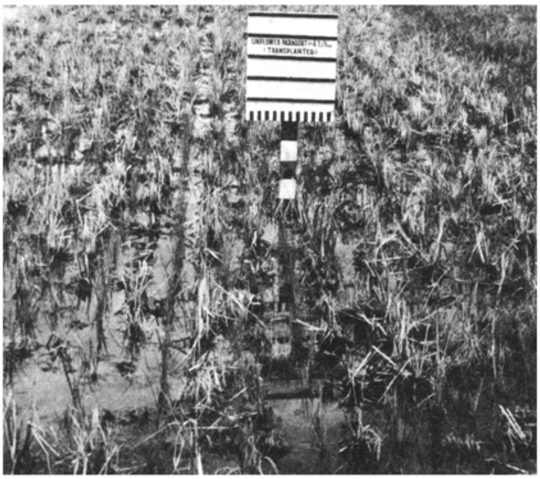
Selection: IR9-60.
Fertilizer: 50 kg N basal; 50 kg N after weeding; 40 kg N at P.I.
MCPA: 1.0 kg ai/ha 25 DAT.
Insecticide: Standard practice.
Date of tillage: January 19.
Date of transplanting: January 22.
Date of harvest: May 28.

Table 28. Yields and relative water use in water management treatments applied to improved and traditional varieties. IRRI, 1966 wet season.

Water management treatment	Grain yield (kg/ha)			Cumulative water use (86 days)*	Water use index (% of deep continuous)
	Metal tanks	Natural paddies			
	IR8	H-4	IR8		
				(mm)	
Rainfed (no irrigation)	5200	3220	4600	458	57
Mid-season drainage	6000	2420	5300	635	79
Shallow (2.5 cm) continuous	5340	2130	5110	568	71
Deep (10 cm) continuous	5570	1560	5075	803	100

* Does not include irrigation for land preparation.

a



b

c

Fig. 31. Land preparation and tillage tests showed that some chemical treatments aided in weed control and that transplanted stands could be established without tillage when soils were flooded, IRRI, 1965 dry season. (a) No cultivation on chemical weedicide treatment; (b) no cultivation but treated with paraquat; (c) plowed and harrowed.

the Ceylonese variety, H-4, was brought about by early lodging induced by the weakened straw and additional height which resulted in that treatment.

The rainfed treatment produced as much rice as did irrigated treatments in the wet season. Although a drought period (see Crop Weather) occurred at heading time, the water impounded by levees was sufficient to bring the crop through with good yields. This is in marked contrast to the yields of upland rice where no impounded water was available and yields in some experiments were below 800 kg/ha.

Entomology

Data from 24 experiments conducted during the last six crop seasons at the Institute show that plots receiving the best insect protection yielded an average of 5.3 ton/ha compared to 2.9 ton/ha in untreated plots. This average increase of 2.4 ton/ha rice attributable to insect pest control illustrates the extent to which insects damage the rice crop. Although several pests are involved, stem borers and leafhoppers cause the major damage. The research program seeks immediate and practical methods of controlling these insects with chemicals, but the long-range efforts are directed toward developing integrated controls by supplementing insecticides with varietal resistance, natural enemies, and sex attractants and sterilants.

Work continued on the study of paddy water application of γ-BHC, the principal results being basic information on the insecticidal activities and residues.

A further finding was that diazinon applied to the paddy water controlled all species of stem borers at the Institute, including the pink borer, Sesamia inferens, *and the rice green leafhopper,* Nephotettix *species, thus preventing the spread of virus diseases in treated plots. The rate of application and price of diazinon place it in the same economic range as γ-BHC, which usually does not effectively control the pink borer and the rice green leafhoppers. Studies on its mode of action, residues and effectivity under diverse environmental conditions are under way.*

Several crosses between resistant and susceptible varieties have shown encouraging results in studies of varietal resistance. A definite sex attractant in stem borer has been demonstrated. Sturmiopsis inferens, *a stem borer parasite imported from India, is being mass reared, evaluated for its parasitic effectivity, and has been released in some rice fields.*

Leafhoppers and Planthoppers

The importance of leafhoppers and planthoppers as pests of rice crops is being increasingly realized throughout the rice-producing areas of the world. They are persistent pests in certain areas but occur sporadically elsewhere. Generally, the leafhopper group refers to those belonging to the family Cicadellidae such as *Nephotettix* spp. and *Inazuma dorsalis,* while the planthoppers belong to the family Delphacidae and include such species as *Nilaparvata lugens* and *Sogatella furcifera.* Although about 20 different species of leafhoppers and planthoppers have been recorded at the Institute, those most common are *Nephotettix* spp., *Tettigella spectra* Distant, *Cicadulina bipunctata* Matsumara, *Sogatella furcifera* Horvath, and *Nilaparvata lugens* Stal. These insects damage the crop either by direct feeding, which may result in loss of plant vigor or complete drying of the crop, or by transmitting virus diseases.

Very little information is available on the ecology, population fluctuation, and bionomics of the common leafhopper and planthopper species in the tropics. During the year, detailed studies were conducted on the field population dynamics of the common leafhopper and planthopper species and on the ecology and basic bionomics of the brown planthopper, *Nilaparvata lugens* Stal. Some aspects of these studies are reported here.

Effect of different temperatures on development

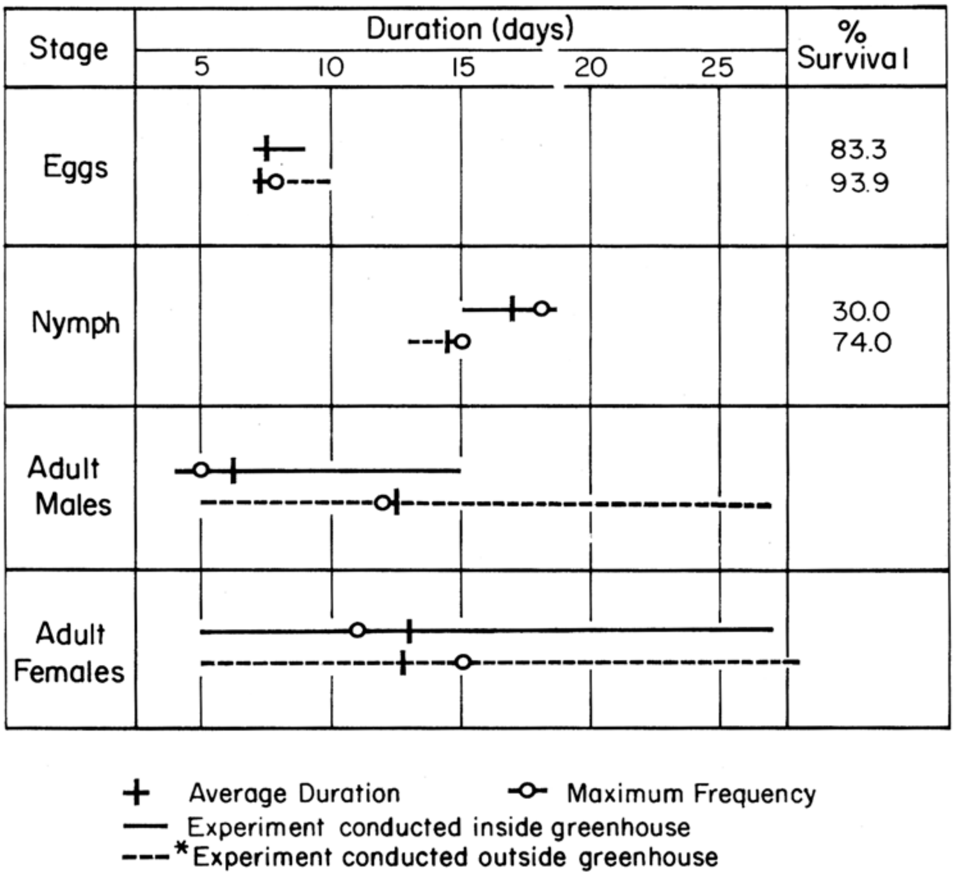
The studies were conducted with laboratory reared, virus-free insects under greenhouse and natural environmental conditions, and with controlled temperature and light in laboratory experiments. Experiments conducted under glass-shaded areas outside a greenhouse represented natural environmental conditions.

In greenhouse experiments 83.3 percent of eggs hatched, and 30 percent of nymphs reached the adult stage in an average period of 7.7 and 17 days respectively, but under natural environmental conditions a higher percentage of eggs hatched and more nymphs reached the adult stage, although the total incubation and nymphal period remained relatively unchanged (Fig. 1). Also, the male planthoppers had significantly shorter lives under greenhouse conditions. When kept at constant temperatures, the adult insects lived longest at 25 C but their longevity declined by from about 60 to 70 percent at higher temperatures (Fig. 2). It is significant that 12-hour exposures to 33 C alternating with either 25 or 29 C did not increase the life duration over that recorded for a continuous temperature of 33 C. The females lived longer than the males and the difference was more pronounced at lower than at higher temperatures.

Eggs incubated either at 25 or 29 C or their combinations hatched normally but failed to hatch when kept at 33 C. Exposure to 33 C even in combinations with 25 or 29 C reduced hatching significantly and increased the incubation period (Fig. 3). Eggs incubated at 33 C showed abnormal embryonic development. When reared at either 25 or 29 C or their combinations, 88 percent of the nymphs reached the adult stage in 2 weeks, but at 33 C no nymphs survived beyond the second instar. Also, their survival was greatly reduced and the nymphal period was considerably prolonged even when reared at the alternating temperatures of 25 and 33 C or 29 and 33 C. The average life span of male and female brown planthoppers was 11.6 and 18.6 days respectively, but was reduced by about 66 percent at 33 C, either alone or in combinations with 25 or 29 C.

The brown planthoppers generally lay eggs in the midrib or the leaf sheaths of the plants. The females, with their sharp ovipositors, insert the eggs in masses in the plant tissues. The number of eggs in an egg mass usually ranged from 1 to 42 and did not change at either of the temperatures studied. The highest number of eggs (an average of 244.2 eggs per female) was laid at 25 C, but the number declined at higher temperatures and no oviposition occurred when the insects were kept at 33 C. However, if freshly emerged adults were first kept at lower temperatures for 4 days and then at 33 C, some oviposition occurred, indicating an increase in tolerance to higher temperatures in older insects.

The deleterious effects of the higher temperatures are of significance and may explain the lower survival of the planthoppers inside the



* Conditions identical to inside the greenhouse except that the maximum temperature in the greenhouse was about 5°C higher.

Fig. 1. Duration of the different life history stages of the brown planthoppers.

greenhouse where the maximum temperature was about 5 C higher than outside. The data also suggest that in places where the temperature reaches 33 C or more, it may act as a limiting factor in keeping the brown planthopper population low. However, as the adult insects were more tolerant to alternating high and medium temperatures, similar to fluctuations occurring in nature, some of the population may still remain active. During the periods when temperatures far exceed 35 C, brown planthoppers may undergo aestivation.

Effect on rice plants of brown planthopper feeding

To determine the level of brown planthopper population capable of causing significant damage to rice plants by direct feeding, a series of experiments was conducted using plants of different ages and different concentrations of nymphs and adults. In separate experiments, potted plants of variety Taichung (Native) 1 were infested at 25, 50, and 75 days after transplanting with 50, 100, 200, and 400 freshly hatched nymphs or 4, 8, 16, and 32 macropterous adult planthoppers. If the plants started wilting, the insects were killed with phosphamidon spray and the plants grown to maturity under normal cultural conditions.

Only 2 days after caging, a population of 400 freshly hatched nymphs caused plants 25 days after transplanting to wilt. Although at this time the nymphs were killed, all plants infested with 400 nymphs, and three replications of those infested with 200 nymphs, died. In observations made 60 days later, the number of tillers in the control and those caged with 50 and 100 nymphs differed only slightly, but was greatly reduced

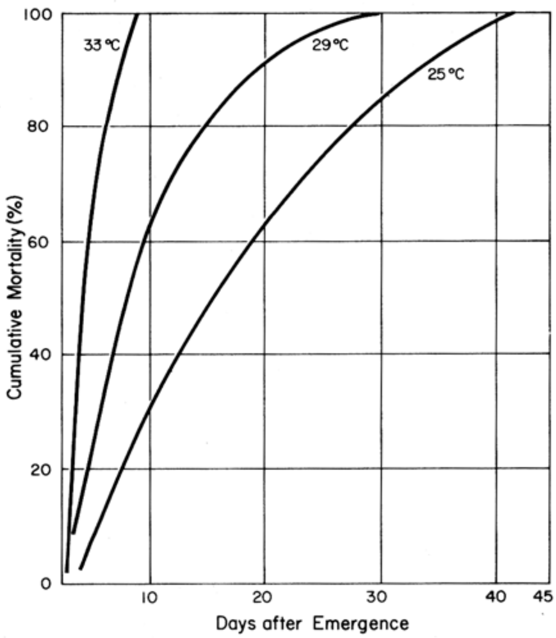


Fig. 2. Life span of the macropterous brown planthopper female at different temperatures. Except that they were shortlived, the male reaction to different temperatures was identical to that of the females.

in those caged with 200 nymphs. Smaller plant height differences between treatments were recorded.

The plants infested at 50 and 75 days after transplanting were more tolerant to damage by direct feeding: those caged with 400 nymphs started wilting in about 2 weeks after infestation, but recovered when the planthoppers were killed at this stage. On these plants, 50 nymphs feeding for 2 weeks did not cause any significant reduction either in plant height or number of tillers per plant, but such damage was evident when higher levels of nymphal population were used (Table 1). The plants infested at 50 and 75 days after transplanting had a high percentage of empty grains but this was not pronounced on plants infested at 25 days after transplanting.

Large insect populations on plants of all ages tested, caused a reduction in the number of tillers, number of panicles, and total grain weight per plant (Fig. 4). Also, 50 nymphs or 4 adults feeding for a period of 2 days and 2 weeks on plants at 25 days and 50 to 75 days after transplanting respectively, did not cause any significant damage. This suggests that although young plants are very susceptible to brown planthopper damage, those at 50 to 75 days after transplanting can tolerate a population below 50 nymphs or 4 adults per plant for several days without any significant damage.

Thus, planthopper infestation of plants at all ages reduces the number of tillers and panicles per plant. Infestation of 50- to 75-day-old plants also greatly reduced plant height and increased the percentages of unfilled grains, but such effects were not apparent on plants infested at 25 days after transplanting.

Varietal Resistance to Rice Stem Borer

Screening for resistance

From the preliminary screening for stem borer resistance of 9,000 rice varieties representing the rice genetic stock of the Institute, and retesting of the promising lines, 71 varieties showing consistency for stem borer interactions were selected for further studies. During 1966 these were tested with a uniform larval population in the greenhouse and under conditions of natural infestation in the field. In separate field experiments tests were made during the dead heart and white head stages to determine any change in resistance at the two stages of plant growth. Most of the varieties showed high consistency in resistance and, apart from the susceptible checks, the stem borer infestation was low. Some varieties, such as Chin-Tsan-Co and Gin-Shan Tsan 18 were not only resistant to stem borers, but also less damaged by leaf whorl maggot, *Hydrellia* sp.

In another field experiment during the months of March to June, 303 hybrids representing the advanced lines of the Institute's breeding program were screened for their stem borer resistance. From these, 70 selections were retested in a replicated field experiment, together with 25 varieties showing differential stem borer susceptibility. Several lines which showed consistently low stem borer infestation have been selected for further evaluation.

From the screening and retesting of the rice genetic stock, 33 varieties were selected and tested in a greenhouse experiment with a uniform stem borer population. At 30 days after transplanting, 12 plants of each variety were

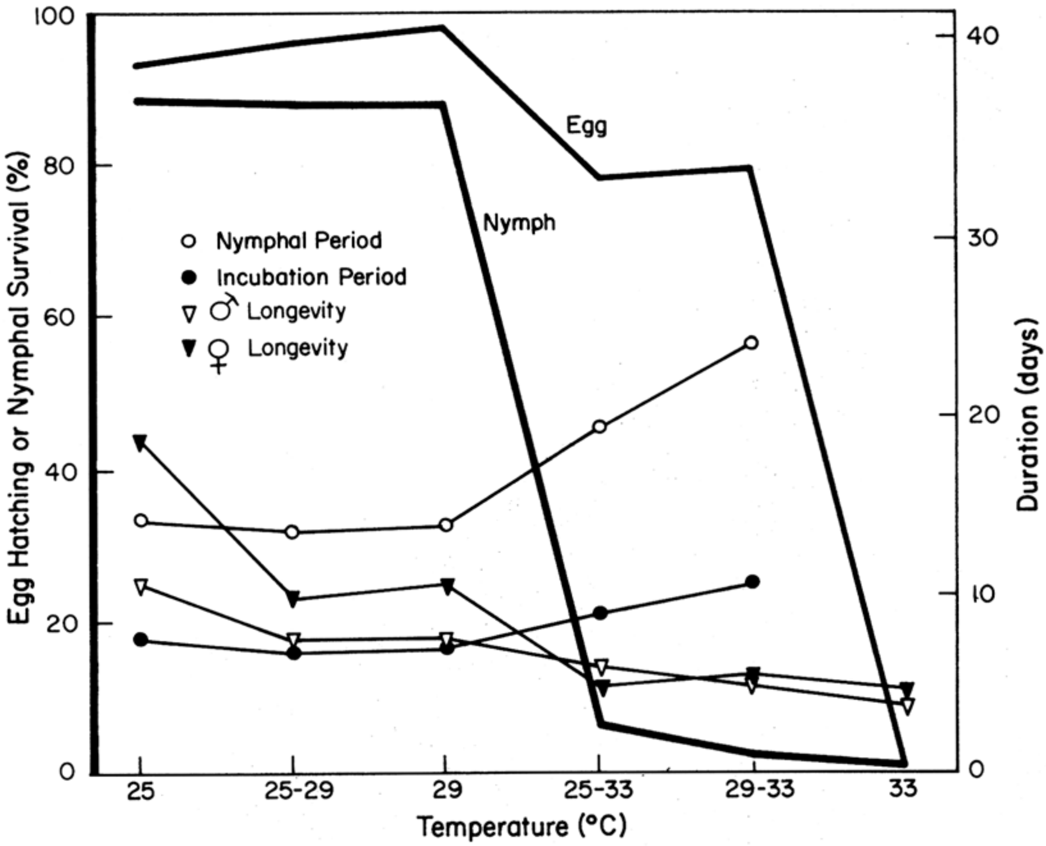


Fig. 3. Effect of temperature on the survival and duration of the brown planthopper at different life history stages.

Table 1. Effect of nymphal and adult brown planthopper feeding on Taichung (Native) 1 plants infested at various ages after transplanting, IRRI, 1965-66.

Insect	No. of insects/ hill	Days after transplanting 25: No. of infested Tillers	25: No. of infested Panicles	25: Plant height (cm)	50: No. of infested Tillers	50: No. of infested Panicles	50: Plant height (cm)	75: No. of infested Tillers	75: No. of infested Panicles	75: Plant height (cm)
Nymphs*	50	29.3	23.8	100.3	30.6	25.0	105.2	39.0	30.2	104.0
	100	26.8	21.0	98.0	26.0	20.0	97.6	31.8	26.0	91.0
	200	17.5	11.0	90.0	25.0	19.0	92.8	20.4	12.4	90.4
	400	—	—	—	22.0	15.0	88.8	18.8	7.5	81.8
Adults†	4	39.6	26.2	106.4	30.4	25.8	101.4	30.3	27.6	106.0
	8	30.6	20.6	105.4	28.8	24.4	98.2	26.4	22.0	97.8
	16	22.0	16.4	99.5	21.8	17.6	98.8	26.0	17.6	93.4
	32	19.7	10.7	96.7	18.8	13.2	87.2	27.5	15.0	81.0
Control	00	33.8	26.6	106.8	33.1	25.1	102.4	32.9	31.6	108.4

* Caged for 3, 16, and 13 days respectively on plants at 25, 50, and 75 days after planting.
† Caged for a period of 5, 16, and 15 days respectively on plants at 25, 50, and 75 days after planting.

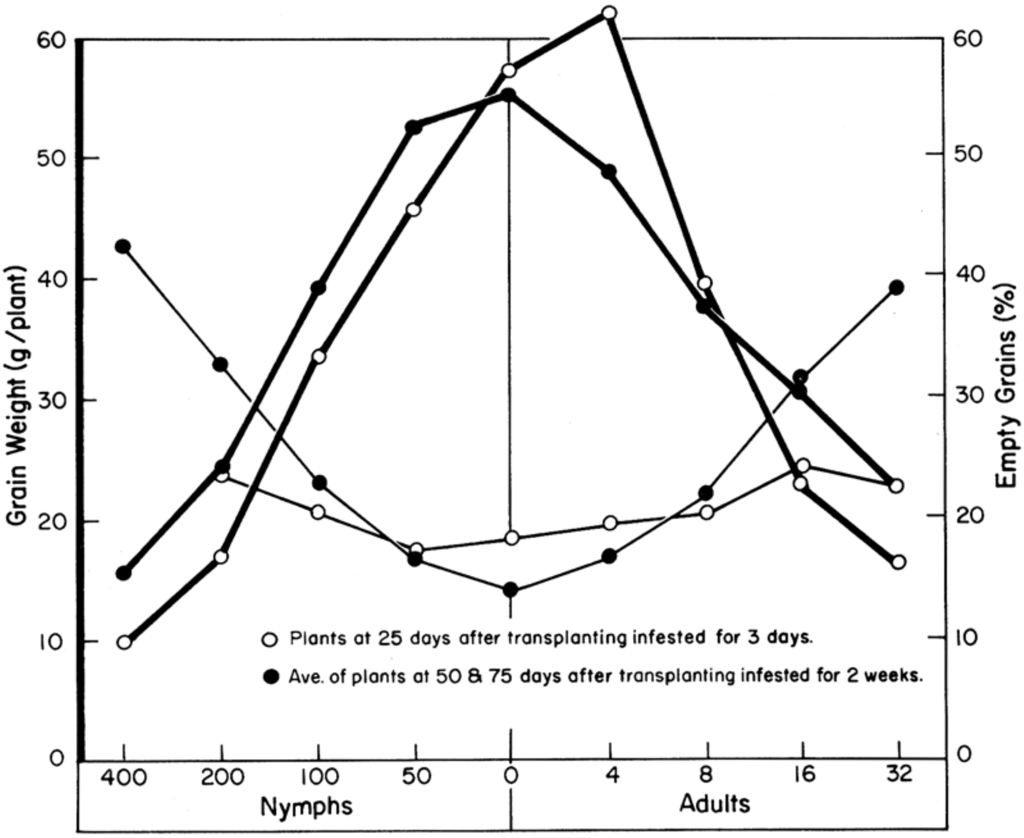


Fig. 4. Feeding injury by nymphs and adult brown planthoppers on Taichung (Native) 1 plants.

individually infested with 10 freshly hatched striped borer larvae. At 30 days after infestation, the number of white heads or dead hearts were recorded on each plant which was then dissected to determine the number of infested tillers and the number of larvae or pupae. On several varieties the insect had less than 20 percent survival and low pupation, while on others more than 60 percent of the larvae survived and up to 90 percent of the surviving larvae pupated. Also, in general, the larvae from varieties affording higher larval survival weighed more than those from varieties showing low larval survival (Fig. 5). Thus, there were distinct differences in larval survival and growth on different varieties.

Consistency of resistance in selected varieties

Based on intensive field and greenhouse screenings, 9 varieties representing those highly resistant and highly susceptible to stem borers were tested in large-plot field experiments. These were planted during a period when most surrounding fields were not planted and the plots would therefore attract a large number of stem borer moths.

Periodic observations on the number of stem borer eggs laid on these varieties showed a distinct preference of the moths for oviposition on certain varieties. The variety TKM-6 received the lowest number of eggs, in contrast to Rexoro which had approximately 8 times more. Significantly, several varieties not preferred by striped borer moths were also not preferred by the yellow borers; several other varieties, however, showed differential response (Fig. 6). In general, varieties receiving a greater number of egg masses also had a high percentage of dead hearts, but some other varieties, such as Yabami Montakhab and Taitung 16, although receiving a large number of egg masses nevertheless developed comparatively few dead hearts. As reported earlier, resistant varieties have exhibited definite antibiosis effects on the stem borer larvae in greenhouse experiments. On the variety Taitung 16, the larvae suffered high mortality and had a slow rate of growth. In addition, the high silica content of the variety Yabami Montakhab interfered with larval feeding and often caused excessive mandible wear.

As these varieties were selected on their past resistant and susceptible reactions, the present data which show their consistency is significant. Some of them were heavily damaged by virus infection later, so no data on white head could be taken.

Five varieties from these tests, together with the variety IR8, were tested more intensively with a uniform larval population in greenhouse

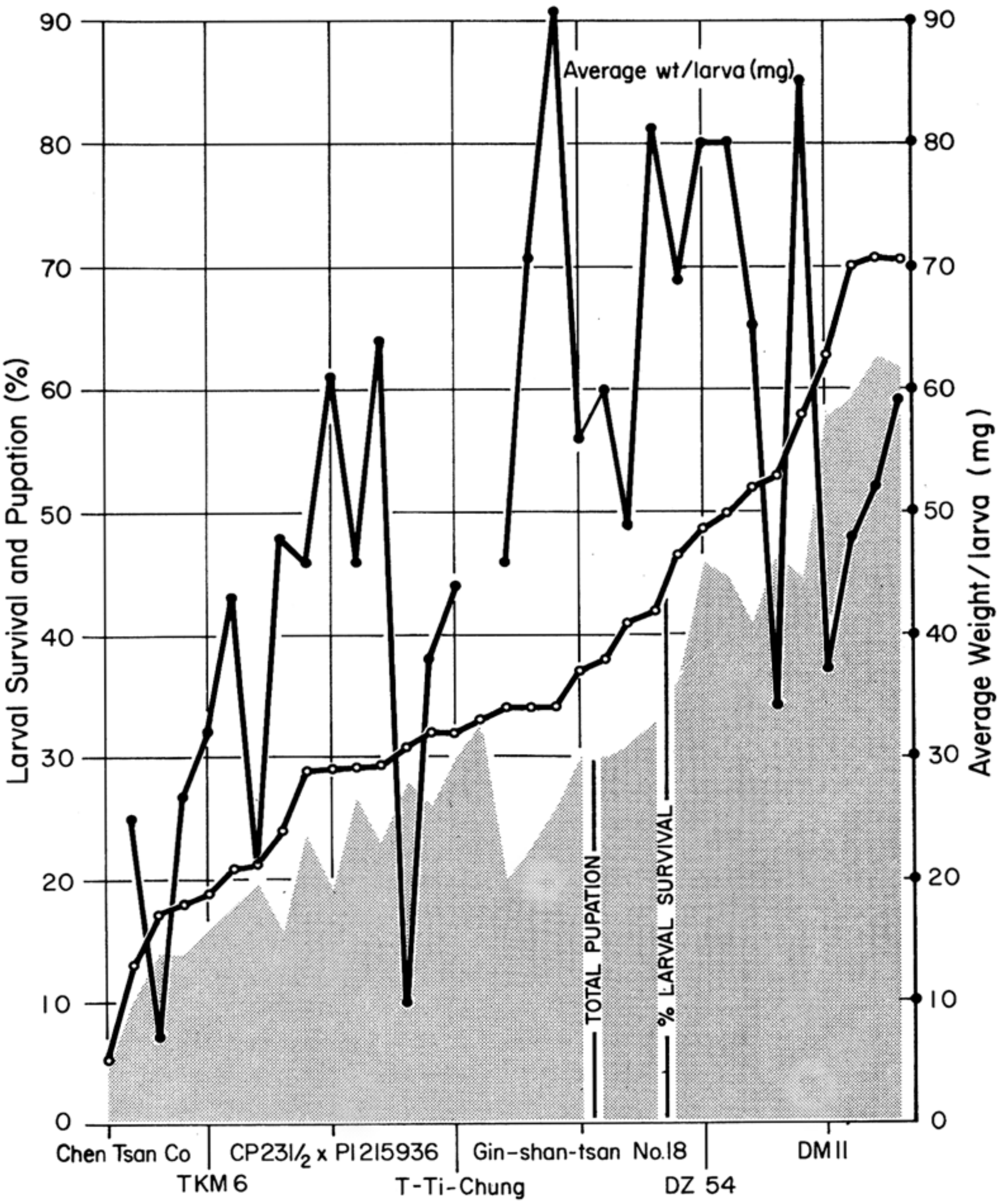


Fig. 5. Survival and growth of striped rice stem borer larvae during 30 days on 33 selected rice varieties. Individual plants at 30 days after transplanting were infested with 10 freshly hatched larvae.

Table 2. Insect-host plant interactions on plant damage and larval growth. Forty-eight potted plants of each variety were individually infested with 10 freshly hatched striped borer larvae for 21 days, IRRI, 1966.

Variety	Percentages				Weight/larva (mg)
	Dead heart tillers	Infested tillers	Borer survival	Pupation	
Rexoro	41.8	86.0	78.1	1.9	71.3
IR8	36.7	75.0	62.0	6.3	65.7
Chianan 2	31.8	72.4	29.5	0.4	52.5
TKM-6	21.2	46.6	38.8	9.2	55.5
Taitung 16	24.1	49.0	12.9	0.0	41.1
Yabami Montakhab	*	59.1	31.7	0.0	21.7

* Flowered early so no data on dead heart but 14.4% of the panicles were white heads.

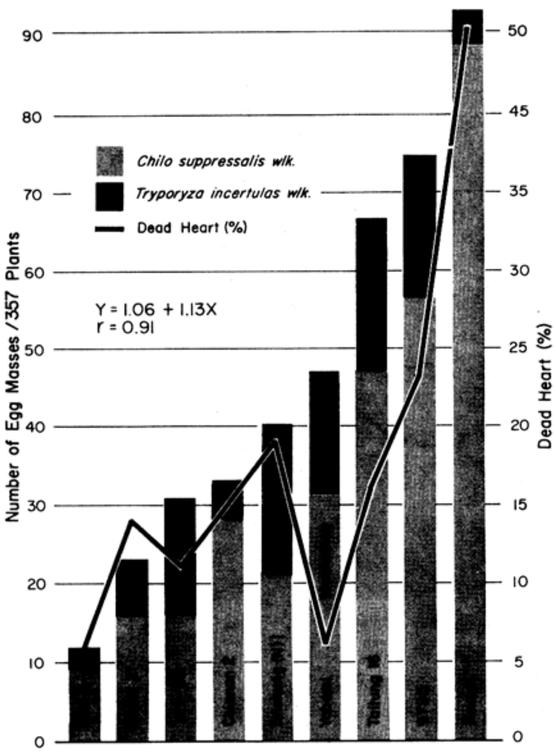


Fig. 6. Ovipositional preference of stem borer moths and percentage dead hearts on selected resistant and susceptible varieties.

experiments. At 30 days after transplanting, 48 potted plants of each variety were individually infested with 10 freshly hatched striped borer larvae. The number of dead hearts was recorded on each plant 21 days after infestation when the plants were dissected to record the number and weight of larvae, percentages of pupation, and total number of infested tillers per hill.

Although all varieties were infested with a uniform level of insect population, they showed definite differences in plant damage. The plants of variety Rexoro had a total of 41.8 percent dead hearts as compared to 21.2 and 24.1 percent in resistant varieties TKM-6 and Taitung 16 respectively. Similar differences were also recorded in the percentages of infested tillers. On the susceptible variety Rexoro, 78 percent of the larvae survived and weighed an average of 71.3 mg per larva compared with 12.9 percent survival and 41.1 mg per larva on variety Taitung 16 (Table 2). Apparently the variety Taitung 16 possessed some feature which significantly reduced larval survival and resulted in smaller body weights. On variety TKM-6, although the larvae had significantly lower survival than on susceptible variety Rexoro, and had lower body weight, their rate of growth was not affected and 9.2 percent of the larvae reached pupal stage in 21 days. As discussed

Fig. 7. In repeated experiments the rice variety TKM-6 has thrived and remained green in the presence of an insect population sufficient to damage severely other test varieties.

earlier, in field experiments TKM-6 was not preferred by the insects for oviposition. Taitung 16, although preferred for insect oviposition, had significantly fewer dead hearts, and the present data suggest this was due to low larval survival. Thus, under field conditions, the non-preference and unsuitability of TKM-6 for insect survival results in low stem borer infestation, while the variety Taitung 16, although receiving a fairly large number of egg masses, is less damaged because of antibiosis factors against insect survival. This contrasts to variety Rexoro which receives a large number of egg masses and is well suited for insect survival. As a result, Rexoro often suffered maximum damage by stem borers in field experiments.

Breeding for stem borer resistance

Several varieties were highly and consistently resistant to stem borers under natural as well as artificial infestations. Some varieties presented the larvae with conditions unsuitable for development, while others were also avoided by ovipositing moths. As these aspects of resistance differed markedly among varieties, efforts are being made to combine different aspects of resistance and accumulate them in one variety. In a cooperative project with the Institute's plant breeders, a large number of crosses were made and the progeny are being evaluated for insect resistance.

The F_1 of these crosses are grown under insect-free conditions but the F_2 is exposed to heavy stem borer and leafhopper populations in greenhouse and field experiments. All susceptible plants in the F_2 and later generations are rejected. As under field conditions TKM-6 also remains comparatively free from virus infection, the hybrid plants showing virus infection are also rejected. This is almost essential in field experiments because the virus incidence is frequently high and insecticides, if used for vector control, interfere with stem borer infestation. TKM-6 is a tall, weak-stemmed, heavy tillering

Fig. 8. F_5 progeny of two stem borer-resistant parents, TKM-6 and Taitung 16.

indica variety. These undesirable plant characters render it unacceptable as a good commercial variety despite its insect resistance and general vigorous growth (Fig. 7). Hence, progeny with undesirable plant characters are also rejected.

During 1966 a large number of hybrids from selected stem borer resistant and susceptible parents, ranging from F_1 to F_4 generations, were tested in field experiments. These were exposed to natural insect infestations and intensively sampled for dead hearts and white heads, leafhopper population, and virus incidence. Five plants from each of a few of the promising F_4 populations were artificially inoculated with bacterial blight, graded 15 days later and susceptible lines rejected. About 200 selections from the F_4 generation have been saved and are being further evaluated for insect resistance. All of these selections have been planted as plant rows and a few have been also bulked and planted in larger plots to obtain preliminary information on their yielding capabilities.

Of the various crosses made, the progeny of TKM-6 and Taitung 16, both stem borer resistant, appear promising. Several have good resistance to stem borers, display low virus infection, and are better plant types than either parent (Fig. 8).

Causes of resistance

Chemical factors. A series of experiments have been conducted to analyze the various causes of varietal resistance to stem borers. Results of studies on the role of several plant morphological and anatomical characters were reported in the 1965 Annual Report. To evaluate the possible chemical factors associated with varietal resistance, plant extracts obtained with different solvents are bioassayed for nutritional value and attraction to the striped borer larvae or moths.

Using the solvents water, methyl alcohol, chloroform, and propanol, which gave best results in previous tests, the attraction to larvae of extracts from rice plants was further evaluated during 1966. Extracts were made from 30-day-old plants of the susceptible variety Rexoro. The larval response was studied by soaking pieces of filter paper with different extracts and exposing them to 5-day-old striped borer larvae in olfactometer experiments. To eliminate the possibility of the attraction being due to

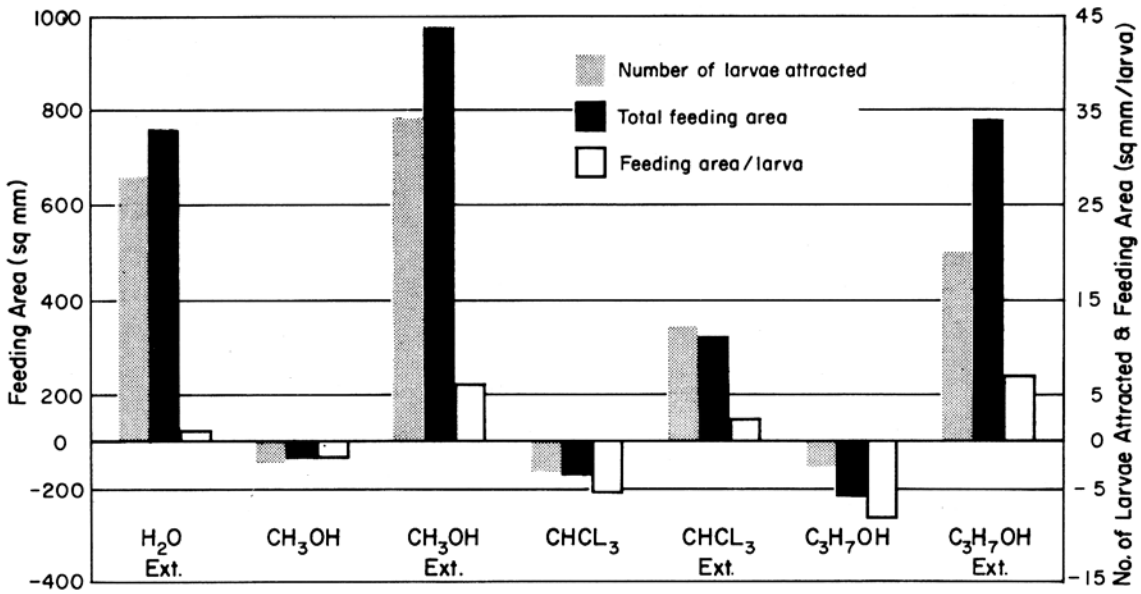


Fig. 9. Attraction and feeding response of striped borer larvae on Rexoro rice plant extracts with different solvents. The zero level is based on larval reactions to filter paper exposed to water alone.

different solvents, filter papers soaked in solvents only were used as controls. It is significant that in all cases the larvae were more attracted to the plant extracts than to the solvent alone (Fig. 9). In preliminary experiments, the moths have been more attracted to plant extracts in carbon tetrachloride than to those in other solvents, and the extracts from the susceptible variety Rexoro were more attractive than those from resistant variety TKM-6. Larvae reared on various plant extract diets lived longest when supplied with water or chloroform extracts.

Varietal Resistance to Leafhoppers and Planthoppers

In experiments on varietal resistance to rice stem borer, 1,350 varieties selected from the field screening of 9,000 varieties were retested in 4-row plots in the field. At 50 and 70 days after transplanting they were also sampled for leafhopper and planthopper populations. Based on these observations, 20 varieties which had high, moderate, and low leafhopper populations were selected for more intensive studies on their leafhopper interactions.

The preference of the brown planthoppers for feeding and oviposition on these varieties was tested by enclosing in a large screen cage eight potted plants of each variety with approximately 4,000 macropterous adult insects. In a separate experiment, the fecundity of, and the damage caused by, the brown planthopper was studied by caging 20 first-instar nymphs for 30 days on individual potted plants of these varieties at 30 days after transplanting.

The planthopper exhibited distinctly different preferences for different varieties both in respect to feeding and the number of eggs laid (Table 3). Low numbers of planthoppers were recorded on varieties Garunbalay, TKM-6, Shoa-hi-den, Panduruwee, and IR8, while the populations were four to five times higher on varieties Taichung (Native) 1, JC-149, I-geo-tze, HBJ 2, and CM-7-6. The same level of planthopper population deposited fewer eggs on several non-preferred varieties, such as TKM-6 and IR8, than on other varieties. Although there were more eggs laid on most of those varieties that were infested with a relatively large number of planthoppers, the varieties Kerr Sail, SC 94-4, and Bir-r-ton-tsan received a relatively large number of eggs despite a low level of adult infestation.

Table 3. Preference, oviposition, and fecundity of the brown planthoppers and the damage caused by them to a few selected rice varieties, IRRI, 1966.

Variety	Preference* for		Effect of 20 nymphs caged on individual plants†		Infestation index
	Feeding (grade‡ of infestation §)	Oviposition (grade of no. of eggs laid§)	Fecundity (grade of infestation)	Grade of plant damage‖	
Garunbalay	1	3	1	1	6
TKM-6	1	1	2	2	6
Shoa-hi-den	1	5	1	2	9
Panduruwee	1	5	3	2	11
IR8	2	2	2	1	7
R-D C.I. 8643	2	5	2	2	11
Skrivimankoti	2	3	1	2	8
R9 Luchai	2	3	2	2	9
Taipei-shuangiam	2	3	2	2	9
Kerr sail SC 94-4	2	5	2	2	11
Bir-r-ton-tsan	2	5	2	3	12
Hill Med Sel 131	2	5	2	2	11
Ziongzo	3	5	2	2	12
Rexoro	3	5	3	3	14
345 Dacca	3	5	4	3	15
CM-7-6	3	5	4	4	16
HBJ 2	3	5	2	2	12
I-geo-tze	4	5	3	3	15
JC 149	4	5	3	2	14
Taichung (Native) 1	5	5	3	2	15

* Four hundred macropterous adults were released in a 2.5 x 3.0 x 3.0 m screen cage containing eight potted plants of each variety. Observations on the number of adults and eggs on each variety were made at 5 and 15 days from infestation respectively.

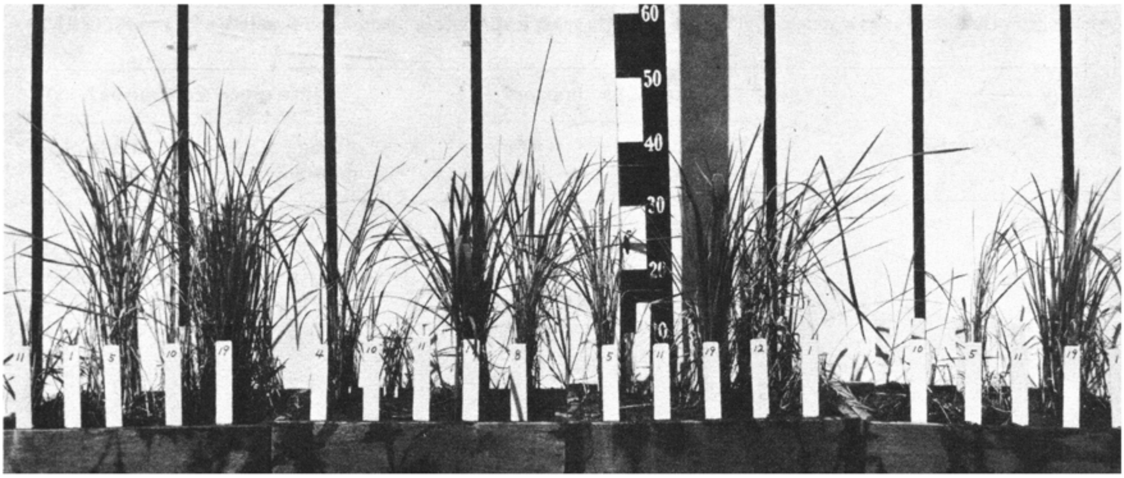
† Twenty-first instar nymphs were caged for 30 days on individual plants at 30 days after transplanting.

‡ Grade	§ No. of insects or eggs on each variety	‖ Grade of plant damage
1	1-100	slight
2	101-200	moderate
3	201-300	heavy
4	301-400	plants killed
5	>400	—

Although initially caged with the same number of nymphs, in 30 days the population on certain varieties became four to five times higher than on other varieties, indicating differences in the survival of nymphs and the fecundity of the emerging adults on different varieties. The smallest population was recorded on varieties Skrivimankoti, Shoa-hi-den, and Garunbalay, and the largest, on varieties CM-7-6 and 345 Dacca. Generally, a large population caused heavy damage, but several varieties showed distinct tolerance: the variety IR8 suffered the least damage but had a relatively high planthopper population. It can be concluded from these results that a low degree of preference, higher nymphal mortality, less oviposition, and greater tolerance contributed to planthopper resistance in certain varieties.

Based on these results, 10 varieties showing differential interactions to planthopper infestation were selected to study their performance in the presence of a large planthopper population.

A



B

Fig. 10. Several varieties have shown high tolerance to brown planthopper (A) and rice green leafhopper (B) damage. The plants were infested with several thousand adult insects for about a week.

They were sown in wooden flats, and 15 days after seeding caged with about 4,000 macropterous brown planthoppers for 7 days. Each was graded for leafhopper population and plant damage at 4 and 14 days after infestation, respectively.

The varieties IR8, TKM-6, and Garunbalay suffered the least damage although they had more planthoppers on them than several other varieties that were severely damaged. There were large numbers of planthoppers on the varieties Hill Med Sel 131 and CM-7-6, which were also heavily damaged (Fig. 10), indicating that these were preferred hosts and lacked tolerance in contrast to varieties IR8 and Garunbalay which exhibited maximum tolerance. In similar studies, the varieties IR8, HBJ 2, and TKM-6 were least preferred and least damaged by the rice green leafhoppers (Fig. 10, Table 4). Such cross resistance to two pests suggest a wide base of resistance (Fig. 9). The variety Garunbalay was tolerant to brown

Table 4. Preference of and damage caused by brown planthoppers and green leafhoppers to different varieties of rice. The varieties grown in 12-inch rows in wooden flats were exposed to heavy leafhopper or planthopper population for 1 week, IRRI,1966.

Variety	Brown planthoppers*		Rice green leafhoppers†	
	Grade‡ of infestation§	Grade of damage‖	Grade of infestation§	Grade of damage‖
IR8	4.0	1.0	1.5	1.0
TKM-6	3.0	1.5	1.6	2.0
Garunbalay	2.5	1.5	1.5	3.8
HBJ 2	2.5	2.0	1.2	1.0
Panduruwee	3.5	2.5		
Rexoro	2.0	3.0	2.2	4.0
Taichung (Native) 1	2.0	3.0	2.8	4.0
Hill Med Sel 131	3.0	3.5	3.4	4.0
I-geo-tze	3.5	3.5	2.9	4.0
CM-7-6	2.5	4.0	1.5	4.0

* Average of two experiments each conducted in four replications.
† Average of five replications.

‡ Grade	§ No. of adults on each variety	‖ Plant damage (proportion of plants killed)
1	1-100	0
2	101-200	>⅓
3	201-300	⅓-⅔
4	301-400	<⅔

planthopper damage but was severely damaged by the green leafhopper, indicating that the same factors were not responsible for resistance to the species.

Insecticidal Control of Stem Borers and Leafhoppers

Screening of insecticides

Fifteen promising compounds, selected from a screening of about 50 insecticides for effectivity on the striped borer and the rice green leafhoppers, were tested more intensively in laboratory, greenhouse, and field experiments during 1966. Their insecticidal activity was investigated by spraying them from a potter's spray tower on striped borer egg masses and on freshly hatched larvae, by applying them as foliar sprays on plants infested with larvae of different ages, and by mixing them with the irrigation water of potted plants which were bioassayed for insecticidal activity by using striped borer larvae or adult rice green leafhoppers.

The compounds methyl parathion, GS 13005, lebaycid, mecarbam, and diazinon caused more than 90 percent egg mortality while the compounds fitios, dimethoate, and SD 9129 were comparatively ineffective ovicides. All these compounds, except dimethoate and fitios, were highly effective for controlling 5-day-old larvae feeding within the rice plants but most of them were much less effective on 10- and 15-day-old larvae (Table 5). Although several compounds caused 100 percent mortality of rice green leaf-

Table 5. Effectivity of insecticidal sprays on striped borer eggs and larvae in laboratory and greenhouse experiments*. IRRI, 1966.

Insecticide (0.1% spray)	Mortality (%)			
	Eggs†	Larvae		
		5‡	10‡	15‡
Azodrin	16.2	96.8	30.2	18.4
Birlane	29.6	87.2	30.1	0.0
Bromophos	42.3	76.6	4.4	0.0
Fenitrothion	86.3	100.0	33.4	0.0
Fitios	0.0	15.3	0.0	0.0
Lindane	15.8	66.9	0.0	0.0
Methyl parathion	91.4	71.0	58.6	4.76
Phosphamidon	36.4	76.0	7.3	6.5
SD 8211	64.7	80.8	46.2	2.5
GS 13005	93.4	97.5	58.4	0.0
Endosulfan	38.8	63.7	6.6	2.4
Lebaycid	91.4	52.5	36.8	12.12
Dimethoate	16.8	21.1	1.6	0.0
Mecarbam	92.5	93.9	0.0	0.0
Diazinon	94.9	87.2	15.6	11.4

* All values shown are adjusted mortality.

† Average of 4 replications. Four egg masses and 15 larvae per replication were used respectively for ovicidal and larvicidal experiments.

‡ Days before insecticidal treatment.

Table 6. Residual toxicity of various insecticides to *Nephotettix impicticeps, IRRI, 1966.**

Insecticide	Concentration in water (%)	Mortality (%) at 48 hours after caging on plants			
		1†	5†	10†	15†
Birlane	0.10	100.0	92	0	
Endosulfan	0.10	12.2	2		
Fenitrothion	0.07	100.0	4		
Methyl parathion	0.10	100.0	0		
Dimethoate	0.09	97.9	50	0	
Gusathion	0.04	100.0	100	60	50
Azodrin	0.08	100.0	85.7	40	8
Mecarbam	0.10	100.0	34.7	2	
Phosphamidon	0.10	100.0	2		
Diazinon	0.10	32.6	0		
Anthio	0.08	77.5	0		
SD 8447	0.10	93.4	10		
B605MR	0.08	100.0	92	2.2	
M 2840	0.04	14.2	4		
Bidrin	0.08	100.0	58.0	0	

* Values shown are the average of 5 replications. Ten test insects constitute one replicate.

† Days after foliar application.

Table 7. Residual toxicity of some insecticides applied to the irrigation water at the rate of 3 kg/ha, IRRI, 1966.

Insecticide	Mortality (%)* at 48 hours after caging on plants							
	Striped borer larvae				Rice green leafhopper adults			
	3†	5†	10†	15†	3†	5†	10†	15†
Birlane	100.0	100.0	100.0	100.0	90.0	100.0	80.0	75.0
Diazinon	100.0	100.0	100.0	57.7	100.0	97.2	57.5	75.0
Dimethoate	0.0	5.2	2.8	0.0	100.0	100.0	100.0	27.5
Phosphamidon	93.6	36.0	0.0	0.0	100.0	63.8	22.5	37.5
Endosulfan	0.0	6.4	3.2	3.8	11.1	2.77	5.0	—
SD 9129	97.0	62.9	6.2	0.0	100.0	100.0	45.0	5.0
Lebaycid	86.5	74.6	8.8	0.0	100.0	100.0	100.0	95.0
SD 8211	100.0	66.0	25.0	0.0	19.44	0.0	7.5	—
GS 13005	100.0	100.0	70.3	11.8	97.22	55.5	12.5	—
Bromophos	18.0	20.6	30.7	3.4	33.3	0.0	7.5	—
Methyl parathion	5.9	90.2	10.7	0.0	52.7	13.8	15.0	7.5
Fitios	0.0	0.0	14.2	0.0	100.0	94.4	75.0	22.5
Fenitrothion	100.0	54.0	5.2	7.3	22.2	0.0	0.0	—
Murfotox	0.0	0.0	2.6	0.0	90.0	41.6	47.5	30.0

* Average of 4 replications, each consisting of 10 test insects.
† Days after treatment.

hoppers one day after treatment, most of them exhibited no effective residual toxicity 4 days later. Gusathion and azodrin (SD 9129) had the longest residual value and caused more than 40 percent leafhopper mortality up to 10 days after treatment (Table 6).

Three days after application to the irrigation water of the potted plants, the compounds birlane, diazinon, phosphamidon, azodrin, SD 8211, GS 13005, and fenitrothion caused more than 90 percent larval mortality. Methyl parathion, although causing low mortality after 3 days, was highly effective 5 days after treatment, but its effectivity had declined in observations made 5 and 10 days later, indicating that it took longer to be absorbed by the plants and had a comparatively short residual period. The longest residual effectivity was exhibited by birlane and diazinon: 100 percent larval mortality 10 days after treatment and 100 and 57 percent mortality respectively 15 days after treatment when none of the other compounds had any effective residual toxicity (Table 7).

Birlane and diazinon, when applied to the irrigation water, also had high initial toxicity and long residual effects on rice green leafhoppers. Both compounds caused 75 percent leafhopper mortality up to 15 days after treatment. Lebaycid, although effective for controlling stem borers only up to 5 days after treatment, caused more than 95 percent mortality of the leafhoppers up to 15 days after treatment (Table 7).

From these results it was evident that application of insecticides to the paddy water was more effective and had longer residual effects than foliar spray. Also, of all the insecticides tested, diazinon and birlane had the longest residual effects on both stem borers and leafhoppers.

As γ-BHC application to the paddy water, which is gaining wide popularity, has been less effective for controlling the pink borer, *Sesamia inferens* Walker, the effectivity of diazinon, birlane and γ-BHC on pink borer larvae was tested in greenhouse experiments. Potted plants of variety Milfor-6(2) 50 days after transplanting were irrigated with 2 liters of 4, 5, and 6 ppm solution of each of these insecticides. Under field conditions these rates correspond to 2, 2.5, and 3 kg active ingredient per hectare.

At 72 hours after treatment, plant stems from the treated pots were caged with freshly hatched pink borer larvae for 48 hours and then dissected to record larval mortality.

Diazinon at all three rates of application caused more than 90 percent mortality of the pink borer larvae, but both lindane and birlane were comparatively ineffective, causing less than 20 percent larval mortality at all rates (Fig. 11).

Greenhouse studies on diazinon

Following these results detailed studies were conducted to obtain basic information on the absorption and translocation of diazinon in the plants, its vaporization effects, optimum rate of application, and initial and residual effectivity on yellow and striped borer larvae. For evaluating the fumigation effect, 3- to 5-day-old *Drosophila* flies in cylindrical cartolina cages, both ends of which were sealed with nylon mesh, were placed at 2 to 3 inches above the water surface of the treated pots. The flies were caged at different times following the insecticidal treatment and their mortality was recorded after 6, 9, and 24 hours. Flies caged on pots not treated with any insecticide served as control.

On topical application diazinon was several times more toxic than lindane to the fourth

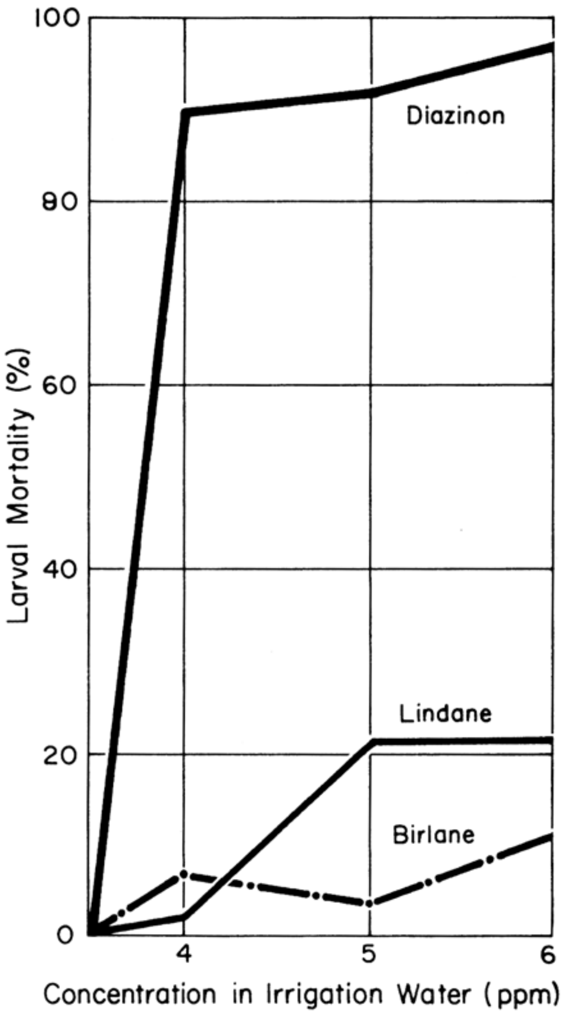


Fig. 11. Mortality of *Sesamia inferens* larvae feeding on potted plants irrigated with solutions containing different concentrations of diazinon, lindane and birlane.

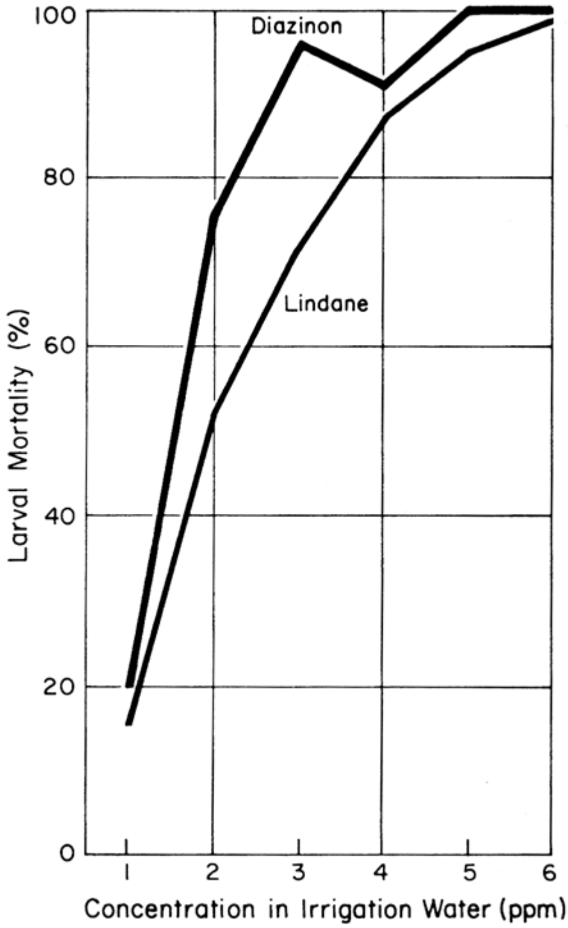


Fig. 12. Mortality of *Chilo suppressalis* larvae feeding on potted plants irrigated with solutions containing different concentrations of diazinon and lindane.

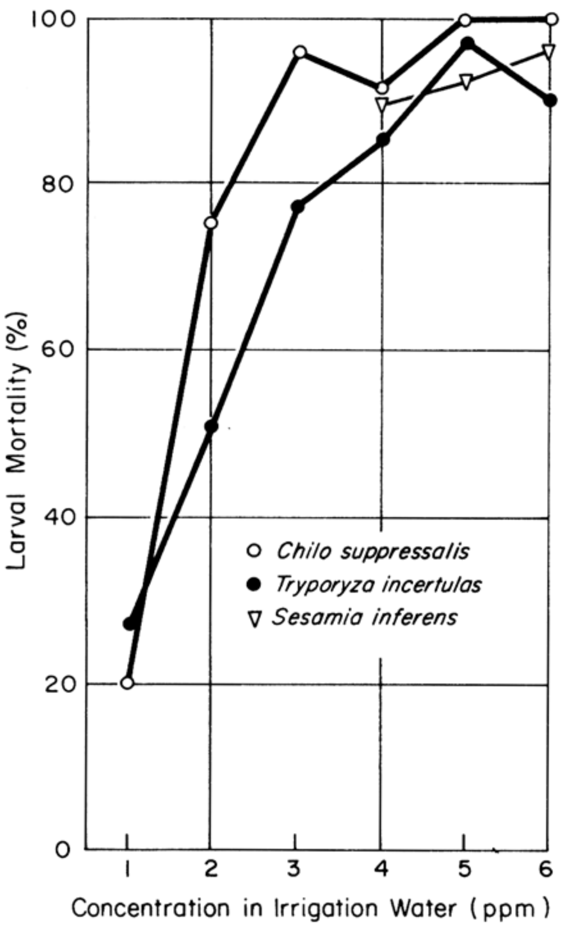


Fig. 13. Mortality of freshly hatched stem borer larvae feeding on potted plants irrigated with 2 liters of different concentrations of diazinon solution.

instar striped borer larvae. When applied to the irrigation water at 1 ppm, both diazinon and lindane caused about 20 percent larval mortality, but at 2 and 3 ppm, diazinon killed about 50 percent more larvae than γ-BHC (Fig. 12). However, at rates of 4 ppm and higher, both compounds had similar effects. These results imply that under field conditions 1 to 1.5 kg/ha of diazinon should provide effective stem borer control. Also, diazinon was more effective than γ-BHC in killing larvae caged on the apical parts of the plants and should thus more effectively prevent white heads.

The effectiveness of different rates of diazinon applied to irrigation water for controlling freshly hatched striped and yellow borer larvae was investigated by sampling plants at 72 hours after treatment and caging larvae on the stems for 48 hours. The larvae of both species caged on stems from plants irrigated with 1 ppm of diazinon recorded less than 25 percent mortality, but it increased significantly with concentration of the toxicant in the irrigation water; both striped and yellow borer larvae recorded more than 75 percent mortality on plants irrigated with 3 ppm (Fig. 13). At higher concentrations there was a gradual increase in mortality, reaching 90 percent for both species at a rate of 5 ppm. More than 50 percent mortality of the two species was recorded with a concentration of 2 ppm.

All yellow and striped borer larvae were killed after 7 and 10 days respectively following irrigation with 6 ppm diazinon. Beyond this period there was a gradual decline in mortality falling to 60 percent for both species at 15 days after treatment (Fig. 14).

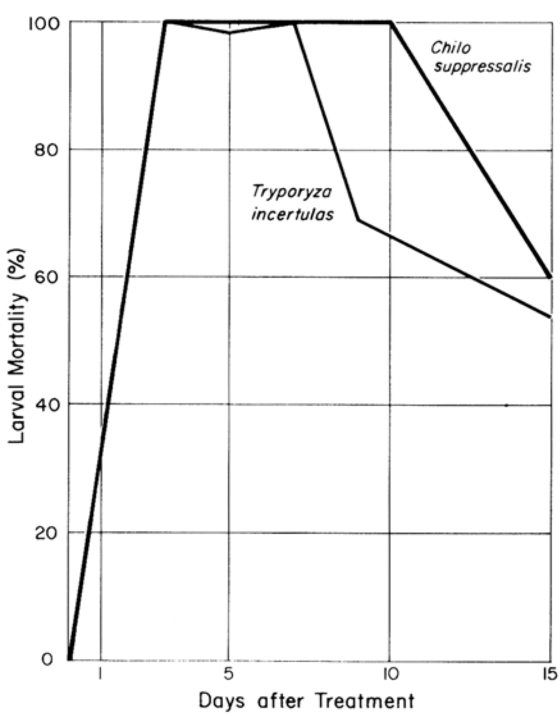


Fig. 14. Mortality of stem borer larvae feeding on rice stems obtained from potted plants irrigated with 2 liters of 6 ppm diazinon.

Table 8. The effectivity of rice pest control of various insecticides when used as 0.05 and 0.1 percent spray at 15-day intervals. Rice variety –9795*. IRRI, February-May, 1966.

Insecticide	0.05% spray						0.1% spray					
	Dead heart† tillers (%)	No. of leafhoppers /10 sweeps: 1 day before second spraying	No. of leafhoppers /10 sweeps: 8 days after third spraying	White head† panicles (%)	Virus-infected hills (%)	Grain yield (kg/ha)	Dead heart† tillers (%)	No. of leafhoppers /10 sweeps: 1 day before second spraying	No. of leafhoppers /10 sweeps: 8 days after third spraying	White head† panicles (%)	Virus-infected hills (%)	Grain yield (kg/ha)
Azodrin	1.61	15.33	1.66	7.48	3.95	5679	1.06	9.00	0.66	6.41	3.95	6221
Phosphamidon	3.82	7.00	3.00	8.30	7.53	4896	1.77	3.66	4.33	5.82	5.62	5696
Birlane	1.01	7.33	3.66	9.39	1.66	5208	0.78	12.00	0.66	7.66	2.08	5586
R-5092‡	1.94	8.33	2.33	9.21	4.58	4636	1.21	6.00	0.66	8.82	2.08	5554
GS 13005§	1.57	11.00	1.66	6.97	7.91	5161	0.89	5.66	1.66	8.26	1.66	5492
Endosulfan	1.62	7.00	4.66	9.49	5.82	4783	1.15	6.33	1.66	9.90	5.41	5383
S-6538‖	1.31	7.66	2.33	7.73	6.85	5429	0.90	6.33	2.00	7.88	1.04	5339
Gusathion	2.18	6.00	0.66	8.80	1.66	4939	0.54	9.00	0.33	7.63	0.62	5356
Methyl parathion	1.72	5.33	5.00	6.03	6.87	4963	1.29	3.66	4.00	11.49	2.49	5306
SD-8211¶	1.88	6.33	4.00	7.58	5.82	4783	1.09	7.00	2.33	6.28	1.24	5182
Lebaycid	2.14	8.00	3.66	10.90	3.74	4740	1.63	6.66	1.33	10.19	2.08	5179
M-2840**	1.47	9.33	2.00	11.07	7.28	5212	1.64	7.00	1.33	9.85	0.00	5151
Bidrin	2.56	12.33	2.33	11.72	3.32	5112	2.14	5.33	0.33	12.63	5.00	4991
Bromophos	2.73	8.66	3.33	13.39	9.16	3913	1.81	9.33	2.33	13.68	5.41	4564
Fenitrothion	1.57	7.33	1.00	8.73	5.41	4573	1.52	4.33	2.33	13.84	2.70	4537
Mecarbam	1.55	11.33	4.33	12.42	7.91	4313	1.80	6.66	2.00	14.12	7.70	4404
UC 8305††	1.99	11.66	2.66	10.94	6.24	4325	2.81	6.66	5.00	12.38	8.53	4357
Fitios	3.48	7.33	3.33	13.03	10.20	3986	2.69	7.66	2.33	13.18	6.87	4134
Malathion	3.58	9.66	2.00	12.67	7.49	3846	2.37	7.66	4.33	16.38	8.33	4045
SD 8447¶	2.93	11.66	2.00	10.49	10.41	4443	2.41	7.00	3.00	13.63	9.99	3944
TPTA‡‡	3.32	9.00	3.33	10.26	23.95	3840	3.63	6.33	5.33	14.00	15.62	3674
Bromex 50	2.79	10.33	4.66	11.75	15.82	3589	2.94	8.33	1.33	15.61	17.08	3347
Control	4.67	12.00	7.66	13.95	32.49	2834	3.00	8.00	4.00	16.26	8.03	3682

When analyzed using Duncan's multiple range, all differences except the dead heart values were highly significant between different treatments.

* IRRI Acc. No. 9795. A selection A-3-47-4P, PI 215936 x CI 9214.
† Dead heart and white head counts were made at 60 and 90 days after transplanting, respectively.
‡ R—Stauffer Chemical Company.
§ GS—Geigy, Switzerland.
‖ S—Sandoz Limited.
¶ SD—Shell Development.
** M—Dow Chemical.
†† UC—Union Carbide.
‡‡ Antifeeding compound (based on triphenyltin acetate).

The vaporization effect of diazinon was of shorter duration than that of γ-BHC. At concentrations of 1, 2, and 3 ppm it did not cause significant mortality of *Drosophila* flies, but at 4 ppm, 50 and 75 percent were killed at 9 and 24 hours after caging respectively. Those caged on pots irrigated with 6 ppm diazinon suffered 90 percent mortality 24 hours after caging, but 7 days after treatment no significant fly mortality was recorded.

Evaluation of 0.05 and 0.1 percent sprays of various insecticides for rice pest control

From the laboratory and greenhouse screening of a large number of insecticides for stem borer and leafhopper control, 22 were selected for testing in field experiments. These were applied as 0.05 and 0.1 percent sprays at 15-day intervals from 2 weeks after transplanting until crop maturity.

Most of the insecticides when sprayed at either concentration reduced the insect infestation and significantly increased crop yield (Table 8). Although highly effective for preventing dead hearts, most compounds afforded poor white head control. The compounds azodrin, birlane, methyl parathion, endosulfan, M-2840, GS 13005, R-5092, and mecarbam were equally effective when used either as 0.05 or 0.1 percent spray but guthion, lebaycid, bromophos, and phosphamidon were more effective at 0.1 percent than at 0.05 percent. The compounds bidrin, malathion, bromex 50, SD 8447, TPTA, and fitios were comparatively less effective against stem borers at either concentration. Except on those treated with bromex 50, fitios, SD 8447, and TPTA, all plots had lower leafhopper populations and lower incidence of virus infection than the untreated control plots. Also, although treatments during the earlier stages of crop growth reduced the larval population significantly, such effects were not pronounced on the crop nearing maturity. This could possibly have been the cause of the high percentages of white heads in these plots.

Translocation and residues of γ-BHC

During the year, detailed studies were conducted on the persistence of γ-BHC in the soil and paddy water and its absorption, translocation, and residues in various plant parts. The γ-BHC determination was made in a gas chromatograph with an electron capture detector with a sensitivity in the parts per billion (ppb) range.

Basic studies on the fate of γ-BHC after its application to the irrigation water were conducted on potted plants in a greenhouse. Separate treatments were made with 3 kg/ha of γ-BHC at 30 and 60 days from transplanting. Plant, water, and soil samples were analyzed at 3, 5, 10, 20, and 40 days after insecticidal application. The plant samples were separated into roots, basal and apical halves of the stem, and the basal and apical halves of the leaves. Each part was analyzed separately.

The concentration of the insecticide in the irrigation water of the pots increased from 0.7 ppm at one day to 1.2 ppm at 3 days after treatment. Beyond this time it slowly declined to less than 0.02 ppm 30 days after treatment. Also, the concentration of the insecticide in the pot soil declined after 3 days following treatment, reaching non-significant levels 30 days after treatment (Fig. 15).

In plants, the highest concentration of the insecticide was recorded in the stem and the leaf sheath followed by the roots and the leaf blades. The age of the plant at the time of treatment did not significantly affect the initial uptake of the insecticide. However, in plants treated at 30 days after transplanting, the concentration of γ-BHC started declining 3 days after treatment, but in those treated 60 days after transplanting, it generally did not decline until after about 10 days. Differences in the rate of plant growth at these two ages were responsible for the rate of decline in γ-BHC concentration, because when the content of the insecticide was determined on the actual weight basis, the amount of γ-BHC increased in the plants up to 10 to 20 days after treatment but declined later.

The concentration in the roots increased for 5 to 10 days after treatment and then started declining. The concentration in the roots was higher than in the soil, showing that the roots continuously absorbed γ-BHC from the soil, leading to increase in the roots and the plants generally.

The lowest concentration of the insecticide

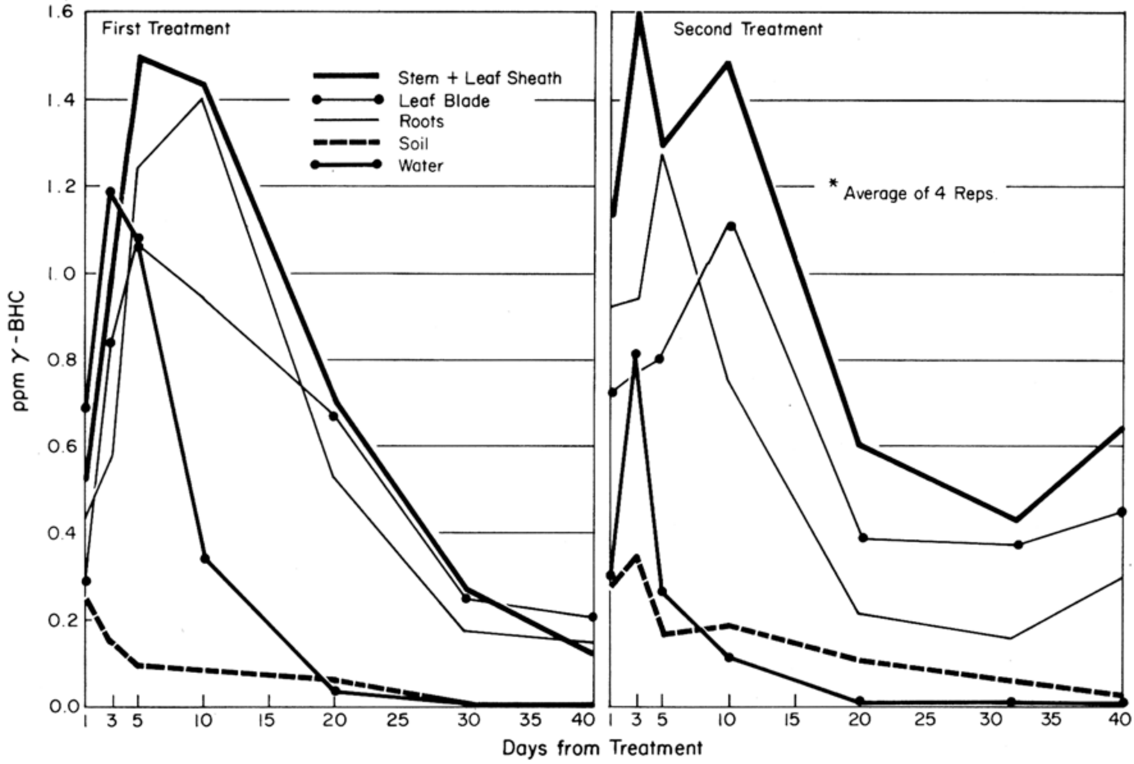


Fig. 15. Gamma-BHC (ppm)* recovered from various plant parts, soil and water at different days from treatment.

Table 9. Gamma-BHC residues in the different plant parts, soil, and water obtained from plots treated with varying numbers of γ-BHC applications to the paddy water, IRRI, 1966.

Treatment (weeks from transplanting)	γ-BHC (kg/ha)		Residue (ppm γ-BHC)*					
	Previous crop	Present crop	Polished rice	Rice hulls	Rice bran	Soil†	Plant† (straw)	Water†
1‡	39	9	0.008	0.252	0.162	0.018	0.483	0.010
3	39	9	0.011	0.120	0.170			
5‡	30	6	0.015	0.143	0.250	0.017	0.779	0.012
7	27	6	0.011	0.267	0.264			
9‡	18	6	0.011	0.262	0.196	0.012	1.846	0.016
10	15	3	0.008	0.224	0.167			
11‡	15	3	0.017	0.287	0.306	0.014	1.526	0.010
12	9	3	0.018	0.237	0.166			
13	6	3	0.014	0.365	0.346			
Control‡	0	0	0.011	0.248	0.266	0.015	0.110	0.005

* Average of 4 replicates. Expressed on dry weight basis.
† Analyses of samples taken at 30 days from last treatment.
‡ Soil, plant and water samples were taken from these treatments only.

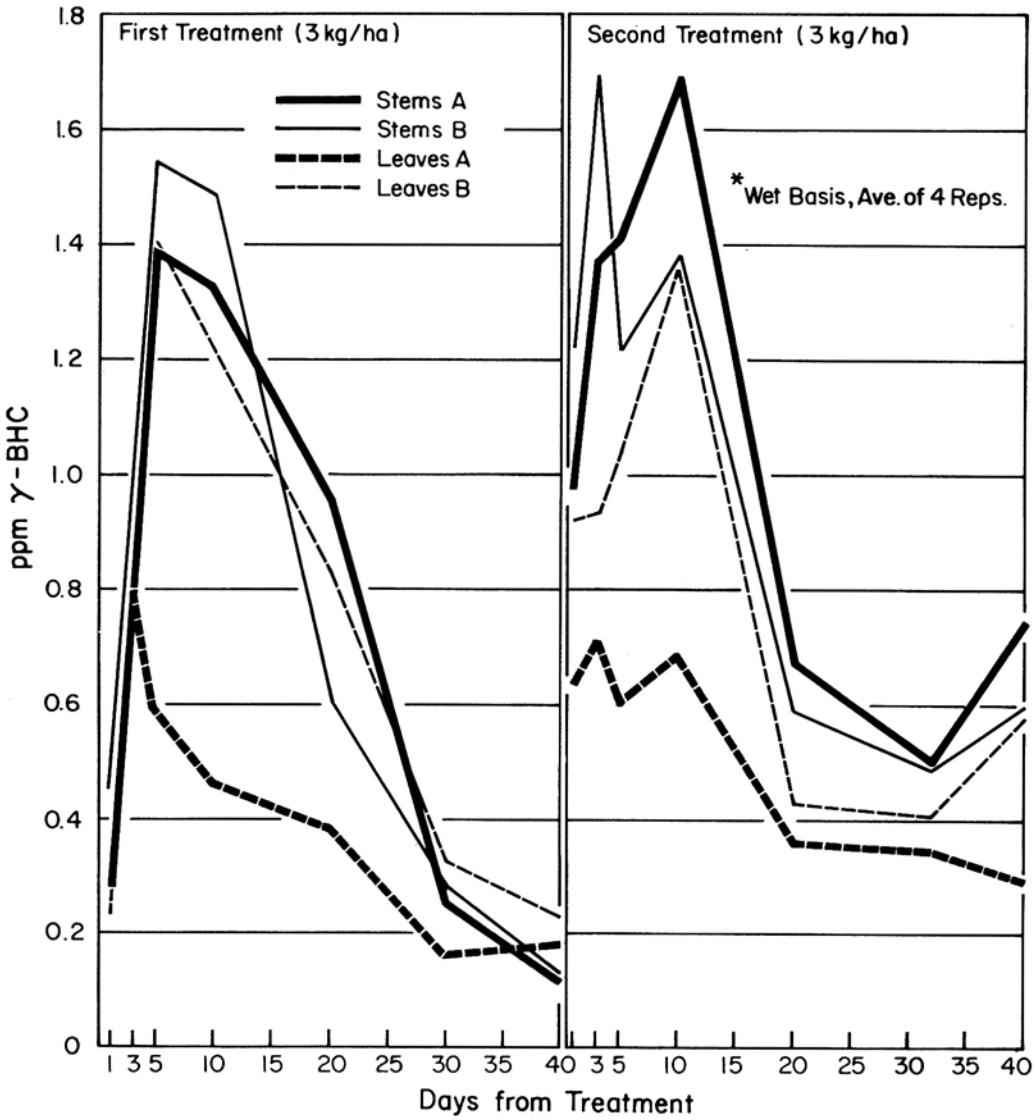


Fig. 16. Gamma-BHC (ppm)* recovered from plant parts at different days from treatment.

was recorded in the upper leaf blades. Although in general the upper parts of the stem had a lower concentration than the basal parts, the difference was not great (Fig. 16).

Cumulative effects of paddy water γ-BHC application on soils, plants, and borer control

As γ-BHC is known to have long residual periods in upland soils, the question has frequently been raised as to whether its application to the paddy water may cause it to accumulate in the soil in quantities sufficient to be phytotoxic to rice plants, or to have other adverse effects. An investigation was therefore conducted between 1964 and mid-1966 in which different amounts of γ-BHC were applied to the paddy water and the same treatments repeated for successive crops on the same plots. Thus, if during one crop season a plot was treated 4 times with 3 kg/ha, and two crops were grown in a year, it received a total of 24 kg/ha in a year. Another plot, to which only a single 3 kg/ha application per crop was made, received only 6 kg/ha in a year.

The results showed that all plots treated with γ-BHC within the first 11 weeks after transplanting had a significantly lower insect infestation and produced higher yields than those treated later or those not treated at all. Highest yields were obtained when the treatments were made within the first 5 to 7 weeks after transplanting. These data, which agree with earlier experiments in this series, show that continuous use of high rates of γ-BHC for up to 4 seasons caused no loss of insecticidal activity and did not affect crop yields.

Intensive analysis of soil samples from treated plots showed that the insecticide was not accumulated in the soil; the amount declined after about 5 days following treatment, reaching non-significant levels 20 days after treatment (Table 9). Irrespective of the total amount of γ-BHC applied, its concentration was low and, in both water and soil, similar for all the treated plots. Any differences recorded in various treatments were more related to the time elapsing between sampling and treatment than to the total amount of the toxicant applied.

Low levels of γ-BHC residues were recorded in the polished rice, rice bran, and hull from all the treatments (Table 9). The total amount of insecticide applied, during either the particular crop season when the samples were obtained or the entire experiment, did not have a direct relationship to the amount recovered in any of the plant parts. It is also significant that the amount present in all plant parts is much below the accepted permissible level of γ-BHC residues. Therefore, the use of this insecticide in the paddy water does not present any problem of soil accumulation or a health hazard for human beings or farm animals.

Optimum rate of γ-BHC on IR8

As reported in the 1964 and 1965 annual reports, the optimum rate of γ-BHC application to the paddy water for a typical tall indica rice variety, Milfor-6(2), was found to be 2 and 3 kg respectively during the vegetative and reproductive stages of the plants. Since the concentration of the insecticide progressively declined towards the apical parts of the plants, it was suspected that shorter plants may require a lower rate of the insecticide for effective insect pest control. As IR8, a new variety developed by the Institute, is considerably shorter than Milfor-6(2) and is gaining wide acceptance by farmers, the optimum rate of γ-BHC for this variety was studied in field experiments.

The insecticide was applied to the paddy water at 1-month intervals at rates of 1.5, 2, 2.5, and 3 kg/ha. Plots not receiving any insecticidal treatment constituted the untreated control.

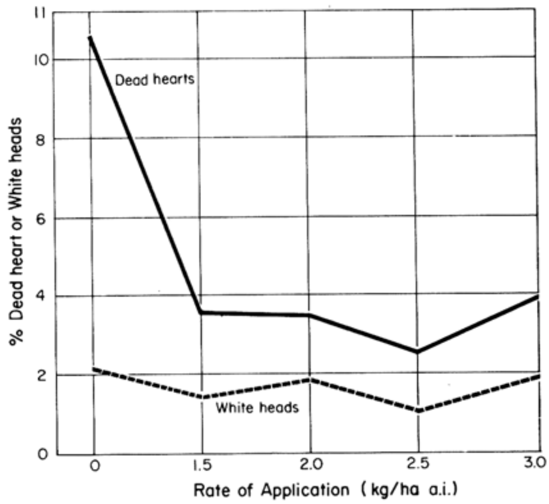


Fig. 17. The incidence of white heads and dead hearts on variety IR8 treated with different rates of gamma-BHC.

All treated plots had significantly lower percentages of dead hearts than the untreated control plots, but the differences among the treated plots were not significant (Fig. 17). The percentages of white heads in all the treatments were low and thus the efficacy of different rates for preventing white heads could not be investigated.

The amount of γ-BHC contained in the paddy water in different treatments was also analyzed at frequent intervals in a gas chromatograph. At 2 days after treatment, the γ-BHC concentration in the paddy water showed a linear relationship with the rate of the toxicant applied and was 0.344 and 0.694 ppm respectively in plots treated with 1.5 and 3 kg/ha. However, the concentration rapidly declined and was not significantly different from the control at 10 days after treatment (Fig. 18). Similar results were

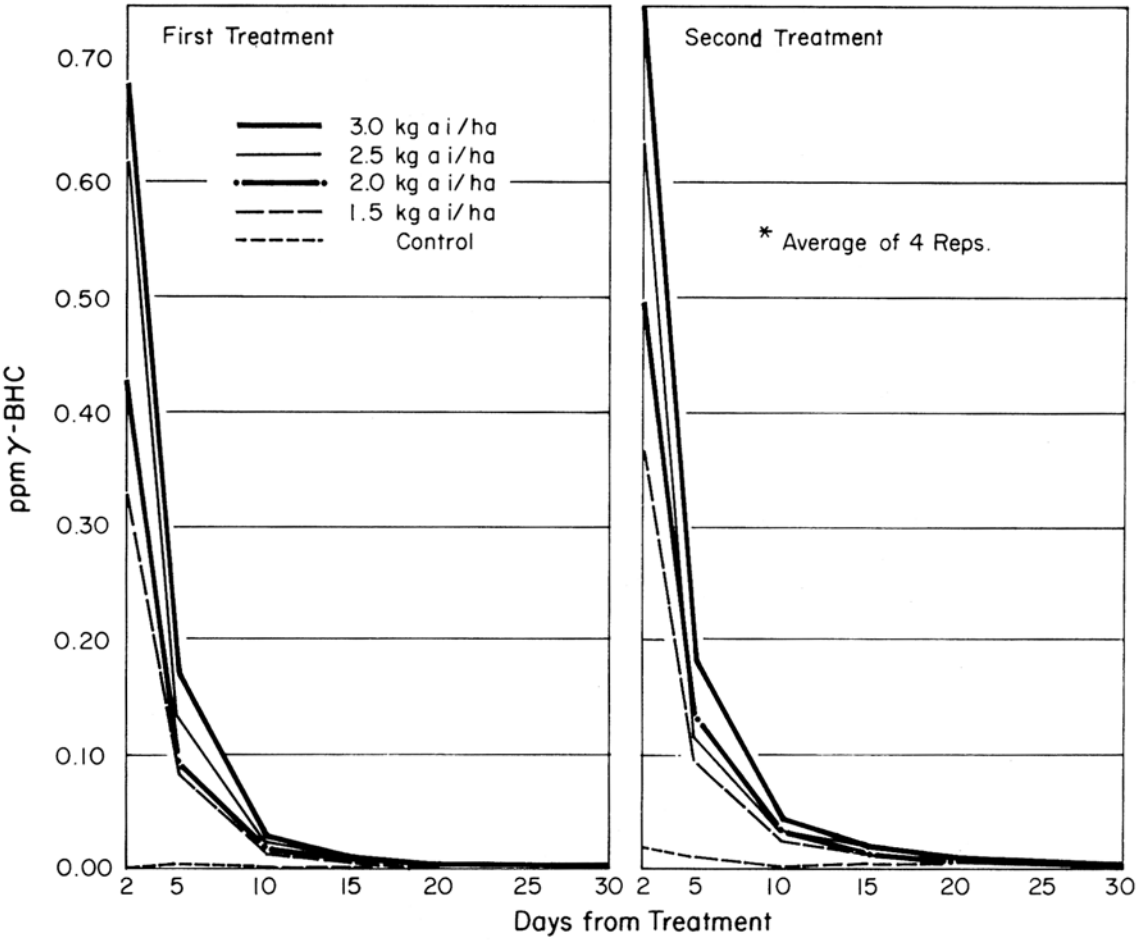


Fig. 18. Gamma-BHC (ppm)* recovered from paddy water treated with different rates of the chemical.

obtained following the second application. Thus the different rates used in this experiment were equally effective in protecting the crop from dead heart and had identical residual effects.

Timing of γ-BHC application based on different percentages of dead hearts

The warmth and the humidity of the tropics coupled with the continuous growth of rice in irrigated areas result in overlapping generations of stem borers throughout the year. Under such situations, the timing of insecticidal applications based on peak moth emergence periods becomes unpractical and, in areas where stem borer is endemic, blanket treatments for crop protection often becomes essential. Although a large number of experiments conducted at the Institute and other locations in the Philippines have shown that stem borers are usually abundant enough to make even blanket applications economical, a definite criterion for deciding the time of application would have great practical significance.

Experiments were, therefore, conducted to determine if application could be timed to follow certain percentages of dead heart in the fields. The experiment was conducted with variety IR8, and γ-BHC applied to the paddy water was the stem borer control. The first application was made when the crop showed either about 5, 10, 20, 25, or 30 percent dead heart, and thereafter applications were repeated at required intervals to protect the crop till harvest. Plots protected continuously, those treated at 25 and 55 days after transplanting, and those not receiving any insecticides were included as controls. The results showed that if the plots were protected following the development of 10 percent dead heart, there was no significant loss in yield. There were moderate losses if protection was not provided as the head heart increased from 10 to 20 percent, but the crop suffered heavily if it was not protected until more than 20 percent dead hearts were showing. However, the tolerance to dead heart will vary with the rice variety and the plant age. Since in this experiment all levels of dead hearts did not develop at the same time, the treatments had to be made on different days from transplanting. The experiment will be repeated using artificial infestation to obtain different percentages of dead hearts on plants of the same age.

Further tests of insecticides applied to paddy water

During the year, two separate batches of insecticides were tested for rice pest control when applied to the paddy water. The first batch consisted of seven insecticides that had shown promise for stem borer and/or leafhopper control. They were applied at 20-day intervals to the paddy water in a field planted with a stem borer-susceptible variety, 9795.

Sixteen days after the first insecticidal application all treated plots had lower percentages of dead hearts than the untreated control plots, but at later stages disulfoton, lebaycid, and bidrin failed to prevent dead hearts. Diazinon and sevidol treated plots had the lowest percentages of dead hearts, but the most effective and persistent leafhopper control was obtained in disulfoton treatments. Diazinon, lebaycid, and bidrin also effectively controlled leafhoppers and significantly reduced virus infection.

The plots treated with diazinon and sevidol had the lowest percentages of white heads, but those treated with disulfoton, lebaycid, and bidrin had even higher percentages of white heads than the untreated control. This was probably because these compounds controlled leafhoppers and other minor pests, thus making the crop more profuse and attractive to the borers which, since they were not controlled effectively by these insecticides, damaged the crop severely. The insect infestation and virus incidence were very severe during the experiments and resulted in almost complete destruction of the control plots. That even with such a heavy insect population, diazinon treatments protected the crop and improved yields, demon-

Table 10. Effect of paddy water application of different insecticides on rice insect pest control. Variety—9795. IRRI, September-December, 1966.

Insecticide	Dead heart tillers (%) 32*	Dead heart tillers (%) 57*	No. of leafhoppers/10 sweeps 32*	No. of leafhoppers/10 sweeps 57*	White head panicles (%) 90*	Virus-infected hills (%) 90*	Grain yield (% of control)
Diazinon	1.01	4.55	18.00	0.00	13.97	32.33	1382.5
Sevidol	1.32	4.13	10.00	1.00	17.45	50.80	830.1
Endosulfan	2.30	5.20	16.50	3.25	19.97	55.75	350.6
Gusathion	2.17	8.10	11.00	2.00	27.62	46.24	524.0
Bidrin	3.18	9.45	14.50	0.75	33.15	38.50	319.2
Lebaycid	2.04	10.06	10.00	1.00	33.17	28.50	298.6
Disulfoton	3.22	20.51	7.25	1.00	49.99	23.91	112.1
Control	4.97	15.56	11.25	6.25	22.04	72.33	100.0
L.S.D.	1.00**	3.68**	—	—	11.94**	19.26	—

* Days after transplanting. The insecticides were applied at 14, 34, 54, and 74 days and the crop was harvested at 97 days after transplanting.

strates the high efficacy of this compound (Table 10).

In another experiment, all compounds which had provided significant stem borer and leafhopper control as foliar sprays were tested for their effectivity when applied to the paddy water. The insecticides were applied at a rate of 3 kg/ha at 20-day intervals from 10 days after transplanting till harvest.

The plots treated with the compounds birlane, fenitrothion, phosphamidon, and endosulfan had lower percentages of dead hearts than the untreated control or those treated with compounds M-2840, mecarbam and disulfoton. Except for endosulfan and mecarbam, most insecticides significantly reduced the leafhopper population immediately after treatment, but the compounds birlane, disulfoton, M-2840, SD 8211, and GS 13005 appeared to have the longest residual effect (Table 11). The plots treated with diazinon, M-2840, birlane, dimethoate, GS 13005, SD 9129, endosulfan, and phosphamidon had the lowest percentages of white heads, which were significantly lower than the untreated control. However, the insect infestation during the experiment was low, and distinct differences in insecticidal performance were not apparent. Therefore, except for a few compounds that failed to control leafhopper and stem borers effectively, all were retested in another field experiment during the wet season.

The results showed that birlane and diazinon most effectively prevented dead hearts and white heads. The compounds dimethoate, phosphamidon, carbaryl, and disulfoton were not effective in reducing the larval population, which was low in plots treated with birlane, diazinon, GS 13005, and azodrin. All treated plots had significantly lower virus incidence than the untreated control. Although several compounds resulted in improved yields, the highest were obtained in plots treated with birlane and diazinon (Table 12).

Table 11. Effect of paddy water application of various insecticides on insect pests of rice. Variety—Milfor-6(2). IRRI, February-June, 1966.

Insecticide (3 kg/ha every 20 days)	Dead heart tillers (%) 57*	No. of leafhoppers/10 sweeps		White head panicles (%) 116*
		32*	57*	
Diazinon	4.69	12.66	1.00	0.48
M-2840	9.56	2.66	1.00	0.98
Birlane	3.69	3.33	1.33	1.36
Dimethoate	6.68	16.33	2.67	1.38
GS 13005	4.95	5.00	2.00	1.39
SD 9129	4.33	10.66	0.33	1.40
Endosulfan	2.26	9.00	8.00	1.68
Phosphamidon	3.54	15.00	2.67	1.79
SD 8211	3.48	16.00	1.33	2.03
SD 9120	3.78	7.00	1.33	2.11
Mecarbam	6.64	10.66	0.67	2.18
RUN-150	3.65	13.66	4.33	2.41
UC-8305	3.96	9.00	1.33	2.42
Folithion	4.76	9.66	3.67	2.64
Fenitrothion	3.56	16.00	1.67	2.80
Bromophos	6.46	18.33	7.33	2.88
Disulfoton	8.44	6.33	2.33	3.31
Lebaycid	6.05	15.00	2.33	3.52
Malathion	5.77	15.00	4.67	4.13
Fitios	5.64	9.66	1.33	4.54
Control	5.24	14.00	12.67	4.20
L.S.D.	2.48	n.s.		1.94**

* Days after transplanting. The insecticides were applied at 17, 47, and 67 days after transplanting.

Table 12. Effect of the paddy water application of different insecticides at the rate of 3 kg/ha at 20-day intervals on rice insect pest control. Variety—IR8. IRRI, August-November, 1966.

Insecticide	Dead heart tillers (%)		Leafhopper population/ 10 sweeps		No. of leafhoppers/ 10 sweeps		Virus-infected hills (%)	White head panicles (%)	Grain yield (kg/ha)
	40*	56*	35*	42*	61*	105*	70*	105*	
Birlane	0.29	0.79	4.00	5.00	0.0	0.33	21.9	0.16	6839
Diazinon	1.35	2.67	12.33	4.00	0.6	5.00	11.5	0.60	6603
Dimethoate	1.65	3.97	11.33	6.30	17.0	4.33	17.7	1.48	5426
Lebaycid	3.02	5.40	9.33	11.00	3.6	5.33	14.3	3.31	5510
Phosphamidon	2.90	3.67	7.33	6.00	13.0	7.00	20.3	2.39	4352
Carbaryl	2.27	3.14	13.33	7.30	10.3	4.33	22.3	2.90	4588
GS 13005	1.35	6.23	9.33	4.00	0.0	4.33	18.0	1.31	5863
Azodrin	3.40	4.36	10.33	6.00	0.0	6.00	18.2	2.33	5255
Disulfoton	2.61	6.05	9.00	4.60	2.3	7.66	14.7	5.21	4465
Control	5.10	5.80	11.66	10.60	9.6	7.33	60.2	3.83	3905

* Days after transplanting. The insecticides were applied at 15, 35, and 55 days after transplanting.

Comparative effectivity of diazinon, sevidol, and γ-BHC

From these previous experiments, it was evident that diazinon provided effective stem borer and leafhopper control. This fact, and its low mammalian toxicity, make it one of the promising compounds for use in rice paddies. The comparative effectivity of diazinon was therefore tested with γ-BHC and sevidol (a granular formulation of 8:8% γ-BHC and carbaryl).

The results showed that all treated plots had significantly fewer dead hearts and a smaller larval population than the untreated control plot. In general, diazinon treatments provided better leafhopper control than either sevidol or γ-BHC. However, the leafhopper population in none of the plots was high enough to cause significant feeding damage, and the virus incidence was also low. For these reasons, all treated plots produced almost identical yields which were 40 to 50 percent higher than the untreated control plots (Table 13).

Effect of diazinon on the field populations of leafhoppers and planthoppers

The effect of diazinon on the common leafhopper and planthopper populations was further investigated during the dry and wet seasons in large-size plots planted with rice selection IR9-60. The population in the untreated control plots showed the natural fluctuations, and the frequency of the treatments was based on these population trends rather than on the residual period of the insecticide. This was to permit diagnosis of any resurgence in leafhopper and planthopper population at the conclusion of treatment. The sampling was done between 8 and 10 a.m. by sweeping with a 36-cm insect hand net.

During both the dry and wet seasons the population of the rice green leafhopper was more abundant than that of the planthoppers (Fig. 19). In general, *Nephotettix* and *Sogatella* were more abundant during the early stages of plant growth but *Nilaparvata* and *Inazuma*

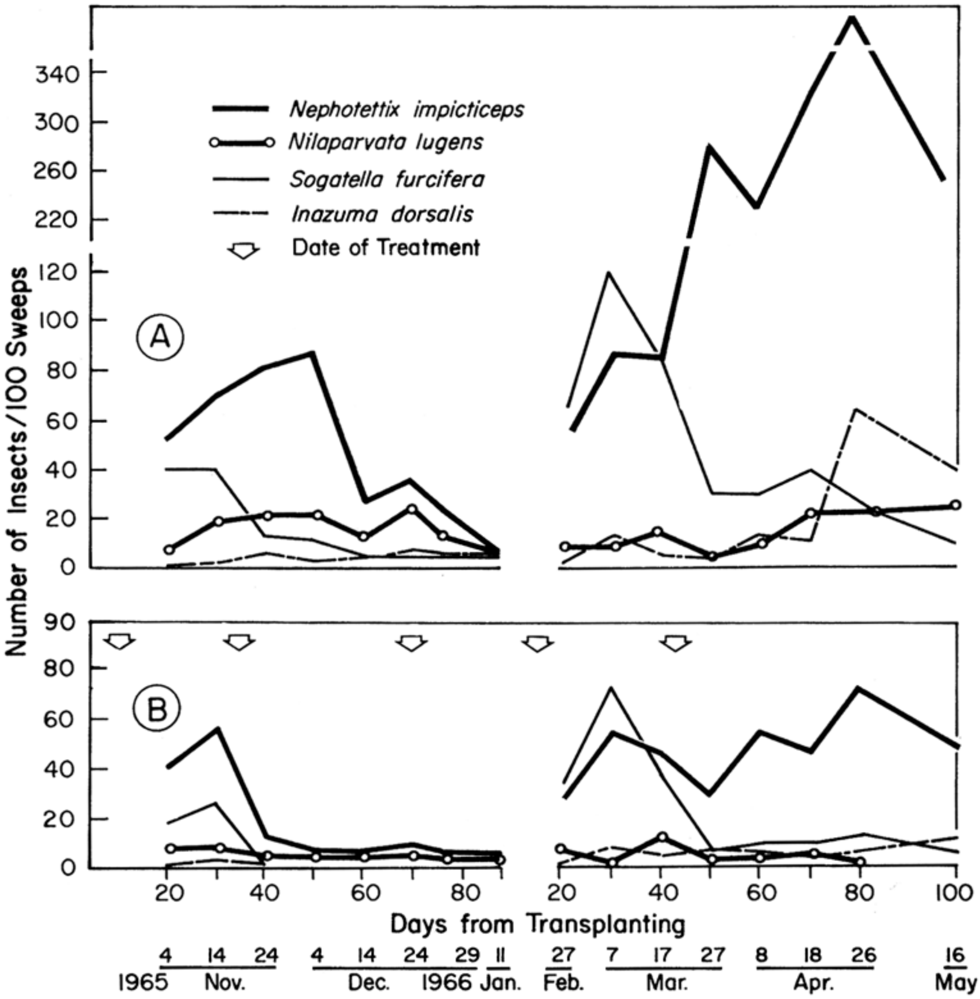


Fig. 19. Common leafhopper and planthopper population in IR9-60 rice plots. (A) untreated control, (B) diazinon granules applied to the paddy water.

became more abundant later. Also, during the dry season the leafhoppers were more abundant than during the wet season.

During the wet season the first diazinon application was made at the rate of 1 kg/ha. At 10 days after treatment the leafhopper and planthopper populations in the treated plots were reduced by about 20 to 50 percent of the untreated control, but 10 days later they started to increase, indicating a loss of insecticidal activity. Therefore, another treatment was made 25 days after the first application and, 30 days later, the treated plots had 3 rice green leafhoppers, 3 brown planthoppers, 1 white-back planthopper and no zigzag leafhopper per 100 sweeps, in contrast to 24 leafhoppers, 9 brown planthoppers, 4 white-back planthoppers and 2 zigzag leafhoppers per 100 sweeps in the untreated plots (Fig. 19), indicating that the insecticidal residual effect was still operative. Another application made at this stage kept the leafhopper population at a very low level till harvest.

During the dry season two treatments at 10 and 40 days after transplanting kept the leafhopper population at low levels till the crop was

Table 13. Insect pest control effectivity of γ-BHC, sevidol*, and diazinon applied to the paddy water at 30-day intervals. Variety—IR8. IRRI, June-September, 1966.

Insecticide (3 kg/ha)	Dead heart tillers (%)	Leafhopper population/10 sweeps		No. of living larvae/5 hills			White head panicles (%)	Grain yield (kg/ha)
	36†	52†	83†	50†	60†	105†		
γ-BHC	2.48	30.2	34.2	3.7	2.0	4.0	1.5	4541
Sevidol	2.09	13.3	22.5	1.2	1.0	8.2	3.7	4850
Diazinon	1.92	10.0	7.0	0.7	1.0	3.7	1.4	4818
Control	11.71	25.7	21.7	3.2	4.0	10.5	1.0	3319
L.S.D.	5.23	n.s.	n.s.	—	—	—	n.s.	948

* A granular formulation of 8:8% γ-BHC and carbaryl.
† Days after transplanting. The insecticides were applied at 20, 50, and 80 days after transplanting.

harvested. Although in comparison with other species the rice green leafhopper population in the treated plots was higher, even at 40 days after the treatment, it was 13 times lower than that in the untreated control plots. The population remained low till harvest, which was about 60 days after treatment, but in laboratory studies only 15 to 20 days of effective residual period had been recorded. Thus no resurgence in planthopper population was recorded, even beyond the insecticidal residual period, even though the untreated control plots were heavily infested. In plots treated with diazinon there were a large number of spider webs which might have helped to keep the leafhopper population low.

Frequency of diazinon treatments to three rice varieties for virus vector control

As established in the foregoing experiments, diazinon is highly effective for controlling stem borers, leafhoppers, and planthoppers, and also for protecting the plants from virus infection. To further confirm the effectivity of diazinon for virus vector control, an experiment was conducted with three varieties having differential virus susceptibility. These varieties were Taichung (Native) 1, highly susceptible; IR9-60, moderately susceptible; and IR8, moderately resistant to the tungro virus under field conditions. Also, since virus infection in the field generally increases during the first 60 days after transplanting, as reported in the 1965 annual report, there were separate treatments in which the plants were protected from vectors only for 60 days from transplanting or alternatively protected till harvest. Plots receiving no protection served as an untreated control. The insecticidal treatment consisted of applying diazinon at the rate of 3 kg/ha to the paddy water every 20 days from 5 days after transplanting for the required period. The initial virus incidence and its spread in each plot was recorded at 15-day intervals from 20 days after transplanting. Periodic observations on leafhopper population and stem borer incidence were also made.

The stem borer infestation in all these three varieties, as evidenced by percentages of dead hearts and white heads, was moderately low. In untreated control plots, the variety IR9-60 was generally less infested than Taichung (Native) 1 and IR8. However, the incidence of stem borer was significantly reduced where the crop was either protected up to 60 days or till harvest (Fig. 20).

There was no significant difference in virus infection between varieties at 20 days after transplanting, irrespective of whether they were protected or not. However, in observations made at 35 days after transplanting and onwards, all protected plots had significantly lower virus infection than the untreated controls, indicating

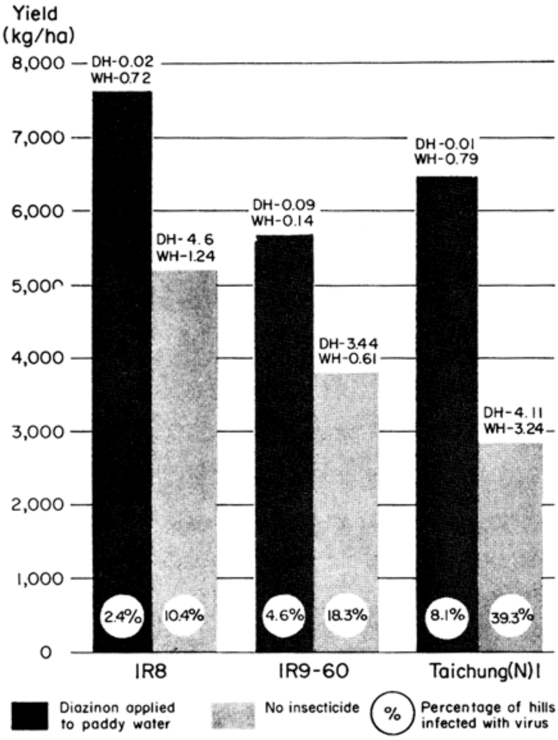


Fig. 20. Effect of diazinon on control of stem borers and leafhoppers on three indica rices.

that protection during this period was extremely important. In subsequent observations, the virus infection in untreated control plots kept on increasing but remained more or less at the same level whether protected up to 60 days or until harvest (Fig. 21). The results therefore indicate that protection up to 60 days was adequate for preventing tungro virus spread.

In the untreated control plots the highest percentage of virus infection was recorded in variety Taichung (Native) 1 followed by IR9-60 and IR8, being respectively 39.3, 18.3, and 10.4 percent. Thus, under field conditions, the varieties IR9-60 and IR8 were twice and four times more resistant than the variety Taichung (Native) 1. Diazinon treatment reduced the virus incidence by about 80 percent for all varieties. Also, under unprotected conditions, the variety IR8 yielded about twice as much as Taichung (Native) 1 and the yield of IR9-60 was intermediate. When protected from virus infection, IR8 produced the highest yield of 7.8 ton/ha (Fig. 20).

This experiment demonstrated that the critical period of virus spread in the field was within the

Table 14. Timing and frequency of diazinon application to the paddy water for rice pest control. The insecticide was used at 3 kg/ha at 20-day intervals. Variety—IR8. IRRI, August-November, 1966.

No. of treatments	Dead heart tillers (%)	Virus-infected hills (%)			No. of leafhoppers/ 10 sweeps			White head panicles (%)†	Grain yield (kg/ha)
	38*	35*	56*	77*	48*	57*	80*		
Protection up to 30 days (1 application)	1.11	2.82	8.29	60.25	6.0	18.5	25.5	3.389	3830
Protection up to 50 days (2 applications)	1.80	4.17	7.24	20.83	4.7	4.0	8.2	2.716	4916
Protection up to 70 days (3 applications)	2.10	3.85	6.71	19.58	3.7	2.5	4.2	1.50	7301
Protection up to 90 days (4 applications)	1.24	2.80	7.21	19.32	4.0	2.7	8.5	0.99	7799
Control	9.47	5.31	20.47	52.49	8.0	11.0	14.0	4.08	4025
L.S.D.	1.98	1.63	5.42**	11.84**	n.s.	8.29**	9.16**	n.s.	605

* Days after transplanting. First treatment made 10 days after transplanting and then repeated every 20 days.
† Five days before harvest.

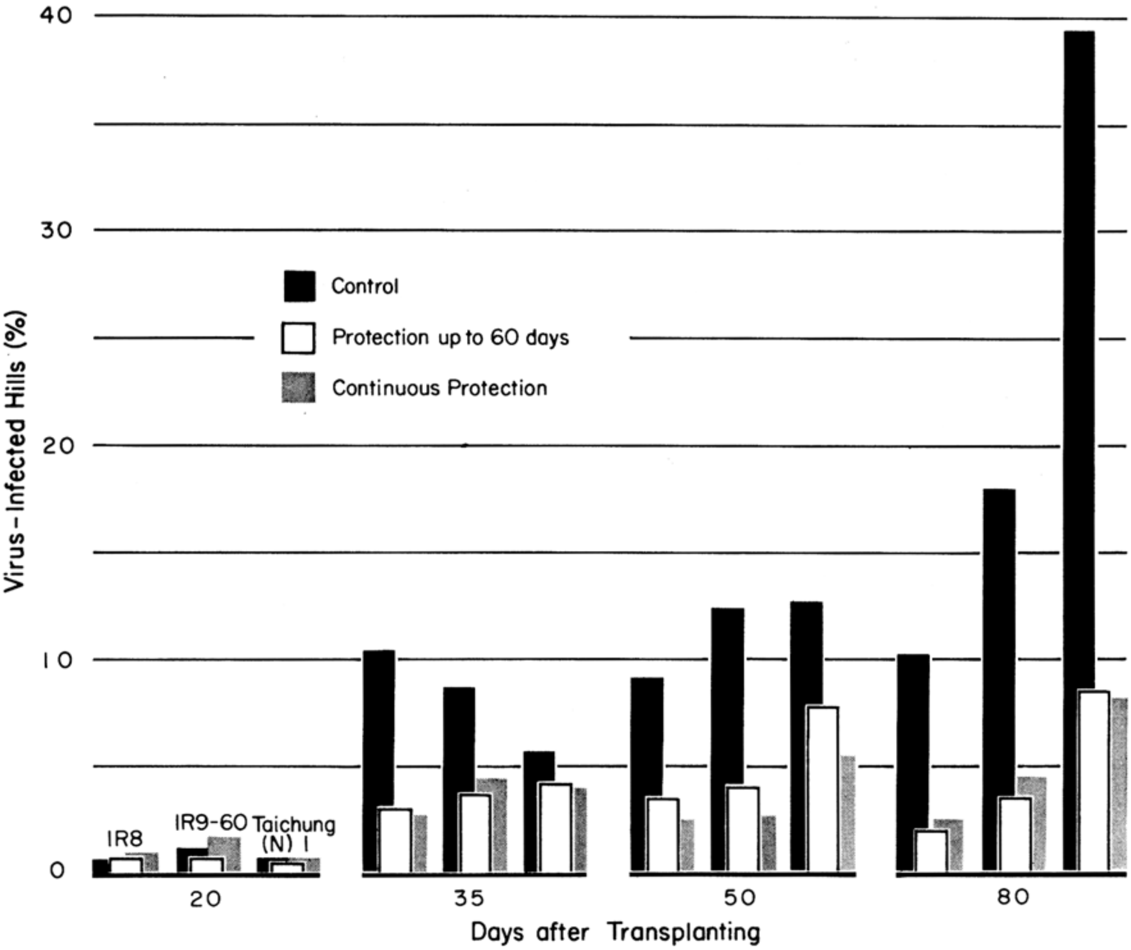


Fig. 21. Percent virus-infected plants in treated and untreated plots of three rice varieties at different days from transplanting.

first 60 days after transplanting. To further verify these results, experiments were conducted with varieties Taichung (Native) 1 and IR8 which were protected for different periods after transplanting. The results showed that for IR8 and Taichung (Native) 1, protection up to 50 and 70 days respectively from transplanting was essential to reduce virus incidence effectively. However, because of other insects, a minimum of three treatments (protection up to 70 days) was essential on both varieties to obtain high yield (Table 14).

Optimum rate of diazinon application

All exploratory experiments with diazinon were conducted at a rate of 3 kg/ha. To determine the optimum rate, diazinon was tested at rates ranging from 1 to 3 kg/ha in field experiments during the dry and wet seasons of 1966. The experiment during the dry season was conducted on variety Milfor-6(2), and the insecticide was used at rates of 1, 2, and 3 kg/ha applied to the paddy water at 20-day intervals starting at 10 days after transplanting. Plots receiving no insecticidal treatment served as untreated control.

The insecticide was effective at all rates in reducing stem borer damage, controlling leafhoppers to prevent virus spread, and in producing higher yields than the untreated plots (Table 15, Fig. 22).

The experiment during the dry season was conducted on variety IR8, and the insecticide was used at rates of 1, 1.5, 2, 2.5, and 3 kg/ha. In this experiment also, all rates of application provided effective insect control and produced significantly higher yields than the untreated control plots. The rate of 1 kg/ha was com-

Fig. 22. With an insect population large enough to damage untreated control plots seriously, plots treated with diazinon remained comparatively insect-free and produced high yields.

Table 15. Effect of different rates of diazinon applied to the paddy water on rice insect pest control. Variety—Milfor-6(2). IRRI, November, 1965-March, 1966.

Rate* (kg/ha)	Dead heart tillers (%)		Living larvae/ 5 hills		Virus-infected hills (%)			Grain yield
	52†	67†	67†	93†	55†	69†	104†	(kg/ha)
1	3.30	4.40	47.00	19.00	5.33	6.71	6.37	5196
2	0.10	1.05	25.33	14.66	3.14	4.25	3.18	5800
3	1.35	0.92	10.00	3.33	5.04	5.44	3.66	5834
Control	6.17	12.09	53.33	20.33	19.70	28.38	33.42	2958

* The treatments were made at 30, 60, 80, and 100 days after transplanting.
† Days after transplanting. The crop was harvested at 114 days after transplanting.

paratively less effective for controlling stem borers but effectively controlled leafhoppers and prevented virus infection (Table 16). Thus a minimum of 1.5 kg/ha of diazinon applied to the paddy water should provide effective insect pest control and produce high yields.

Combination of paddy water application and foliar sprays

Several insect pests which feed on the rice inflorescence and grains can be more effectively controlled by foliar sprays than by applying the insecticides to the paddy water. However, the latter method is more effective and persistent for stem borer and leafhopper control. Therefore, the insecticidal effectivity of diazinon or γ-BHC applied to the paddy water and supplemented with guthion foliar spray was studied in field experiments.

All treated plots had low insect infestation and produced significantly higher yields than the untreated controls (Table 17). The results

Table 16. Effect of different rates of diazinon applied to the paddy water for rice pest control. Variety—IR8. IRRI, August-November, 1966.

Rate* (kg/ha a.i.)	Dead heart tillers (%)	Leafhopper population/ 10 sweeps		No. of living larvae/ 5 hill samples		Virus-infected hills (%)	White head panicles (%)	Grain yield (kg/ha)
	40†	42†	51†	42†	58†	63†	105†	
1.0	5.18	7.75	1.0	11.5	0.0	9.13	1.64	5989
1.5	2.42	6.75	1.0	20.5	0.0	8.59	1.12	6330
2.0	1.93	10.50	1.2	10.2	2.2	11.48	0.61	6618
2.5	1.67	7.25	0.7	12.2	0.5	7.22	0.96	6920
3.0	1.52	7.75	0.7	14.7	0.0	7.09	1.12	6669
Control	5.06	15.50	3.2	7.2	9.0	23.08	3.53	3960

* Treatments made at 13, 43, and 65 days after transplanting.
† Days after transplanting.

Table 17. Combination of paddy water application and foliar spray methods of insecticidal application for rice pest control. Variety—IR8. IRRI, August-November, 1966.

Treatment*	Dead heart tillers (%)	Leafhopper population/ 10 sweeps			No. of living larvae/ 5 hill samples		Virus-infected hills (%)	White head panicles (%)	Grain yield (kg/ha)
	30†	43†	51†	61†	58†	105†	63†	105†	
Diazinon (10, 35, and 60)†	1.6	1.75	1.0	1.25	1.00	10.00	4.40	2.32	5532
γ-BHC (10, 40, and 70)†	1.5	5.60	4.5	3.30	0.75	3.50	0.93	0.64	5630
Diazinon (10, 35)† + γ-BHC (60)†	1.6	1.00	1.5	1.70	0.25	7.25	5.74	1.08	6178
Diazinon (10, 35)† + guthion (55)†	3.8	1.50	2.2	0.25	0.75	5.50	6.40	1.87	6179
γ-BHC (10, 40)† + guthion (70)†	2.5	5.50	4.4	5.00	0.25	3.25	7.95	0.66	6246
Control	7.5	5.70	6.0	3.00	6.25	9.25	13.86	2.09	4026

* Diazinon and γ-BHC were applied to the paddy water at rate of 3 kg/ha while guthion was used as 0.1% foliar spray.
† Days after transplanting.

show that two initial applications of γ-BHC or diazinon supplemented with a guthion spray provided effective insect control throughout the crop period and produced high yield. However, the difference between the paddy water application alone and supplemented with foliar sprays was not significant.

Sex Pheromones in Stem Borer Moths

During 1965 studies were initiated to explore the possibility of obtaining sex attractants in the stem borer moths, isolating the compound, and using it for luring the moths of opposite sexes. These investigations involve basic studies on the mating habits, behavior and attraction of moths to opposite sexes.

Large numbers of adult moths of the common stem borer species were collected either from light traps or by sweeping from the rice fields. The species *Chilo suppressalis, Tryporyza incertulas,* and *Sesamia inferens* were collected at the Institute, and *T. innotata* was collected from Iloilo. The sex ratio of these collections was determined and the female moths were dissected to record the number of spermatophores which represented the number of matings by each moth. These collections revealed that, in nature, the females were more abundant than the males (Table 18). Also, the field collections showed that approximately 20 percent of the females of all species were unmated. While both species of *Tryporyza* had, in nature, mated only once, the females of *Chilo suppressalis* and *Sesamia inferens* had undergone as many as three matings (Table 18).

In laboratory experiments, a change in mating frequency of *Chilo suppressalis* moths was recorded by caging moths together in different sex ratios. When, in separate tests, a female moth was caged with a varying number of male moths, the mating frequency increased with an increase in female: male ratio (Fig. 23). In all experiments where two or more females were caged with a single male moth, about 20 to 30 percent of the female moths remained unmated. However, up to a male: female ratio of 1:10 there was no decline in the percentages of the mated females, although in none of these tests were more than two matings per female recorded. Increased number of matings resulted in more eggs per female moth. The unmated females laid scattered sterile eggs.

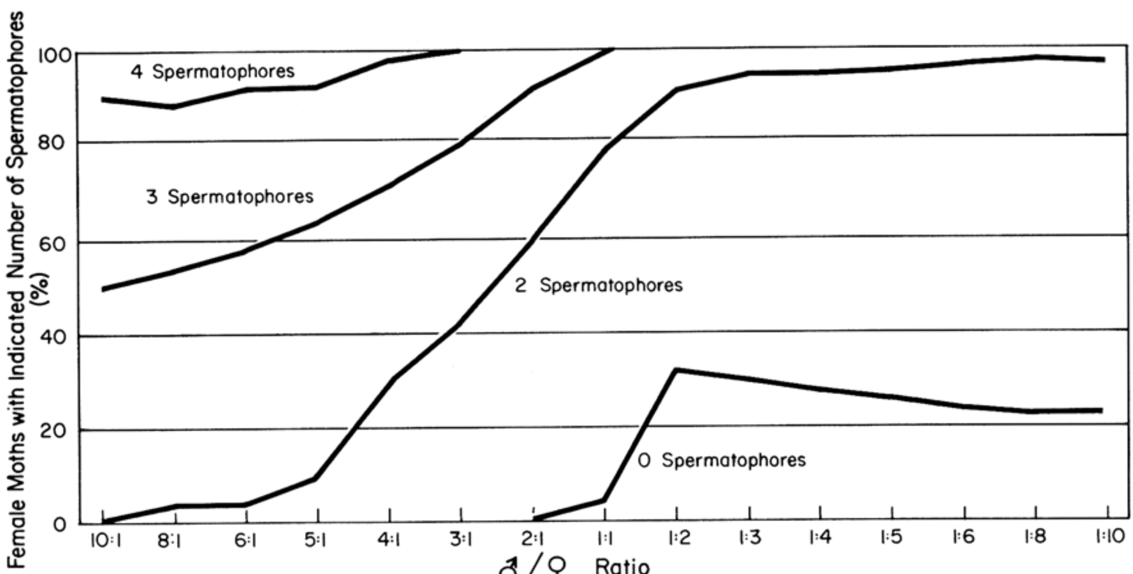


Fig. 23. Frequency of mating of *C. suppressalis* moths, based on spermatophore counts with varying male: female ratios.

Table 18. Mating frequency of field-collected females of the different species of rice stem borers, IRRI, 1966.

Rice stem borer species	Source of collection	Date of collection	No. of moths collected			Mating frequency of dissected females (%)*				Sex ratio
			Males	Females	Total	0	1	2	3	
Chilo suppressalis (Walker)	IRRI farm	Oct., 1964	1342	3889	5231	18.9	67.1	11.2	2.8	1:2.9
Sesamia inferens (Walker)	IRRI farm	January-June, 1966	198	664	862	23.6	65.5	10.3	0.6	1:3.4
Tryporyza incertulas (Walker)	IRRI farm	January-June, 1966	659	902	1561	20.4	76.6	—	—	1:1.4
Tryporyza innotata (Walker)	Iloilo†	April-June, 1966	398	647	1045	22.1	77.9	—	—	1:1.6

* Based on the number of spermatophores.
† Collected from BPI Experiment Station, Iloilo City.

Table 19. Number of male moths caught in traps containing newly emerged male and female moths. Traps without any moths constituted controls, IRRI, 1966.

Date of collection	Male moths caught in baited traps containing: Newly emerged female	Newly emerged male	Control
Jan. 13-22, 1966	64	0	0
Jan. 16-24, 1966	73	0	0
Feb. 5-13, 1966	48	0	0
Feb. 11-19, 1966	57	0	0
Feb. 14-23, 1966	49	0	0
Total	291	0	0

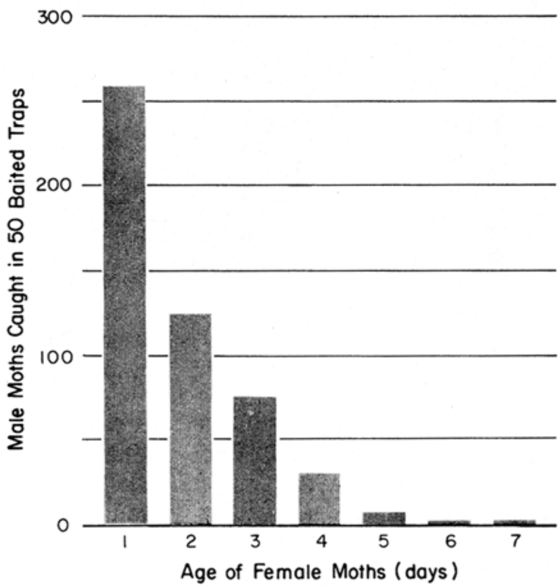


Fig. 24. Number of male *C. suppressalis* moths caught in traps baited with virgin female moths of different ages.

From a series of experiments, a definite attraction of males to female moths was recorded. In laboratory experiments the moths usually mated between 8 and 10 p.m. and the attraction period coincided with mating periods. Newly emerged female moths were most attractive and their attractiveness declined as they became older (Fig. 24). In laboratory experiments, whenever an air stream from containers of virgin females was passed through another container of unmated males, the male moths showed a typical mating response. Under field conditions, virgin females attracted several wild male moths (Fig. 25, Table 19). A total of 291 males were attracted to 50 female-bait moths and were caught inside the cages. No moths were attracted to the cages containing newly emerged male moths or to the empty cages which served as controls. Also, no female moths were attracted to any of the cages. In another experiment where unmated female moths were caged at different heights in the field, the largest number of moths were attracted to the cages at

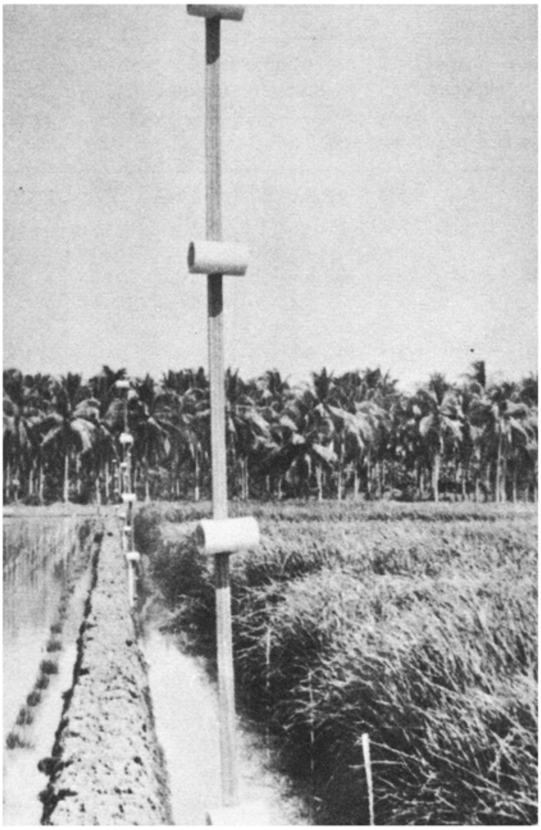


Fig. 25. Cages used in attraction studies with the wild stem borer population. Cages baited with unmated females attracted a large number of male moths.

6 feet height from ground level; a total of 200 females attracted 1,489 male moths. These results definitely suggest a strong attraction by virgin females to male moths.

The Biological Control of Rice Stem Borers

Studies on the biological control of rice stem borers started in 1965 were continued through 1966. The first phase of the program, consisting of a study of the relative and overall abundance of the different borer species and their natural enemies, was completed in 1966.

The abundance of borer species and their parasites

Monthly sampling for borers in Isabela, Nueva Vizcaya, the Central Luzon Plain, Laguna, and the Bicol region was carried out on the wet—as well as on the dry—season crop. In the wet-season crop, *Tryporyza incertulas* was the dominant species in all the regions, ranging from 41.9 per cent of the population in Isabela to 77.2 percent in Laguna (Table 20). *Chilo suppressalis* was the next most abundant species in all the regions, except Isabela where *Sesamia inferens* was found in large numbers. *Chilotraea polychrysa* was the least abundant of the four species.

In the dry season *Tryporyza incertulas* was still the dominant species in Laguna with *Sesamia inferens* a distant second. However, in Isabela and Bicol region *Chilo suppressalis* was found to be the most abundant borer; *Chilotraea polychrysa* was quite rare.

The overall borer abundance was calculated on the basis of the number of borers collected per 100 tillers. It was highest in Nueva Vizcaya in the wet season with a value of 4.1, and lowest in Isabela in the dry season where only 0.5 borers per 100 tillers were found.

The laboratory rearing of borers collected from the field yielded information regarding the natural parasitism of the borers. The extent of parasitism varied considerably from region to region, being highest in the Central Luzon Plain with a value of 7.5 percent in the wet-season crop, and lowest in Isabela in the dry season when no parasitism was recorded. An ichneumonid, *Temelucha* sp. near *nigromaculata* Cameron, was the most common parasite in the Central Luzon Plain and Nueva Vizcaya. In Isabela and Bicol a braconid, *Shirakia schoenobii* Viereck, was reared most frequently from borers. In Laguna, *Eriborus sinicus* (Holmgren) was the most abundant natural enemy.

The cumulative picture of the extent of parasitism of the rice stem borers on Luzon island is shown in Fig. 26. The estimated proportion of parasitized borers in the field was very low— about 4 to 6 percent. This clearly shows the ineffectiveness of the indigenous natural enemies in keeping the borer population in check.

The introduction of foreign parasites

The second phase of this program, consisting of the introduction of suitable foreign natural enemies, was started in 1966. A study of the available stem borer parasites of the various

Table 20. **Summary of the results of monthly sampling for the various rice stem borers and their natural parasitism on Luzon, Philippines, IRRI, September, 1965–June, 1966.**

Region	No. of localities sampled	Total borers recovered	Abundance (%) *Tryporyza*	*Chilo*	*Sesamia*	*Chilotraea*	Borer abundance (per 100 tillers)	Parasitism (%)
Wet-season crop, 1965								
Isabela	4	344	41.9	23.8	32.0	2.3	2.3	1.6
Nueva Vizcaya	4	569	52.9	35.1	11.8	0.2	4.1	4.3
Central Luzon Plain	4	316	57.9	20.9	12.3	8.9	1.9	7.5
Laguna	8	373	77.2	21.7	1.1	0.0	2.5	3.7
Bicol	6	473	50.8	33.8	8.6	6.8	3.8	7.0
Total	26	2076	55.7	28.4	12.6	3.3	2.9	4.6
Dry-season crop, 1966								
Isabela	4	94	22.3	75.5	2.1	0.0	0.5	0.0
Laguna	8	418	72.2	11.7	13.4	2.6	2.5	7.0
Bicol	6	289	37.7	56.1	6.2	0.0	3.3	6.4
Total	18	801	53.9	35.2	9.5	1.4	2.1	4.5

* Sampling sites in Nueva Vizcaya and the Central Luzon Plain were single-cropping areas.

rice-growing areas of the world was conducted and a list of some of the more promising ones prepared. The first of these, *Sturmiopsis inferens* Townsend, a tachinid parasite of stem borers in the Indo-Malayan region, has already been obtained from India and is currently under study. Another parasite, *Metagonistylum minense* Townsend, is being imported from Barbados. Its first shipment of 200 puparia was delayed in transit and all the flies perished. This, as well as two more parasites, *Apanteles chilonis* Munakata and *Isotima javensis* (Rohwer), are being considered for importation in early 1967.

In July 1965, 103 puparia of *Sturmiopsis inferens* were received from the Indian Station of the Commonwealth Institute of Biological Control. Since then this insect has been reared through four generations in the laboratory (Table 21). *Sesamia inferens* appears to be slightly superior to *Chilo suppressalis* as a host for this parasite. However, *Chilo suppressalis* is reared much more easily in the laboratory; hence most of the inoculations have been made on it. Parasitism in the laboratory has been quite favorable, ranging from 45.9 to 76.7 percent.

Greenhouse and field releases of *Sturmiopsis inferens*

In the months of September and October some

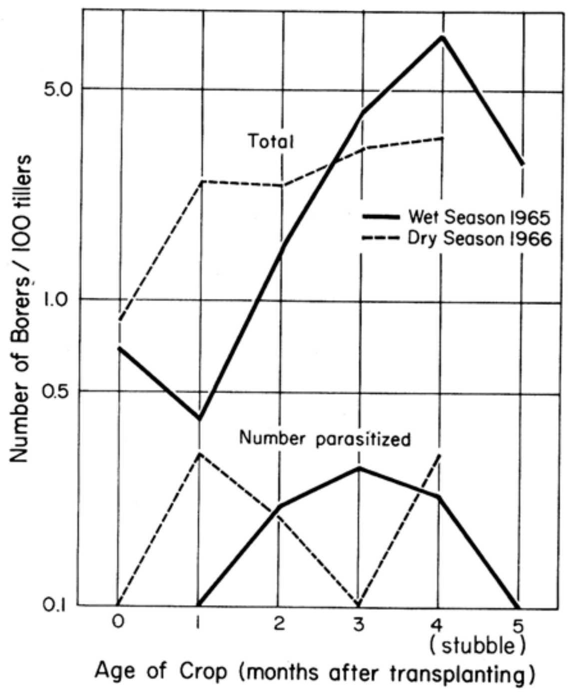


Fig. 26. Estimation of the relative abundance of parasitized and total borers, on Luzon, Philippines.

Table 21. A summary of laboratory inoculations of the rice stem borers with the parasite, *Sturmiopsis inferens*, IRRI, 1966.

Month	Species	No. of borers*			Parasitism
		Inoculated	Diseased	Parasitized	(%)
July	*C. suppressalis*	260	9	170	73.6
	S. inferens	6	6	23	76.7
August	*C. suppressalis*	1929	120	831	45.9
September	*C. suppressalis*	923	63	475	55.7
October	*C. suppressalis*	323	11	152	48.7
	S. inferens	355	40	196	61.6

* Third to fourth instar larvae were used as hosts.

preliminary releases of *Sturmiopsis inferens* were made to determine its effectiveness under greenhouse and field conditions. No males were included in the releases and the females that were released had all duly mated and completed their gestation period of 10 to 15 days.

On September 27, 38 females were released over artificially infested potted rice plants in the greenhouse. Two weeks later, out of a total of 408 borers recovered, 67 were found to be parasitized. A field release of 25 females in San Miguel, Bulacan, was also quite encouraging. All of the 11 borers collected 3 weeks after the release of the parasite were found to be parasitized by it. A second release of 10 females in the same area, however, failed to yield any parasitized borers.

Effort was also made to determine the effectiveness of the parasite on the Institute farms where insecticides are used extensively. Twenty-three females were released on October 12. On December 2 out of 1,974 borers recovered from the field, 2 were found to be parasitized by this fly.

These results indicate that *Sturmiopsis inferens* is capable of parasitizing *Chilo suppressalis* and *Sesamia inferens* in the Philippines, not only in the laboratory and the greenhouse, but also under actual field conditions. It is too soon, however, to conjecture regarding its ultimate effectiveness in the regulation of stem borer populations in this country. Its further laboratory multiplication is underway. In December 1966 and January 1967 larger releases are planned for the Institute farm and the Central Luzon Plain.

Agricultural Engineering

Land preparation studies have prompted further development of wide rotary tillers powered by large tractors. Prototypes have been designed and fabricated, and attempts made to eliminate weaknesses as they are revealed during tests. By surveys and time tests, information has also been gained on the economics of using hand tractors for wet land preparation. These machines are gaining wide popularity in some parts of the Philippines.

Experiments on anhydrous ammonia application have examined the effects of both vertical and horizontal placement. The results have confirmed the value of deep placement and indicated that yield is not adversely affected by placing the fertilizer at a horizontal distance of 25 cm from the plant row.

Efforts to devise suitable equipment for direct seeding was continued. One of the main problems is that the wave formed by the tractor wheels disturbs swaths already sown.

Other studies have been concerned with measuring evapotranspiration, its relationship to plant growth, and the effect of solar radiation on dry matter production.

To collect basic information on existing methods of rice culture in the Philippines, weekly observations of farm operations and crop conditions are being made at 145 sites in Central Luzon.

1966 ANNUAL REPORT, The International Rice Research Institute *Mailing Address:* Manila Hotel, Manila, Philippines

Land Preparation

Prototype design and fabrication of 300 cm and 360 cm wide rotary tillers was continued. The tillers were used to prepare wet and dry rice fields at rates of 4,000 to 8,000 sq m/hour when powered by tractors with a PTO rating of 35 to 45 horsepower (Fig. 1). Local manufacture of the frame would be possible by a good welding shop if bearings, transmission, and blades were available. The major difficulty has been in obtaining transmissions. Several modifications were made to strengthen the tiller frame yet reduce the weight; bearing seals were fabricated and tested to reduce mud and water entry; and depth-sensing mechanisms were fabricated and tested in an attempt to use the automatic draft control features of the tractor to control the depth of land preparation. Demonstrations and drawings of the prototypes have been provided to interested persons to encourage their participation in improving and manufacturing transmissions, frames, bearing seals or depth control devices.

The following advantages may be cited in favor of the wide rotary tiller:

1. Less power is consumed in wheel slippage and rolling resistance as most of the power is provided through the more efficient gear train.
2. The soil surface is left in a more even condition with fewer furrows and high spots.
3. The wider rotor provides more push to the tractor to assist in overcoming rolling resistance.
4. When the rotor width equals or exceeds outside-wheel dimensions and the turning radius of the tractor, the tractor can work in small

Fig. 1. Extended rotary tiller in use on a soft paddy soil.

fields without leaving untilled edges and corners and without excessive loss of time in turns.

Hand tractors in Laguna

A cooperative research project was conducted with the Agricultural Engineering Department, University of the Philippines College of Agriculture, to study the use of hand tractors on lowland rice farms in Laguna Province. A survey in the province indicated the presence of 400 units. The first 3 units were purchased in 1960. The total number of hand tractors on farms in Laguna has grown rapidly as follows:

Year	*No. of units purchased*	*No. on farms*
1960	3	3
1961	11	14
1962	41	55
1963	87	142
1964	53	195
1965	139	334
1966 (part of year)	66	400

These hand tractors are largely the tractive type tillers designed to pull plows, comb harrows and small trailers (Fig. 2). They are usually sold with both plow and comb harrow but the comb harrow is most widely used. A total of 365 comb harrows have been purchased for use with tractive type tillers while only 37 rotary tillers were purchased.

Timed tests of harrowing operations indicate that about 540 to 740 sq m may be harrowed in a single pass per rated horsepower (Rhp) hour of the tiller. Thus, a 6-Rhp tiller could make a single pass on 1 ha in about 2.6 hours. From 3 to 5 passes of the harrow are required for complete land preparation on soft soils. Thus a 6-Rhp tiller could not be expected to completely harrow more than 1 ha/day. Gasoline consumption was about 4 to 6 liter/ha for a single pass of the harrow and would probably run about 12 to 30 liter/ha for complete harrowing. Only a few tests were made on rotary tilling flooded fields but they indicate that about 10 to 16 liter/ha of diesel and 10 to 27 liter/ha of gasoline were required for rotary tilling 1 ha, whereas plowing averaged about 33 liter/ha of gasoline. One liter of gasoline provided about 3.3 Rhp-hours of machine power. On this basis, the following estimates of power requirements for preparing lowland rice fields in Laguna Province have been made:

Fig. 2. A hand tiller with cage wheels and comb harrow can prepare soft soils in 3 to 5 passes.

Method A.

Plowing	33 x 3.3 =	110 Rhp-hr
Harrow, 3 passes	5 x 33 x 3.3 =	50 Rhp-hr
	Total =	160 Rhp-hr

Method B.

Rotary tiller, 1st pass	20 x 3.3 =	66 Rhp-hr
Harrow, 3 passes	3 x 5 x 3.3 =	50 Rhp-hr
	Total =	116 Rhp-hr

These two methods compare well with the values of 60 hours for animal plowing and about 60 animal-hours for harrowing.

Rental rates of the 6-Rhp tiller for 8 hours is about US$9.00 per day or about 90 kg of dry clean rough rice at the farm. Rental rate including operator's wage, fuel, repairs, depreciation, etc., is about US$0.25 or 2.5 kg of palay per machine Rhp-hr, assuming the machine operates only 75 percent of the time or 6 hours/day. The man and animal rental rate is about US$2.50/8 hours but actual work is only about 6 hours. The cost would be about US$0.40/animal Rhp-hr which perhaps explains the rapid increase of hand tractors in Laguna.

Equipment repairs were highest during the first year of operation and consisted mainly of replacing wheel axles and bearings, cylinder heads, contact points, ignition coils, spark plugs, and condensers.

Fertilizer Application

A 100-gallon anhydrous ammonia tank was mounted on the front of a tractor (Fig. 3). Pipe, hose, valves, and applicator blades were installed to permit the application of nitrogen while preparing land with the rotary tiller. Standard blades were used in hard soils to stabilize the tiller and utilize the negative draft. In soft soils, reverse curved skid-like blades were used to reduce draft requirements and to prevent trash building up.

A field experiment was conducted to determine the effect on plant yield of horizontal and vertical placement of anhydrous ammonia. Distance between drilled rows of plants was constant at 50 cm. Fertilizer placement and row relationship varied from 0 to 5, 10, 15, 20, and

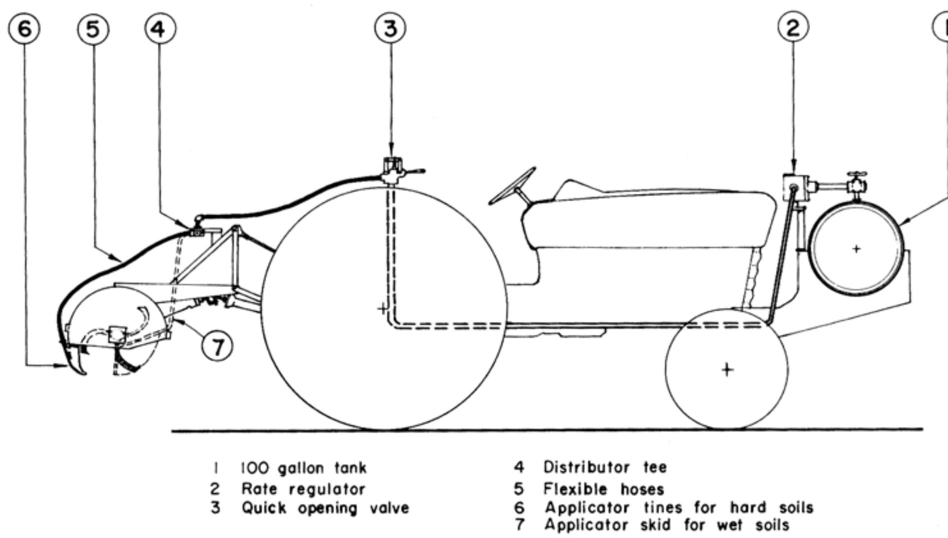


Fig. 3. Anhydrous ammonia applicator.

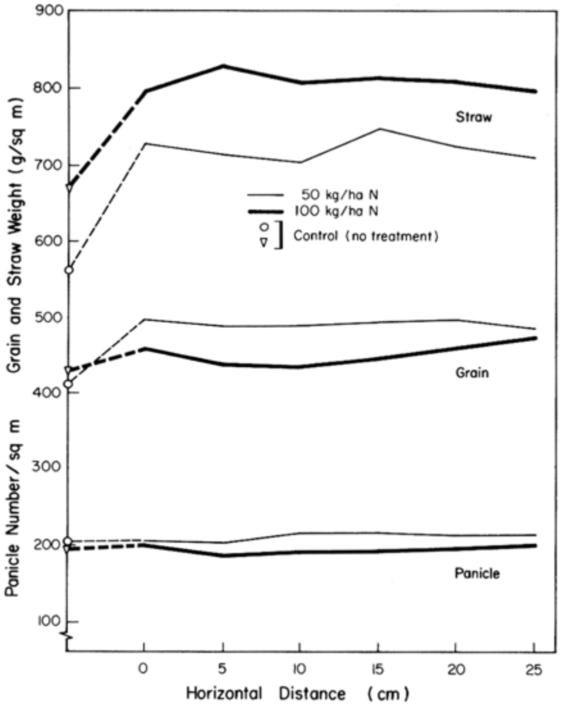


Fig. 4. Relation between distance of ammonia application from drill row to panicle number and grain and straw weight. (Average of five depths of placement.)

25 cm from the row. Figure 4 indicates that horizontal placement up to 25 cm from the row had little effect on the yield. Figure 5 indicates that deep placement up to 25 cm, and probably even deeper, is more effective than shallow placement.

Direct Seeding

Direct seeding in drill rows different distances apart was continued with a seed rate of 200 viable seeds/lin m. Figure 6 shows the reaction of IR9-60 and Fujisaka 5 to row spacing at different dates of planting.

Yield usually decreased at row spacings less than 30 cm due to disease, lodging, and death of lower leaves. Yield also decreased at spacings beyond 70 cm due to lack of complete ground cover to absorb the sunlight. Data from four varieties and three dates of planting indicated that rows should be spaced from 40 to 60 cm apart for most consistent yield on fertile soils. The only planting of Fujisaka 5 almost free from blast gave an excellent yield for the

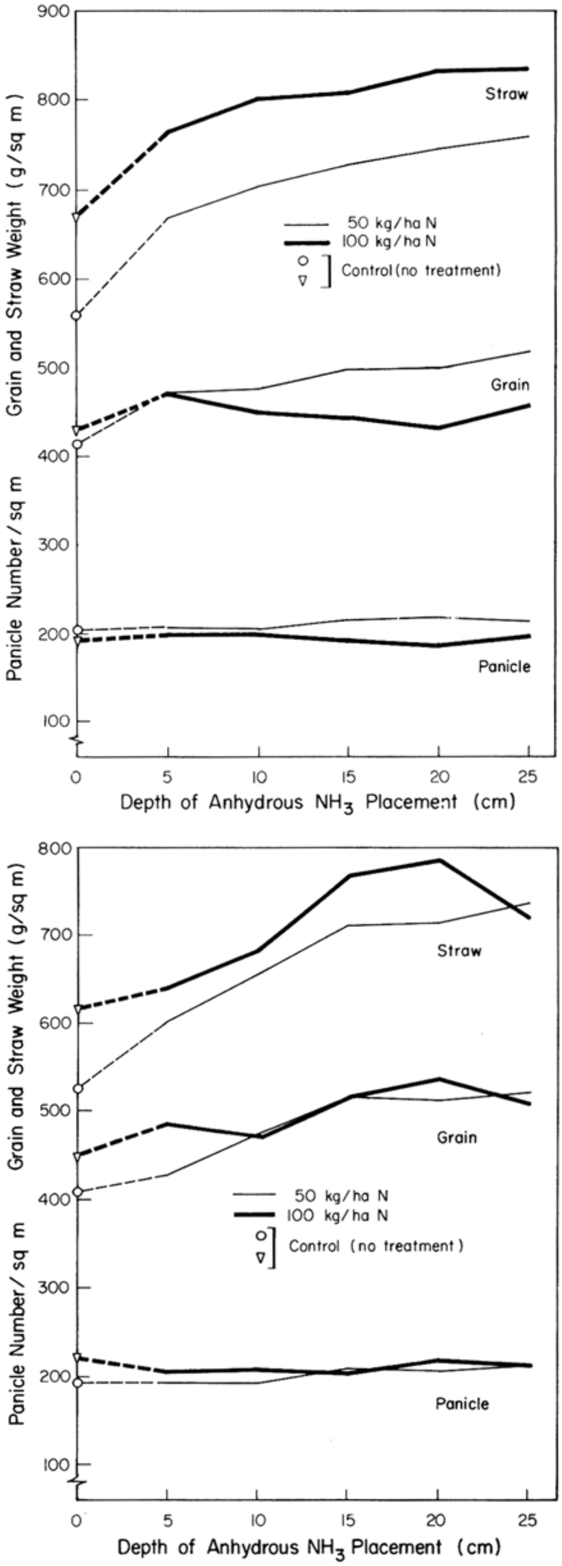


Fig. 5. Relation between depth of anhydrous ammonia application and panicle number and grain straw weight; (a) average of six horizontal spacings, and (b) where placement was midway between rows 50 cm apart.

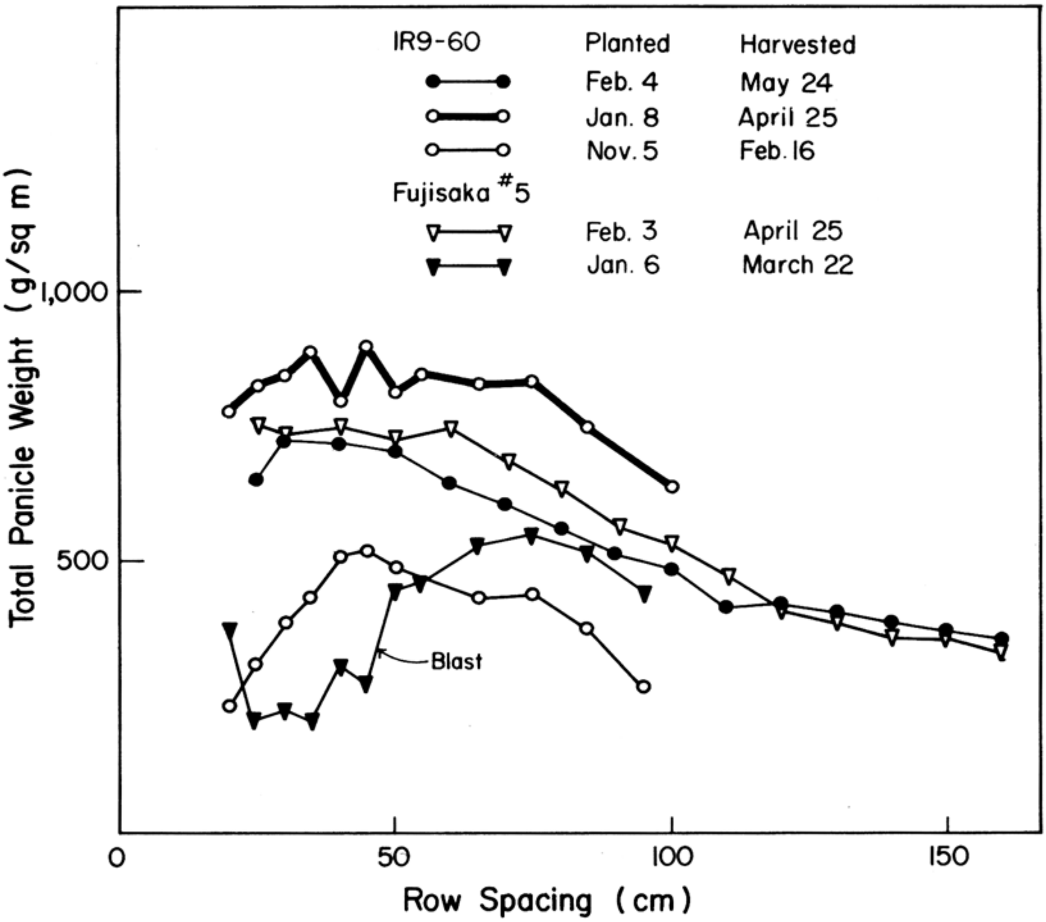


Fig. 6. Relation between total panicle weight and row spacing. Seed rate was 200 seeds/lin m.

February 3, 1966 planting; the yield exceeded the yield of IR9-60 planted on the same date but harvested a month later. The other yields were severely depressed by blast. IR9-60 gave more consistent yields. The highest yield was harvested on April 25 as the weather was more favorable than for the crop harvested on May 24.

A second experiment was started June 30, 1966 with a single row spacing of 50 cm and a variable seed rate of from 25 to 225 seeds/lin m. Figure 7 indicates that rates of 100 to 200 seeds/lin m are adequate, but rates as low as 25 seeds/lin m can still yield well. The heavy seed rate treatments looked much better for the first few weeks but as all rows were kept clear of weeds, extra tillers compensated for the low seed rate. Some lodging occurred at the heaviest seed rate. However, for ease of planting and to insure a good stand, a seed rate of 150 or more seeds/lin m would seem preferable. Panicle number per square meter becomes about constant at that point.

A third experiment was conducted in cooperation with the Varietal Improvement Department to test the yield potential of 50 promising lines when direct seeded on mud in 50-cm rows at 200 seeds/lin m. Most varieties grew well and the average yield slightly exceeded the average yield for the same lines grown under transplanted conditions in the plant breeder's plots (Fig. 8). No direct comparison is possible as the cultural practices and field conditions were not the same. However, the data will support the hypothesis that:

(1) Many varieties yield as well when direct seeded in 50-cm drill rows as when transplanted.

(2) Early maturing and low-tillering varieties will probably yield better when direct seeded.

(3) The best varieties yield well under both conditions.

Hand weeding of the 50-cm rows was found to be easier than rotary weeding. The worker straddled one row and weeded two middles or 100 cm at one pass. When the push-type weeder was used, it was necessary to make several passes and then still hand weed within the row.

The experimental data seem adequate to justify the design of a multi-row direct seeder for use on puddled mud. A row width of 50 cm and a seed rate exceeding 100 seeds and up to 300 seeds/lin m would seem feasible. Almost any seed metering device should be adequate provided the seeds were dropped, and stayed in position on top of the mud. A prototype direct seeder was assembled by mounting 6 seeders on a levelling board behind the 300-cm tiller. The seeds were placed reasonably well on the first swath but when a second swath was made, the mud and water from the tractor wheels disturbed the first swath. The seeder units were then mounted on a 125-mm diameter aluminum irrigation pipe and pulled behind an animal. The animal's pace resulted in a seesaw motion of the pipe and, consequently, wavy rows. An attempt to mount the seeders on a 5-Rhp hand tractor was also disappointing as the depth to the hard pan was uneven and the unit was difficult to handle. Future plans are to use a 400- to 1,000-cm wide planter with 8 to 20 row seeders mounted on a 35- to 45-Rhp standard tractor. The success of the unit will depend on the development of a sensing device to maintain the unit level as discussed under the first section on land preparation. This unit should be wide enough to eliminate the wave action from the wheels disturbing the previous swath, sensitive and stable enough to level out the wheel tracks, maintain a straight line, and deposit the seeds on top of slight ridges.

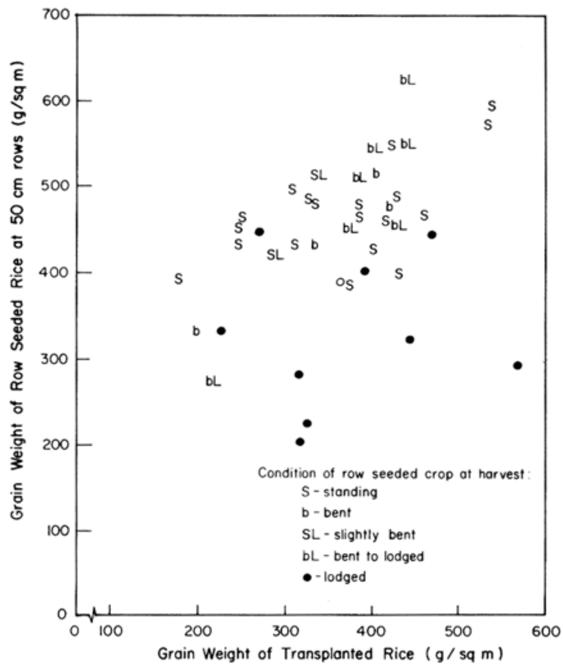


Fig. 8. Comparison of grain yields obtained from row-seeded crops with those of the same varieties grown in the same season but transplanted.

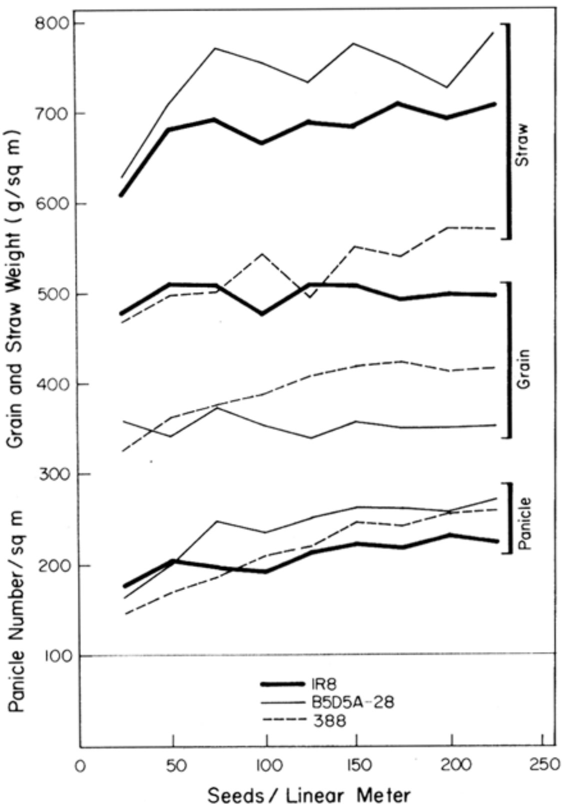


Fig. 7. Relation between seeding rate and panicle number and grain and straw weight.

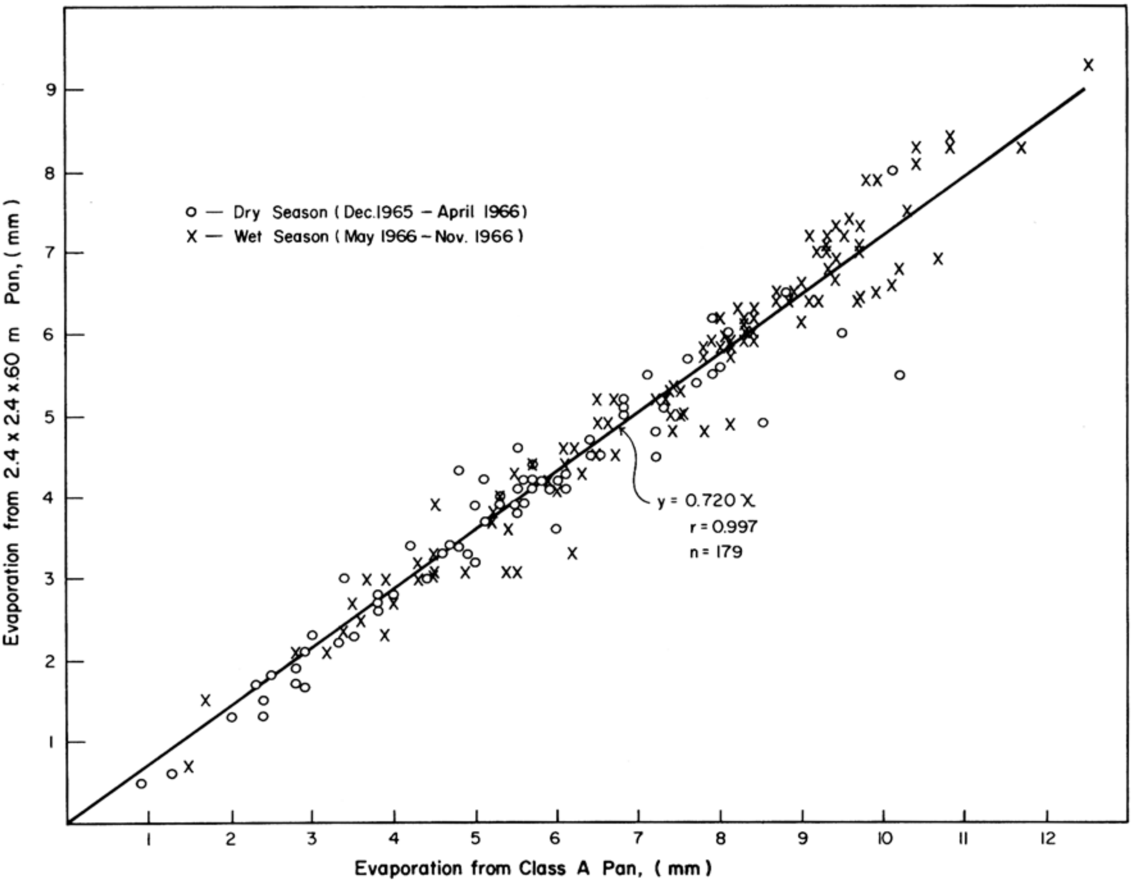


Fig. 9. Relation between evaporation recordings as measured by two types of evaporimeters.

Irrigation

Evaporation

A standard, 4-foot diameter U.S. Weather Bureau Class A evaporation pan was installed on a level grass sod near the 2.4 x 2.4 x .60 m sunken pan which was reported in 1964 and 1965.

Stilling wells and a micrometer hook gauge were used to indicate changes in water level in the Class A pan and in one of the 2.4 x 2.4 x .60 m pans. A water level recorder was used in the other sunken pan. Evaporation from the 2.4 x 2.4 x .60 m pan was taken as the average of the hook gauge and water level recorder readings.

In Fig. 9 the dry season (December, 1965 to April, 1966) and the rainy season (May, 1966 to November, 1966) data are represented by 111 and 68 points, respectively. Days with more than 2 mm rain were excluded. With the Class A pan as the X-axis and the 2.4 x 2.4 x .60 m pan as the Y-axis, linear regression equations $y = 0.724x$ and $y = 0.707x$ for the dry and wet seasons, respectively, were obtained. The combined dry and wet season data (December, 1965 to November, 1966) were represented by $y = 0.720x$.

Plant growth and solar radiation

An experiment was conducted during the dry season to relate solar radiation and dry matter production. Knowledge of this relationship is necessary to calculate the water necessary for plant growth and dissipation of the excess heat due to the solar radiation. Three plots each of four varieties were transplanted January 28. One plot of Fujisaka 5 was spaced at 5 x 20 cm

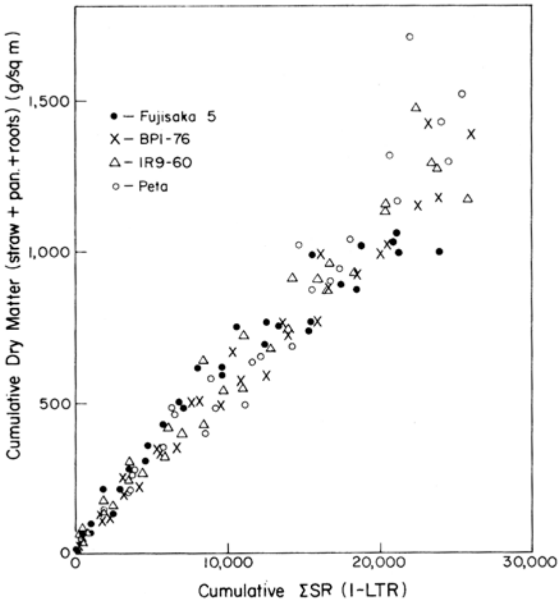


Fig. 10. Relation between accumulated intercepted solar radiation and dry matter accumulation.

and two plots at 10 x 20 cm, while all IR9-60, Peta, and BPI-76 plots were spaced at 20 x 20 cm. Preliminary analysis of the data (Fig. 10) indicates that approximately .060 g/sq m of dry matter was produced per g-cal/sq cm of solar radiation intercepted by the plant. Land area and time have a productive value only when a healthy plant population with a high average (1 — LTR) is exposed to solar radiation and cooled and nourished by water. The (1 — LTR) value of light intercepted depends upon the dry matter distribution on a unit area and not necessarily upon the LAI of healthy leaves. LAI and total dry matter are highly correlated for the first leaves, but as death of leaves occurs the two are not related. Dead or diseased leaves and stems may intercept as much sunlight as productive leaves. Data from the four varieties indicate that an equation may be developed to relate LTR and plant dry matter which may be as useful as the LTR = e^{-KLAI}

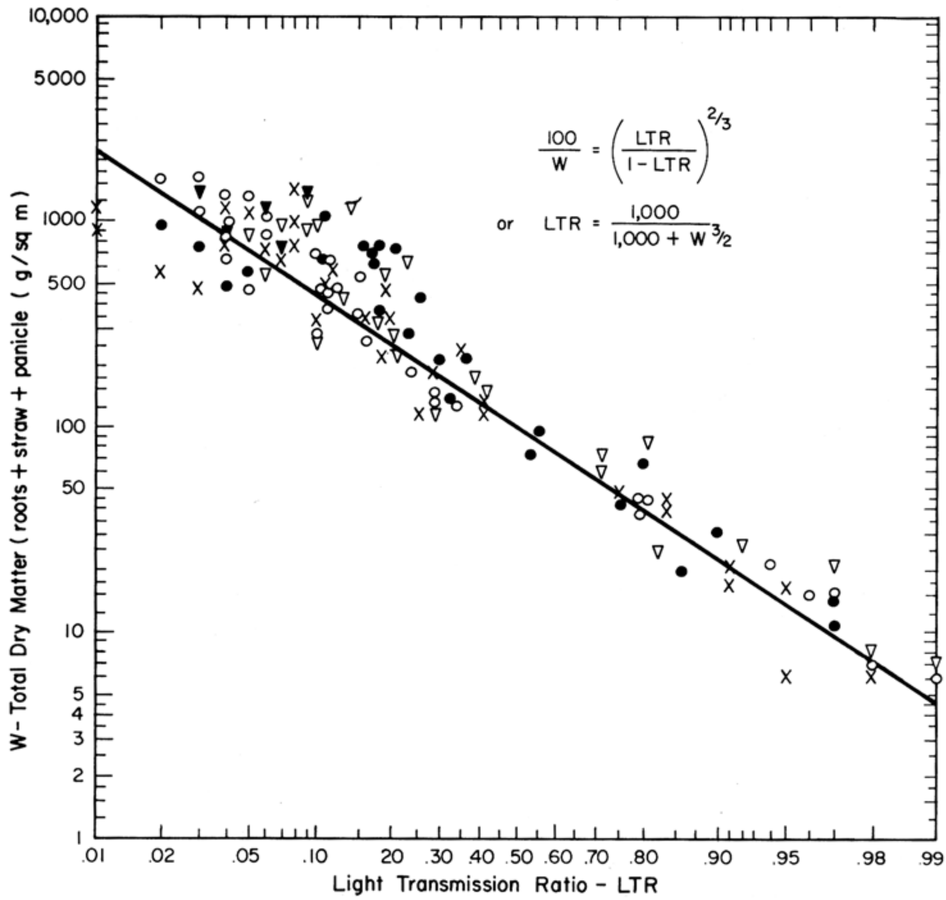


Fig. 11. Relation between light transmission ratio and total dry matter.

equation that is so widely used. Engineering analysis of plant growth would be possible if the following relationships were known with some accuracy:

1. Solar radiation intercepted by the plant to dry matter production. Institute field measurements indicate a range of from 0.045 to 0.075 with an average net dry matter accumulation of about 0.06 g/sq m per g-cal/sq cm (Fig. 10). The slope varies due to dead leaf area, respiration, and error in measurement.

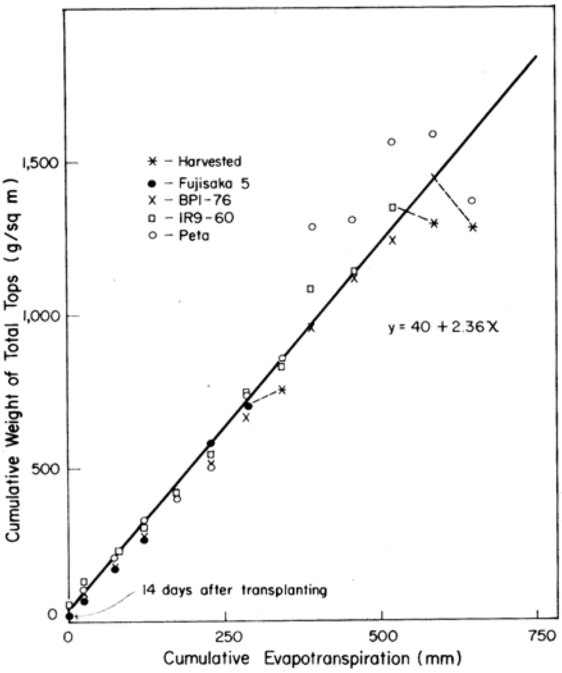


Fig. 12. Relation between cumulative evapotranspiration and cumulative weight of total top growth.

2. Dry matter g/sq m to LTR. Institute field values are shown in Fig. 11. The data plot a straight line on both "Logit" and "Probit" paper. Fifty percent of the sunlight is "killed" or intercepted by 60 to 120 g/sq m of dry matter. A tentative equation of

$$\frac{100}{W} = \left(\frac{LTR}{1 - LTR}\right)^{2/3} \quad \text{or} \quad LTR = \frac{1000}{1000 + W^{3/2}}$$

seems to be a good graphic fit.

3. Solar radiation to maximum dry matter accumulation before lodging occurs. This relationship is important in estimating the maximum dry matter that can accumulate before the photosynthesis accumulation is halted and starts to decrease. Present recorded accumulated dry matter totals in the field of 1,200 to 1,800 g/sq m seem to be the upper limit in the wet and dry seasons respectively. These totals may be made up of all straw or of grain and straw. The grain : straw ratio and the maximum level would seem to control grain yields. If the ratio is 1 to 1 then maximum grain yields are 6 to 9 ton/ha.

Plant growth and evapotranspiration

Four varieties were planted in plots both inside and outside the 400 sq m plot from which evapotranspiration was measured in 1964 and 1965. Each variety had a quadrant of 100 sq m in the evapotranspiration plot. No plants were harvested from these plots but daily evapotranspiration was recorded as reported in the 1964 and 1965 Annual Reports. In Fig. 12, the cumulative values of the crop cuts in the outer plots are compared to the cumulative values of evapotranspiration. There appears to be a linear relationship from 14 days after transplanting until harvest with 424 g of water lost per g of plant tops produced. However, the curve would be sigmoid if the first 14 days were included. The 424 g of water per g of dry matter indicates that rice uses water efficiently.

A Survey of Farm Operations in Central Luzon*

In May, 1966, a field survey was initiated to collect data on the farm operations sequence, and water, soil and crop conditions by sampling sites along the major highways of Central Luzon. Following an exploratory trip, it was decided to use kilometer posts as reference points and to make weekly observations some 25 m from the road edge. Finally, 145 survey sites were selected and, where practicable, located on alternate sides of the road at successive sites. Observations on land preparation, source of power, stage of crop, and weed, pest, and disease infestation have been made weekly since May, 1966. Harvest samples are being collected from a 4-sq m area at each site.

* This survey is a portion of USAID Contract No. AID/csd-834 for "Research on Farm and Equipment Power Requirements for Production of Rice and Associated Food Crops in the Far East and South Asia."

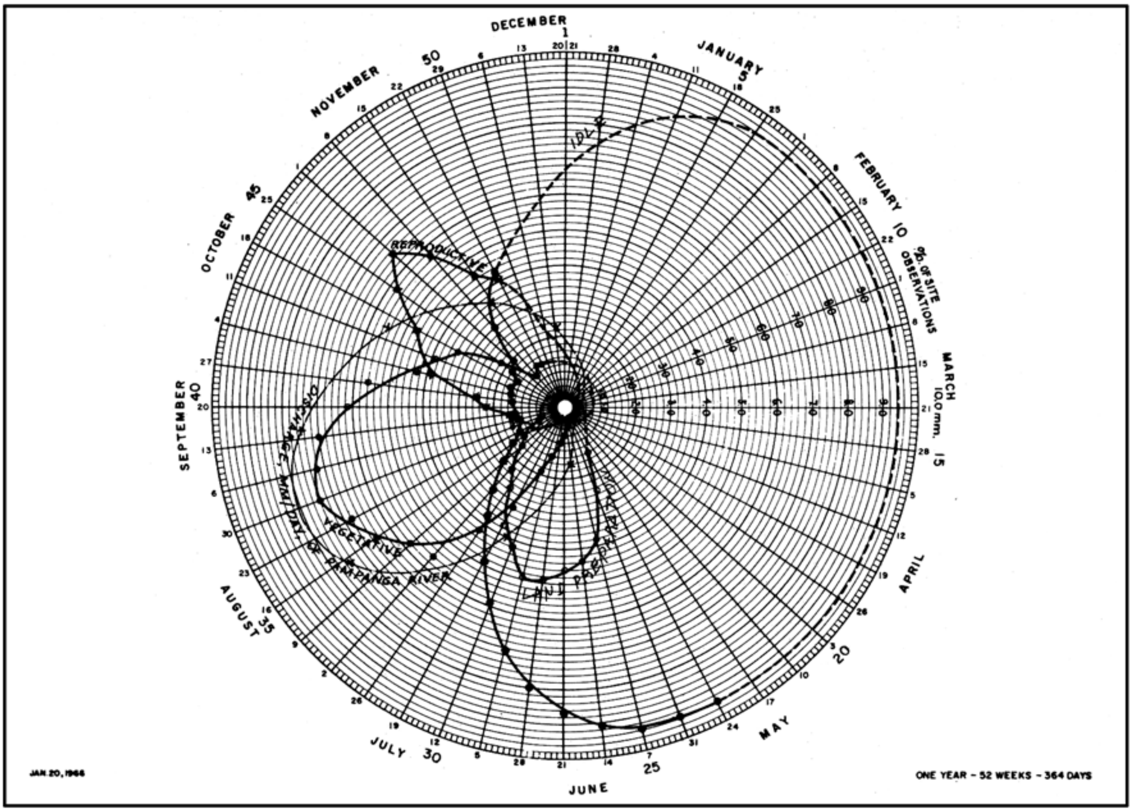


Fig. 13. Annual cycle of land use and flow of the Pampanga River, Central Luzon, 1966.

A summary of observations made each week is plotted as shown in Fig. 13. Discharge of the Pampanga River, the largest one in Central Luzon, is also plotted as an indication of surplus rainfall in the area. It is interesting to note that the river discharge pattern coincides very well with the vegetative phase of the rice crop. Lack of adequate irrigation facilities forces the farmer to a single crop which coincides with the rainy season. Additional analysis will be made in which irrigated areas are separated from non-irrigated areas to show the change in the sequence of operations. The future of tropical rice production will probably be on irrigated areas with continual cropping. The sharp peaks would be replaced by concentric circles.

Agricultural Economics

The research program in Agricultural Economics dealt with factors affecting the growth of rice production at both national, or regional, and farm level. In the first section of this report, sources of output growth in Taiwan are compared with those in Central Luzon and Central Thailand. The second section is concerned with productivity and efficiency in rice production. Experimental and farm survey data were analyzed to measure: (1) rice production costs and income potentials under existing and improved levels of technology, and (2) interaction between labor intensity, cultural practices and yields. The final section reports on the investigation of changes in rice output due to changes in price for the various regions of the Philippines.

Research on Sources of Output Growth*

The 1964 Annual Report examined historical trends and regional differences in rice production, area and yield in the Philippines. A similar analysis for Thailand was reported in 1965. Taiwan is included this year and a comparison is made between rates of output growth in all three countries. Two countries, the Philippines and Thailand, are hopefully just now on the threshold of a yield take-off. The third country, Taiwan, began its yield take-off in the early 1920's. It is important, therefore, to examine the factors which contributed to the growth in yield achieved by Taiwan.

Table 1. Changes in production, area and yield of paddy (rough rice) in Taiwan, 1900-1964.*

Year	Arable land (ha)	Percent of arable land: Irrigated	Percent of arable land: Double-cropped	Rough rice (ha)†	Percent total rice land: Ponlai	Percent total rice land: Non-glutinous	Percent total rice land: Glutinous	Percent total rice land: Upland	Yield (mt/ha)‡	Total production (1,000 m tons)‡
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1900	347,309	56	N.A.	325,653	0	88	6	6	1.35	407
1905	624,501	49	N.A.	447,432	0	85	5	10	2.00	895
1910	674,100	49	N.A.	456,276	0	86	7	7	1.88	858
1915	700,080	49	N.A.	491,089	0	84	8	8	2.00	982
1920	749,419	49	33	500,169	0	81	10	9	1.99	995
1925	775,468	48	34	550,835	12	65	16	7	2.40	1322
1930	808,329	49	36	614,390	21	59	14	6	2.46	1511
1935	831,003	58	38	678,629	43	38	13	6	2.76	1873
1940	869,456	62	38	638,622	51	39	6	4	2.54	1622
1945	816,017	62	37	502,018	52	45	1	2	1.83	919
1950	870,633	61	37	770,262	47	44	2	7	2.65	2041
1955	873,002	61	38	750,739	51	41	2	6	3.09	2320
1960	869,223	60	38	766,409	61	34	2	3	3.58	2744
1964	882,239	60	38	764,935	66	30	2	2	4.22	3228

* Source: Taiwan Food Statistics Book, 1965.
† One crop counted as 1 hectare.
‡ 1 kg brown rice=14,358 kg of paddy.

Rice production, area and yield in Taiwan

Table 1 shows hectarage, yield and total production figures for Taiwan rice. Two important elements contributing to the increase in total production have been irrigation and double cropping. The percentage of irrigated and double-cropped land is shown in columns 3 and 4. Another factor leading to steady yield increases was varietal improvement (with concomitant increases in fertilizer and insecticide application). The introduction of high-yielding ponlai (japonica) varieties began in 1922. The percentage of riceland planted to the major types is shown in columns 6 through 9 of Table 1. The rapid increase in ponlai hectarage in the 1920's and 1930's is indicated more clearly in Fig. 1. The shortage of fertilizer and other inputs during the war years encouraged a rapid shift back to the non-glutinous varieties. The continued popularity of the non-glutinous varieties in the postwar period can be explained by examining Fig. 2. During this period all lowland varieties of rice have shown steady increases in yield per hectare. Varietal improvement in the ponlai group has been matched in other groups (as for example, the non-glutinous Taichung (Native) 1). Only the upland varieties have shown no yield improvement, and in fact there has been little effort in this direction.

* Some of the materials presented in this section are taken from S. C. Hsieh and V. W. Ruttan, "Technological, Institutional and Environmental Factors in the Growth of Rice Production: Philippines, Thailand and Taiwan," which is expected to be published in Stanford University, *Food Research Institute, Studies*.

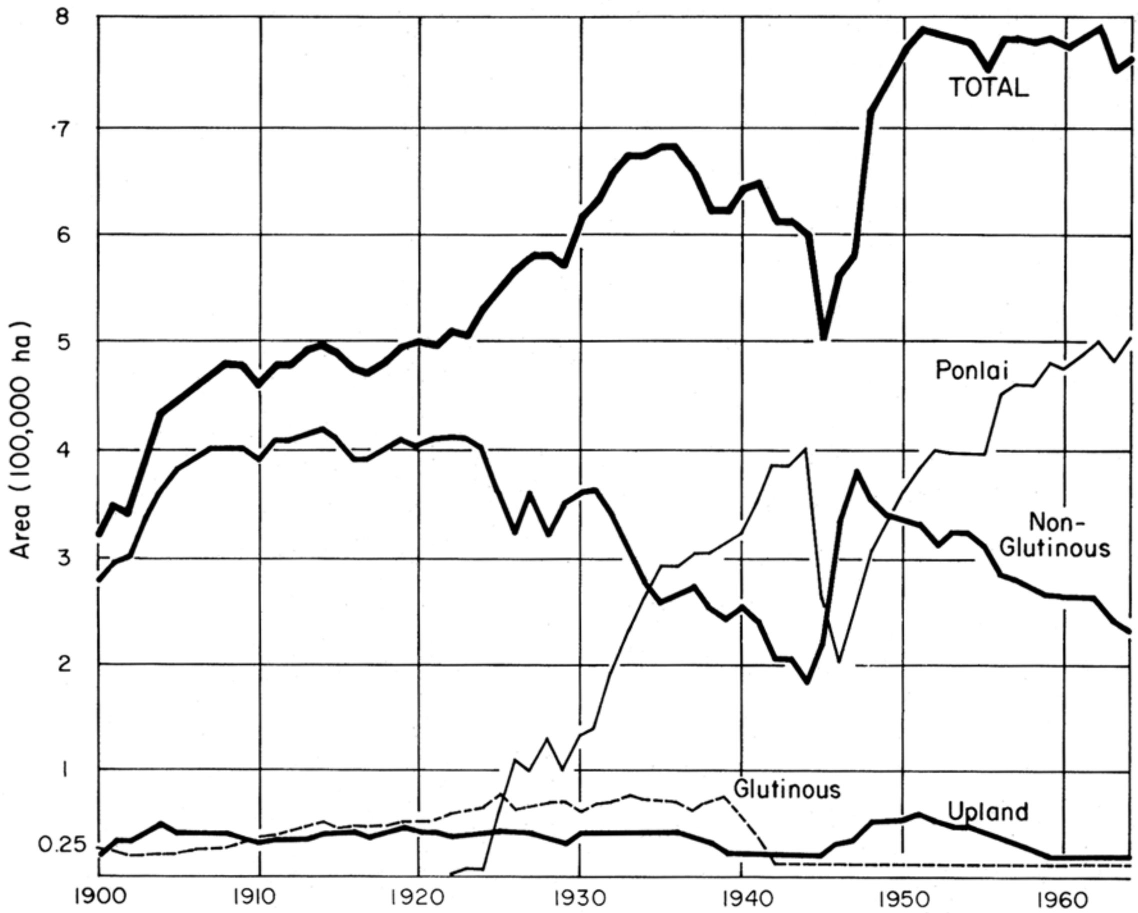


Fig. 1. The area of rice production in Taiwan (1900 to 1964).

Yield differences among regions in Taiwan

In Taiwan, two crops of rice per year are grown in most areas. The rice crop harvested before August 15 is considered the first dry-season crop and that after August 15, the wet-season crop. Yields for the first crop are usually considerably higher than for the second crop.

Figure 3 shows the variation in rice yield for the hsiens (or prefectures) in Taiwan. The low-yielding area is in the north, and the high-yielding ones are in the central and southernmost part of the island. Differences in yield for the six food districts shown on the map are due to a number of factors including: (1) percentage of land in first and second crop rice, (2) percentage of land in ponlai vs other varietal types of rice, and (3) percentage of irrigated paddy, rainfed paddy and upland. The Taiwan figures do not permit distinction between irrigated and rainfed paddy. However, the proportion of each region represented by the other factors is shown in Fig. 4. Using the national hectarage distribution as a base (upper right-hand corner of Fig. 4), the yields for each region are now standardized or adjusted for yield differences due to the three factors mentioned above. The actual and standardized yields (3-year average, 1961-1963) are shown in Table 2. This table indicates that yield differences between regions are more pronounced after standardization. For example, had the hectarage distribution between: (1) first and second crops, (2) varietal types, and (3) paddy vs upland, been the same for the Northern Taipei Food District and the Southern Kaohsiung Food District, the yields in the Kaohsiung District would have been more than 50 percent

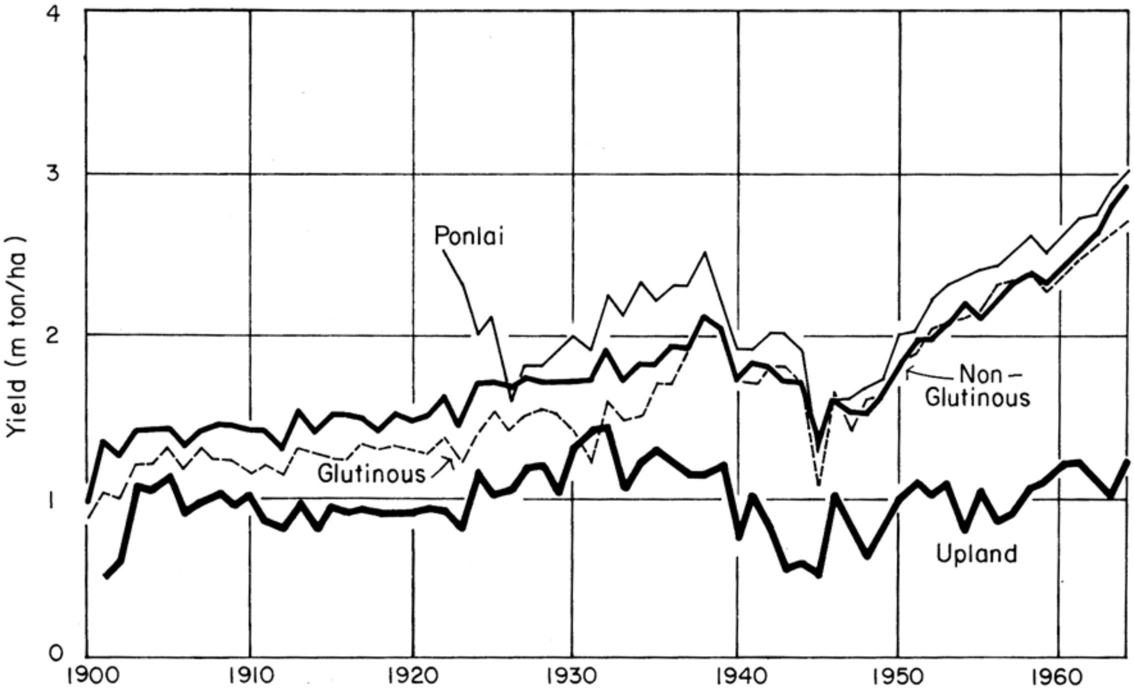


Fig. 2. Yield of paddy rice and upland rice in Taiwan (1900 to 1964).

higher (4,378 kg/ha vs 2,864 kg/ha). The greater variability of standardized estimates in Taiwan contrasts with the earlier experience for the Philippines and Thailand where standardization resulted in a convergence of regional estimates.

Table 2. Effects of differences in regional production patterns on regional average yield in Taiwan (1961-1963).

Region	Actual yield		Standardized yield	
	Kg/ha rough rice	Index	Kg/ha rough rice	Index
Taiwan	3520	100.00	3520	100.00
Taipei	2965	84.23	2864	81.36
Hsinchu	3158	89.71	3021	85.83
Taichung	3904	110.92	3785	107.53
Tainan	3530	100.30	3762	106.90
Kaohsiung	3793	107.76	4378	124.38
East Taiwan	3224	91.61	3224	91.61

Regional yield comparison between the Philippines, Thailand and Taiwan

A comparison in this section is made between three major rice-producing regions: (1) Central Luzon in the Philippines, (2) Central Plain of Thailand, and (3) Taiwan. Taiwan is treated as a single region because of the relative uniformity of yields throughout that country, and because the entire rice-growing area is approximately equal to that of Central Luzon and is less than a third of the area represented by Central Thailand.

Table 3 shows a comparison of yield of rough rice in these three regions from 1953/54 to 1963/64. The yields in Central Luzon and Central Thailand have been approximately 50 percent of those of Taiwan. These yield ratios have remained remarkably stable over the past decade, indicating that yields in all the regions have been growing at about the same rate.

Table 4 is similar to Table 3 with the exception that Taiwan yields are reported for the period 1924/25 to 1934/35. This is the period of Taiwan's yield "take off" when the ponlai varieties were being rapidly introduced (see Fig. 2). There are two important factors to observe. First, even in this early period, yields in Taiwan were more than 25 percent higher than they are today in the other two regions. Second, the comparison of yield ratios indicates that the trend in growth rate is as rapid today in Central Luzon and Central Thailand as it was in Taiwan in this earlier period.

It would appear from this comparison that the first two regions have entered their own yield take-off stage. However, a closer examination of the factors contributing to yield increases in each region suggests that this may not necessarily be the case. First, consider Taiwan.

The infrastructure needed to support a rapid yield increase was already highly developed in Taiwan by the early 1920's. Approximately 50 percent of the rice-growing area was irrigated. The irrigated area increased to 60 percent of the total in the period 1953/54 to 1963/64. This compares with irrigated areas of approximately 35 percent in Central Luzon and less than 45 percent in Central Thailand for this latter period. An even more meaningful comparison can be made between double cropped areas: 38 percent in Taiwan vs 12 percent in Central Luzon, and

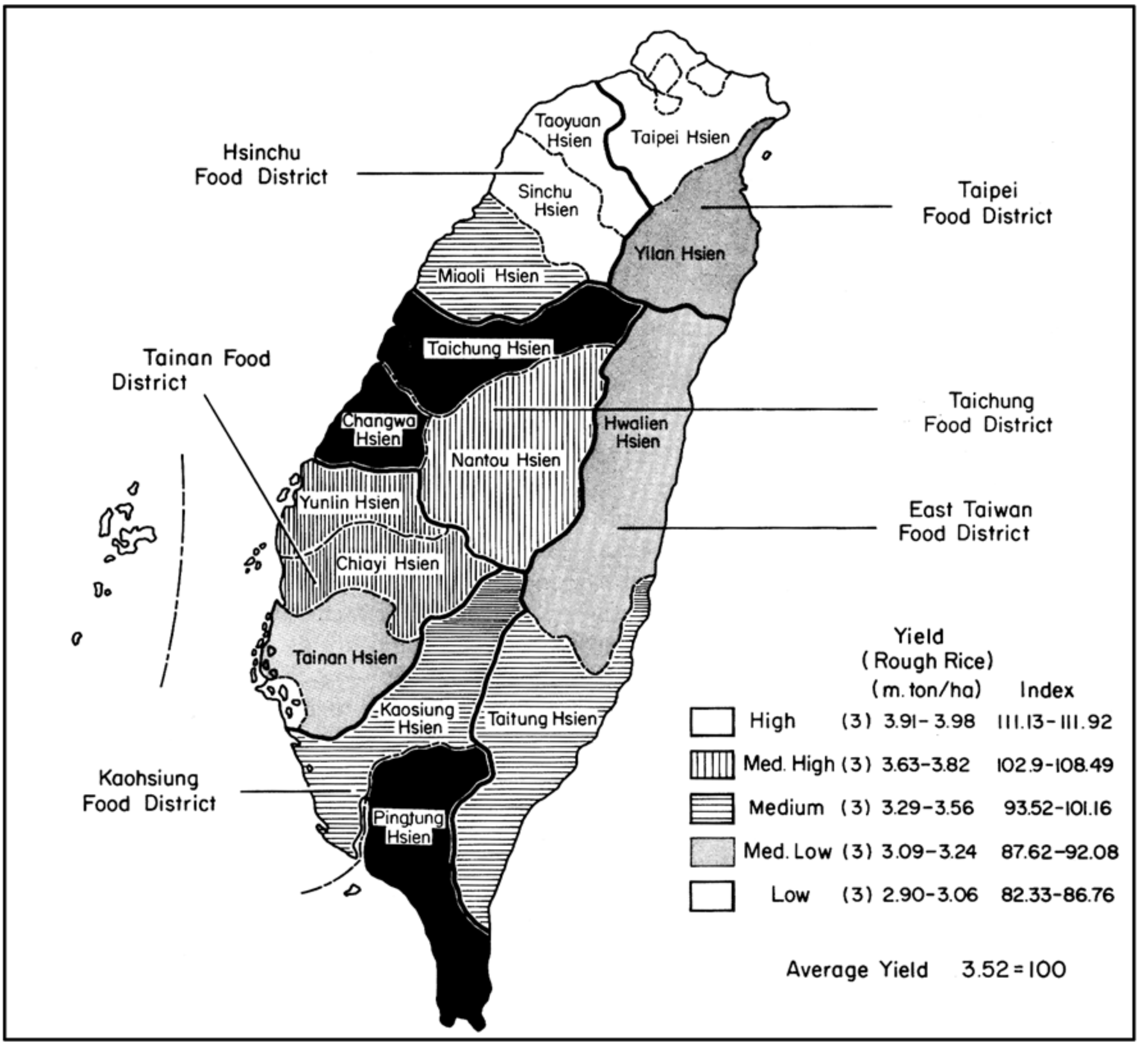


Fig. 3. Distribution of rice yields among hsiens, 1961-1963 average (Taiwan).

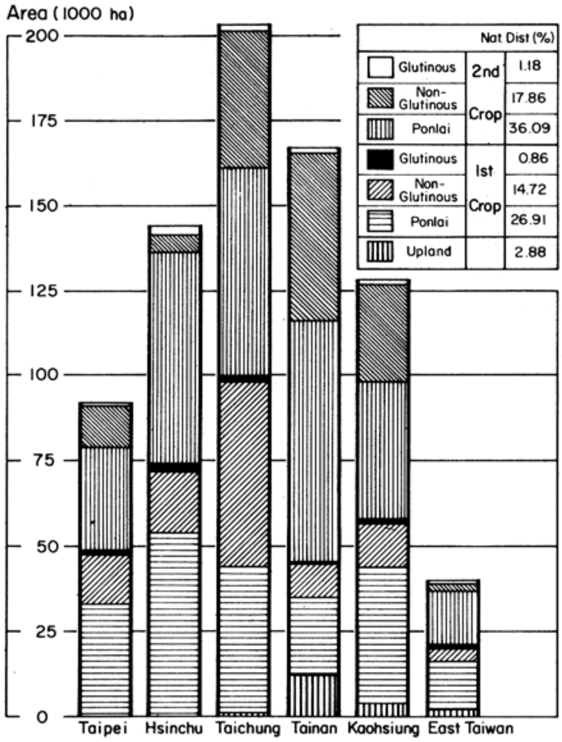


Fig. 4. Distribution of rice area by food districts (Taiwan, 1961-1963).

less than 1 percent in Central Thailand. Taiwan also had the advantage of a system of farm cooperatives organized with government support that could rapidly extend the improved ponlai varieties and the necessary complementary inputs such as fertilizer. The first farmer's cooperative was established in 1900. The institutional structure of Taiwan was further strengthened by the introduction of irrigation associations beginning in 1922, and by land reform in the early 1950's.

The yield increases that have occurred recently in Central Luzon, on the other hand, appear to be due in large part to a sharp decline in hectarage. Between 1953/54 and 1963/64 hectarage planted to rice dropped by more than 20 percent. Some of this decline can be explained by the competition between rice and sugar cane which has resulted in the shift of marginal rice land to sugar cane production.

The yield trends in the Central Plain of Thailand have been influenced by yet another phenomenon, weather. A relatively high variation in yield from year to year can be explained by the amount of excessive flooding in this region. Crop damage due to flooding was very light in the early 1960's in contrast to the mid- and late 1950's.

Both in Central Luzon and Central Thailand, some of the yield increase may have been due to adoption of better varieties, use of more fertilizer and other inputs, but these do not appear to have been the dominant factors contributing to recent yield increases.

Strategy for increasing rice production in Southeast Asia

The analysis of the role of environmental, technological, and institutional factors in accounting for yield differences among areas raises some important questions. What is the appropriate strategy for increasing rice production in the Philippines, Thailand and other Southeast Asian countries which have depended previously on increases in area for growth of rice production? It seems clear that the Philippines and Thailand cannot simply repeat the experience of Taiwan. In Taiwan, development of infrastructure, technological change and institutional innovations have moved hand in hand for nearly half a century. In the Philippines and Thailand, agricultural development efforts following World War II have concentrated heavily on institutional development to the neglect of varietal improvement. Extension and farm cooperative organizations were developed without the basic technology, inputs, and knowledge required to raise yields. Their development in this sense was premature. Efforts are now being made to close the technological gap by the introduction of high-yielding, fertilizer-responsive rice varieties. However, the irrigation gap cannot be closed except by concentrated effort over a much longer period of time. Thus to a large extent a country's potential for increasing yields in the relatively short run is limited by the capacity of its irrigation system. The speed at which irrigation can be developed will depend upon a number of factors including: (a) the potential for developing a low-cost system, and (b) the degree to which small ground water

Table 3. Comparison of yield of rough rice in Central Luzon, Central Thailand and Taiwan, 1953/54-1963/64 (m ton/ha rough rice).

Year	Central Luzon (1)	Central Thailand (2)	Taiwan (3)	Ratio (1):(3)	(2):(3)	(1):(2)
1953/54	1.33	1.61	2.86	0.47	0.56	0.83
1954/55	1.50	1.38	2.82	0.53	0.49	1.09
1955/56	1.61	1.53	3.80	0.42	0.40	1.05
1956/57	1.61	1.60	3.08	0.52	0.52	0.01
1957/58	1.41	1.30	3.19	0.44	0.41	1.08
1958/59	1.51	1.56	3.14	0.48	0.50	0.97
1959/60	1.39	1.46	3.28	0.42	0.45	0.95
1960/61	1.57	1.59	3.39	0.46	0.47	0.99
1961/62	1.80	1.51	3.49	0.52	0.43	1.19
1962/63	1.82	1.73	3.70	0.49	0.47	1.05
1963/64	1.86	1.86	3.86	0.48	0.48	1.00

Sources: Department of Agriculture and Natural Resources, Philippines, and Taiwan Food Statistics Book, 1965, Taiwan Provincial Food Bureau.

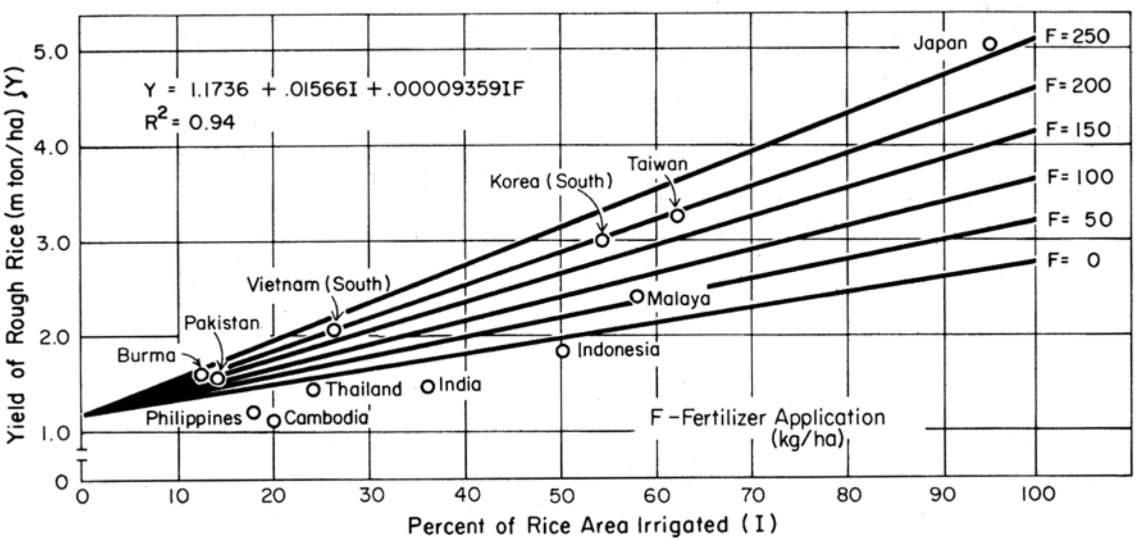


Fig. 5. Relationship between yield per hectare of rough rice and percent of rice area irrigated in selected countries (5-year average, 1959/60-1963/64).

Table 4. Comparison of yield increases of rough rice in Central Luzon, Central Thailand (1953/54-1963/64) and Taiwan (1924/25-1934/35) (m ton/ha rough rice).

Year	Central Luzon (1)	Central Thailand (2)	Year	Taiwan (3)	Ratio	
					(1):(3)	(2):(3)
1953/54	1.33	1.61	1924/25	2.19	0.61	0.74
1954/55	1.50	1.38	1925/26	2.06	0.73	0.67
1955/56	1.61	1.53	1926/27	2.22	0.73	0.69
1956/57	1.61	1.60	1927/28	2.18	0.74	0.73
1957/58	1.41	1.30	1928/29	2.14	0.66	0.61
1958/59	1.51	1.56	1929/30	2.24	0.67	0.70
1959/60	1.39	1.46	1930/31	2.22	0.63	0.66
1960/61	1.57	1.59	1931/32	2.52	0.62	0.63
1961/62	1.80	1.51	1932/33	2.32	0.78	0.65
1962/63	1.82	1.73	1933/34	2.56	0.71	0.67
1963/64	1.86	1.86	1934/35	2.52	0.74	0.74

Source: See footnote, Table 3.

pump irrigation can be used as opposed to major gravity flow systems.

The comparison between technological change and water resource development is extended to the other countries in Southeast Asia in Fig. 5. This figure shows the percent of rice area irrigated on the horizontal axis and the yield per hectare of rough rice on the vertical axis. Twelve countries are plotted. Based on data for each of these countries an equation was devised showing yield (Y) as a function of irrigation (I) and fertilizer-irrigation interaction (IF). This equation is shown at the top of Fig. 5. Although fertilizer observations are used, it is obvious that the fertilizer variable is a proxy for those items previously referred to as technological change or improved cultural practices (varietal improvement, fertilizer, chemicals, etc.) which are highly complementary inputs.

The particular form of the equation was used because it was observed that some countries had increased rice yields by emphasis on irrigation (e.g. Indonesia) while others had increased yields by combining technological change with water resource development (e.g. Korea). Based on the experience of these 12 countries the lines drawn on the graph express the potential for increasing yields per hectare given the percentage area irrigated. For example, it is apparent that countries such as the Philippines, Thailand and Indonesia can benefit immediately from the introduction of high-yielding, fertilizer-responsive rice varieties. However, given the present level of irrigation development, the national yield potential for the Philippines and Thailand is around 2 m ton/ha, while the potential for Indonesia is 3 m tons. The estimating procedure is admittedly crude since (1) it ignores many of the factors which affect yield differences between countries, and (2) the quality of irrigation varies greatly from country to country. Nevertheless, Fig. 5 does emphasize the important interrelationships between irrigation and technology which are fundamental in the formulation of a strategy for increasing rice production.

The problem for any given country is how to organize to achieve the complementary investments in: (a) the research and development required to produce the high-yielding, fertilizer-responsive rice varieties, (b) the physical infrastructure (irrigation, drainage, flood control) needed to achieve the potential productivity gains inherent in the results of research, and (c) the institutional structure needed to extend the research results to the barrio or village level and to extend along with this the other essential factor inputs such as fertilizer and chemicals. Figure 5 indicates that the emphasis given to any one of the above three elements in the short run is likely to differ from country to country depending on the present stage of development of these three aspects.

The steps that must be taken to organize research programs to produce the biological, chemical and engineering technology necessary to achieve increases in yield are becoming better understood. It is increasingly recognized that there is little if any improved rice production technology from the United States, or Japan or even Taiwan that can be immediately transferred to Southeast Asia. The ecology of the monsoon tropics rules out the transfer of existing rice production technology. What can be transferred is: (a) the propensity and the capacity to focus the scientific manpower and other resources on technical problems of economic significance, and (b) the skill that comes from having solved similar problems although in a different environment.

The magnitude of the investment required to realize the production potential generated by this research effort is much less clearly understood. This investment must be made in three major areas: (1) irrigation, drainage and flood control, (2) production of fertilizer and chemicals, and (3) development of trained manpower. To date, in many countries, the public sector of the economy has assumed major responsibility in areas (1) and (3), while the private sector has provided the bulk of the investment in area (2). However, the performance of the public sector appears to vary widely from country to country, raising doubts as to where the emphasis should be placed in an optimum development strategy. Considerable investment has been made, for example, to train manpower, with apparently little effect. This stems in large part from a failure to recognize that the skills needed to improve rice production must be learned in the paddy. Raising the potential productivity (and concomitantly the potential return) through the investment in research could provide the private producers with the incentive to invest in irrigation and trained manpower along with cash inputs such as seed, fertilizer, and chemicals.

The strategy emphasized here differs sharply from the strategy suggested by some development economists. These economists have suggested that initial emphasis should be placed on infrastructure followed by innovations that do not require large increases in the use of purchased inputs. They recommend emphasis on such innovations as high-yielding varieties, improved crop rotation, optimum time of planting, and better seasonal distribution of the workload. However, the real production potential is realized only by combining these changes with fertilizer and pest control in the tropical rice-producing regions of South and Southeast Asia. Unfortunately, investment in research and development has not opened up a new low-cost route to the rapid growth of agricultural output in the rice-producing areas of South and Southeast Asia.

Projected sources of output growth for the Philippines, 1966 to 1980

The previous section indicates the broad strategy that must be followed if productivity is to be increased to meet the rising demand for food. In this section projections have been made to indicate the magnitude of the output increase and the sources of output growth in the Philippines.

First, consider the growth in demand for food. Ignoring possible inflationary effects, this growth stems from two sources: population and income. The growth rate for food demand in four countries in Asia from 1950 to 1960 was as follows: Japan 5.6, Taiwan 5.7, Philippines 4.5 and Thailand 4.9.* These figures from countries

* U.S. Department of Agriculture, E.R.S., Foreign Agricultural Economic Report No. 27, *Changes in Agriculture in 26 Developing Nations, 1948 to 1963*, p. 4. Table 2.

at different stages of development suggest that in developing Asian economies the growth in demand for food does not decline at least for a considerable period of time. If the demand for food grew at 5 percent per year for the Philippines, the quantity demanded would double in the 14-year period from 1966 to 1980.

This demand must be met on the supply side by: (a) added hectarage, (b) added yield per hectare, or (c) some combination of increased hectarage and yield per hectare. Table 5 shows the projected increase in food output stemming from these three sources under different rates of hectarage increase. For example, if hectarage were to increase by 3 percent per year over this 14-year period there would be 51 percent more cultivated land in 1980. It would be necessary for yield per hectare to increase by 31 percent in this period. The added hectarage multiplied by the added yield per hectare would account for the remaining 18 percent needed to achieve the doubling of food output. These computations are made under the assumption that (consistent with past trends) there would be no drastic shift in hectarage between the commercial crop area and the food crop area. The food crop area represents about 75 percent of the total cultivated land area and has fluctuated between 70 and 80 percent in the postwar period. It is interesting to note that in the 14-year period from 1950 to 1964, Taiwan increased total rice production by 60 percent. This output increase was achieved with essentially no change in acreage of riceland, and an annual growth in yield of approximately 4 percent (see Table 1).

In the two right-hand columns of Table 5 the source of yield growth has been divided between added labor per hectare and other factors. The purpose is to show the impact of changes in the cultivated hectarage per worker upon the yield per hectare.

For the 30-year period between 1918 and 1948 the farm labor force was a constant two-thirds of the total labor force (and thus grew at about the same rate as population). In the postwar period the farm labor force declined to about 60 percent of the total labor force. In this same period cultivated hectarage was increasing rapidly. As Fig. 6 indicates, the growth rate in cultivated land exceeded the growth rate in the farm labor force for almost a decade. However, by the late 1950's, cultivated area per person in the agricultural labor force had begun to decline

Table 5. Source of output growth required by 1980 to meet 5 percent annual increase in demand for food under four projected rates of increase in cultivated land, Philippines, 1966 to 1980.

Projected annual increase (%)			Source of output growth (%)*			Source of yield growth (% output growth)	
Food demand	Cultivated hectares	Yield/ha	Hectares	Yield/ha	Added ha x added yield/ha	Added labor/ ha†	Capital technology, irrigation, double cropping‡
5	3	1.94	51	31	18	1.4	29.6
5	2	2.94	32	50	18	5.9	44.1
5	1	3.96	14	72	14	10.9	61.1
5	0	5.00	0	100	0	11.2	88.8

* Assuming quality of additional hectarage equivalent to quality of existing land, and ratio of food to commercial crops remains constant.

† Based on a growth in farm labor force of 3.5 percent per year.

‡ Plus the increase in labor and land productivity associated with additional inputs.

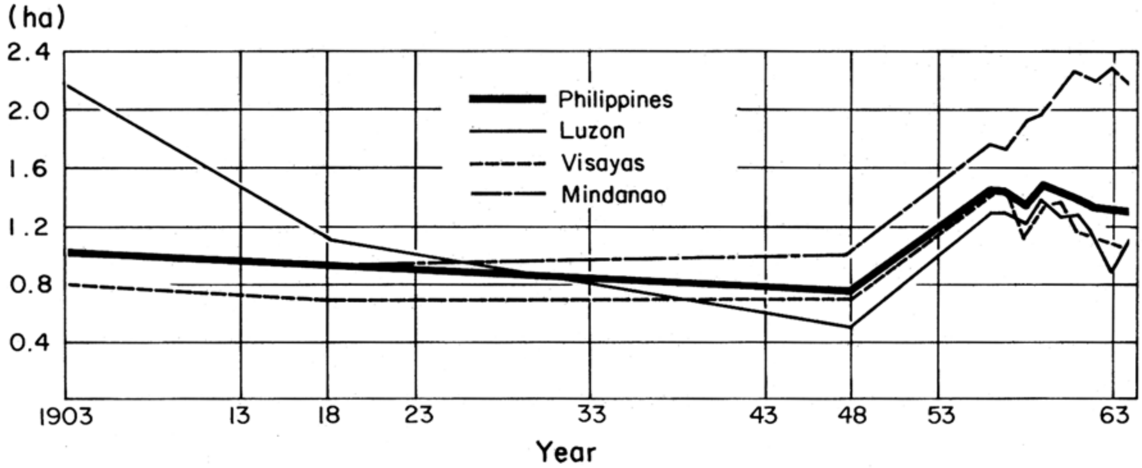


Fig. 6. Cultivated area per person in the agricultural labor force, Philippines, 1903-1964.

due principally to a leveling off in growth of cultivated land area.

It is difficult to know what the rate of growth in cultivated hectarage is likely to be in the future. The growth in the farm labor force by 1980 can be predicted with much greater certainty since this future labor force has already been born. A conservative annual growth rate of 3.5 percent was used in the analysis. If cultivated land were to increase as rapidly as farm labor supply there would be no change in yield due to added labor. However, the farm labor force is likely to increase much more rapidly than cultivated hectarage between 1966 and 1980. The marginal physical productivity of labor per hectare was calculated from a survey of irrigated and non-irrigated rice farms in Central Luzon in 1964/65. (This study is described in more detail in the section which follows.) Rice represents approximately 53 percent of food crop hectarage. Based upon this analysis, it was possible to estimate the impact on yields of additional labor inputs. Table 5 shows that with a very slow growth in cultivated hectarage the yield increase due to additional labor inputs alone accounts for more than 10 percent of the total increase in output. This is a conservative estimate since it assumes that the marginal physical productivity of labor remains constant and the values are based only on rice. However, additional irrigation and technology would increase the productivity of this added labor.

A slow rate of increase in cultivated land relative to labor would drive the ratio of cultivated land per farm worker down to the 1948 level of .8 or below by 1980 (see Fig. 6). The results reported in Table 5 suggest that if there had been no rise in this ratio between 1948 and 1960 rice yields would have risen by about 10 percent.

In summary, these projections indicate the magnitude of the problem facing the Philippines. The growth in food output in the past 5 years (1960/61 to 1964/65) has been approximately 2.5 percent annually or one-half of the amount that would appear to be necessary to meet increases in demand for food. The growth of rice and corn production has been considerably below this level. The growth rates in almost all other sectors of the agricultural economy have been higher than this during the same period. For example, the physical output has been increasing annually at the rate of: (1) 3.7 percent for food crops other than rice and corn, and (2) 4.4 percent for commercial crops. On the surface, this raises an interesting economic question as to how resources should be most effectively allocated to maximize output growth in the agricultural sector. It also emphasizes the importance of analyzing the economic potential of the rice technology being developed at the Institute. Research in this area is discussed in the following section.

Table 6. Comparison of costs and returns (pesos)* per hectare of producing traditional and improved varieties of rice in the Philippines, 1964 to 1966.

Costs and returns	Item, variety and cultural practices, year of estimate, source of data, season, location, irrigation								
	I Traditional 1965-66 15 farms wet & dry Laguna I‡	I Traditional 1965-66 9 farms wet Laguna NI‡	II Traditional 1965-66 budgeted wet & dry Nueva Ecija I	III Traditional 1964 budgeted N.S. Central Luzon I	IVa Improved 1966 budgeted wet N.S.† I	IVb Improved 1966 budgeted dry N.S. I	Va Traditional 1966 2 farms wet Laguna I	Vb Improved 1966 2 farms wet Laguna I	VI Improved 1966 24 farms wet Rizal I
1. Cash crop costs§	18.81	0.13	77.00	33.68	299.00	384.00	86.09	226.68	357.56
2. Labor days‖	79	67	47	80	N.S.	N.S.	N.S.	N.S.	N.S.
3. Labor cost¶	119.11	180.07	164.50	280.00	198.00	198.00	125.50	165.00	N.S.
4. Total cost	603.08	1032.47	720.11	726.00	1456.00	1835.00	N.S.	N.S.	N.S.
5. Land and labor as % of total cost	57	59	51	67	35	22	N.S.	N.S.	N.S.
6. Cash expenses as % of total cost	13	6	8	5	42	50	N.S.	N.S.	N.S.
7. Yield in cavans	44.7	75.00	40.00	45.4	125.00	150.00	35.8	125.00	127.00
8. Cost per cavan	13.49	13.77	18.00	16.00	11.65	12.23	N.S.	N.S.	N.S.
9. Net return¶	156.82	242.53	—40.11	45.80	699.00	715.00	N.S.	N.S.	N.S.

* ₱3.9 = U.S.$1.00.
† N.S.: Not specified.
‡ I: Irrigated; NI: not irrigated.
§ Seed, fertilizer, and chemicals.
‖ Does not include harvesting and threshing.
¶ At ₱17/cavan.

Productivity and Efficiency in Rice Production

This section reports the results of research on three topics related to productivity and efficiency: (1) cost of producing rice using traditional and improved varieties and cultural practices, (2) cost and returns for growing rice under varying resource situations, and (3) interaction between labor intensity, cultural practices, and yields. The purpose in all three areas of research is to examine economic efficiency under a wide range of cultural practices and resource situations. It is important not only to compare existing and potential levels of performance, but also to consider how the individual rice producer with limited resources should move from his existing level toward higher productivity and economic efficiency.

Cost of production under traditional and improved methods

As earlier studies in the Philippines have indicated, cost of producing rice varies widely depending on the location, the resource situation and the technology or cultural practices followed. With respect to technology, cost estimates can be measured for four categories: (1) traditional varieties and cultural practices, (2) improved varieties and traditional cultural practices, (3) traditional varieties and improved cultural practices, and (4) improved varieties and improved cultural practices. The word 'traditional' refers to common varieties and cultural practices that have been used in the Philippines to date. The word 'improved' in the case of varieties refers to the group of short, stiff-strawed varieties that are capable of producing high yields of 5 m tons (110 cavans) or more under improved cultural practices. 'Improved cultural practices' refers principally to the use of insecticides, fertilizer, weed control and water management.

A number of studies have been conducted recently which show the cost of producing rice under situations (1) and (4). A summary of these studies is presented in Table 6. The source of the cost studies is as follows:

I. Department of Agricultural Economics, U.P. College of Agriculture, Farm Record Keeping Project, Laguna.
II. Gallego Institute of Agriculture, Nampicuan, Nueva Ecija.
III. The Rice and Corn Study Committee, assisted by the U.P. College of Agriculture staff.
IV. The International Rice Research Institute, College, Laguna.
V. Abel Silva, rice producer, Sta. Rosa, Laguna.
VI. Agricultural Development Council of Rizal.

The roman numerals above correspond to the numerals assigned to each column in Table 6. As indicated in this table, there are five cost estimates based upon traditional varieties and practices, and four cost estimates based upon IR8 and improved practices. Most of the estimates are for wet season, irrigated conditions. Five estimates are based upon farm data, and four have been budgeted.

The first line of Table 6 compares cash crop costs. The costs are much higher for improved methods. The principal item of expenditure is insecticide. Application of insecticide on traditional varieties would also raise yields, but the yield response probably would not be sufficient to encourage farmers to follow this practice.

The second and third lines of the table indicate labor requirement and costs. Information here for new varieties and cultural practices is unfortunately incomplete. There appears to be no evidence that labor costs are higher, but there have been no studies conducted to verify this point. In fact, it seems obvious that improved cultural practices will require more labor input, particularly between transplanting and harvesting.

The total cost of producing rice by traditional methods appears to be about P700 per hectare taking the consensus of these studies (line 4). Of this cost, approximately 60 percent is composed of land and labor, and less than 10 percent represents cash expenses. The comparison of traditional with the improved estimates is striking. The cost of production per hectare is almost double for the improved methods. More cash inputs are used and more must be paid to handle additional harvest. However, yields are about three times as high (line 7) and this doubling of cost per hectare therefore leads to a lowering of cost per cavan (line 8). Net return per hectare is at least three times as great using improved varieties and improved methods. The differences in returns reflect differences in yields.

At this point one might raise two questions. First, what happens if improved varieties are used with current practices? Second, what happens if improved cultural practices are used with traditional varieties? In the first case, limited available evidence suggests that yields would be no worse than for local varieties under most conditions, and would be superior where even a limited amount of improved practices were adopted. In the next year or so additional experimental results and field experience should provide a more complete answer to this question.

Use of improved cultural practices with traditional varieties would result in higher yields. However, these yield increases are substantially lower than with improved varieties. The additional returns may cover the added costs but are an inadequate incentive to farmers considering the additional risks involved.

Resource efficiency and income potential

The analysis of profitability and efficiency in the use of inputs is extended in this section to cover a wider range of resource situations. The objective is to determine under what conditions the new output-increasing technology is likely to result in income levels that will: (a) encourage adoption of the new technology, and (b) result in returns to labor comparable with returns in other sections of the economy.

For Southeast Asian countries, the rice production systems include the following types:

(a) upland rainfed
(b) single-cropping rainfed
(c) single-cropping irrigated
(d) double-cropping irrigated
(e) multiple cropping irrigated

Under systems (b) and (c) rice is normally the dominant crop while under (d) and (e) rice is frequently grown in combination with other crops. An analysis was conducted for single and double cropping farms where rice was the only crop grown. Current levels of income and resource returns were determined by analyzing survey data from 123 farms, 61 in Central Luzon and 62 in the Central Plain of Thailand. Income potential was measured by budgeting the cost and returns under improved technology levels. As shown in Table 7, columns 1, 2 and 6, farms were stratified in the survey by size (2-ha and 4-ha) and by irrigation system (irrigated and rainfed).

Resource efficiency was determined by fitting a Cobb-Douglas function to the data in each of the farm groups. The function was of the following form:

$$Y = a X_1^{b_1} X_2^{b_2}$$

where:

Y = gross return per farm in U.S. dollars
X_1 = man labor per hectare in days, 1964/65 (8–hr adult equivalent)
X_2 = annual operating capital per hectare in U.S. dollars

This equation assumes constant returns to scale for inputs of land, labor and capital. For example, if land, labor (X_1) and capital (X_2) were doubled, presumably gross returns (Y) would double. This assumption, in a developing economy, is reasonable for small farms which have very little fixed capital equipment.

Marginal returns (or marginal value product) for labor and capital, calculated for each of the farm types, are shown in columns 3 and 7 of Table 7. The marginal return is the return for the last unit of resource input. For example, adding (or removing) 1 day of labor on a 2-ha irrigated farm in Central Luzon would increase (or decrease) returns by US$.67 (₱2.61). If labor were hired at the minimum wage of US$.90 (₱3.50), the added return would not be adequate to cover the added cost. The ratio of marginal return to marginal cost is only .74. For all other farm types the marginal return is less than the cost of labor. However, most of the labor being used in agriculture is not paid at this official hired wage rate. Alternative employment opportunity for family farm labor is limited. It is therefore rational to use labor even when the return to the labor is below the hired wage rate.

The supply of capital in contrast to labor is very limited. The results in Table 7 are based upon a 12-percent annual interest rate for capital. For the irrigated farms in Central Luzon the return on capital is approximately 2 to 1. The return to capital on Thai farms is lower because of a much lower rice price. Marginal return exceeds marginal cost for capital even on

Table 7. Marginal return, factor costs and marginal return to factor cost by types and sizes of rice-producing farms, Philippines and Thailand, 1964/65.

Farm type and size	Philippines				Thailand			
	No. of farms and units of inputs* (2)	Marginal return (U.S.$) (3)	Factor cost† (U.S.$) (4)	MR/MC: (3)/(4) (5)	No. of farms and units of inputs* (6)	Marginal return (U.S.$) (7)	Factor cost† (U.S.$) (8)	MR/MC: (7)/(8) (9)
Irrigated								
2-hectare (no.)	24				20			
Labor (days)	84	0.67	0.90	0.74	96	0.38	0.44	0.86
Capital (U.S.$)	20	1.89	1.06	1.78	7	1.48	1.06	1.40
4-hectare (no.)	15				15			
Labor (days)	75	0.71	0.90	0.79	87	0.41	0.44	0.93
Capital (U.S.$)	15	2.10	1.06	1.98	7	1.57	1.06	1.48
Rainfed								
2-hectare (no.)	12				15			
Labor (days)	64	0.45	0.90	0.50	78	0.27	0.44	0.61
Capital (U.S.$)	17	1.32	1.06	1.25	5	1.21	1.06	1.14
4-hectare (no.)	10				12			
Labor (days)	57	0.51	0.90	0.57	67	0.32	0.44	0.73
Capital (U.S.$)	13	1.39	1.06	1.31	5	1.37	1.06	1.29

* Labor and capital inputs measured at geometric mean.

† Based on a farm wage rate of ₱3.50 in the Philippines and 9.05 baht in Thailand plus 6 percent interest on capital for 6 months. ₱3.9=U.S.$1.00=20.58 baht.

rainfed farms. However, it cannot be concluded from these figures that farms are using inadequate amounts of capital. Due to the shortage of capital, the risks involved and the frequently high interest rates, even a return of 2 to 1 is not likely to be adequate to encourage additional capital inputs. In spite of the considerable difference in rice price and capital inputs between Central Luzon and Central Thailand, the yield levels have been almost identical for a number of years (see Table 3). This suggests that until the present, the regions have been dominated by technological limitations. Under these circumstances a higher rice price has relatively little effect upon yield per hectare.

Current and potential incomes are shown in Tables 8 and 9. The value in parentheses below the income figure is an index based on a 2-ha, rainfed farm equalling 100. Adopting improved varieties and cultural practices more than double incomes on irrigated single-cropped farms. The highest income potential, of course, is achieved with a double-cropping system under improved practices. This income is more than five times as great as might be expected on single-cropped farms with current cultural practices.

There are two important questions with respect to income potentials: (1) Will the income be adequate to encourage investment in improved cultural practices leading subsequently to higher rice production, and (2) will the income from rice production provide the average rice farm worker with an adequate standard of living compared with other farm and non-farm

Table 8. Return to land operator and family labor by type and size of rice-producing farm in Central Luzon, 1964/66.*

Farm type and size	Current level		Improved level	
	Single-cropped (₱)	Double-cropped (₱)	Single-cropped (₱)	Double-cropped† (₱)
Irrigated				
2-hectare	1,053 (120)‡	1,665 (189)	2,317 (264)	5,394 (614)
4-hectare	1,513 (172)	2,398 (273)	3,405 (387)	8,447 (961)
Rainfed				
2-hectare	879 (100)		1,308 (149)	
4-hectare	1,143 (130)		2,081 (237)	

* Based on rice price of ₱16.56/cavan of 44 kg. ₱3.90=$1.00.

† Assumes: (1) adequate irrigation, (2) increased levels of fertilizer, weed and insect control, (3) short-stemmed varieties such as IR8 in irrigated areas, and improved local varieties such as BPI-76 in rainfed areas.

‡ Figures in parentheses below income represent index of income based on 2-hectare rainfed equal to 100.

Table 9. Return per farm worker on tenant-operated farms in Central Luzon, 1964/66.*

Farm type and size	Current level		Improved level	
	Single-cropped (₱)	Double-cropped (₱)	Single-cropped (₱)	Double-cropped† (₱)
Irrigated				
2-hectare	160	252	351	817
4-hectare	193	307	437	1,083
Rainfed				
2-hectare	133		198	
4-hectare	147		267	

* Assumed a 50-50 share in return and variable costs (one-half of return to land and labor in Table 3 divided by 3.3 farm laborers on 2-ha farm and 3.9 farm laborers on 4-ha farm).

† See footnotes, Table 1.

workers? The first question is of more immediate concern and perhaps the more difficult of the two to answer. In the Philippines, there appears to be a growing interest among large landowners in improved rice culture. The largest source of savings and potential capital investment rests with this group. It remains to be seen to what extent these income potentials will attract private capital investment in improved technology and water management.

Table 9 expresses the current and potential income levels in terms of returns per farm worker. The return is based upon a 50-50 share rent (for both output and factor costs). Currently in the Philippines, the minimum farm wage rate (based upon 300 days) is ₱1,050 ($269) per year while the minimum non-farm wage rate is ₱1,800 ($462). The minimum farm wage rate is approached or exceeded only on these farms with a double cropping system employing improved practices. An appropriate further step in this study would involve comparison of income potentials for rice in combination with other crops.

Interaction between labor intensity, cultural practices, and yields

In a developing agricultural economy, capital is limited. Labor also may be limited at certain peak times of the year, and in surplus at other periods. An important question is how capital and labor resources should be combined to achieve the highest rate of return. For a crop such as rice, this question can be analyzed by examining the response of rice yields: (a) to various forms of capital inputs, (b) to labor inputs at specific periods in the year, and (c) to the interaction between capital and labor inputs. The economic optimums can be determined only after the physical response relationships are established. For example, if one knows the yield advantage gained by timely land preparation, then it is a routine matter to compare the monetary gain from the higher yield with

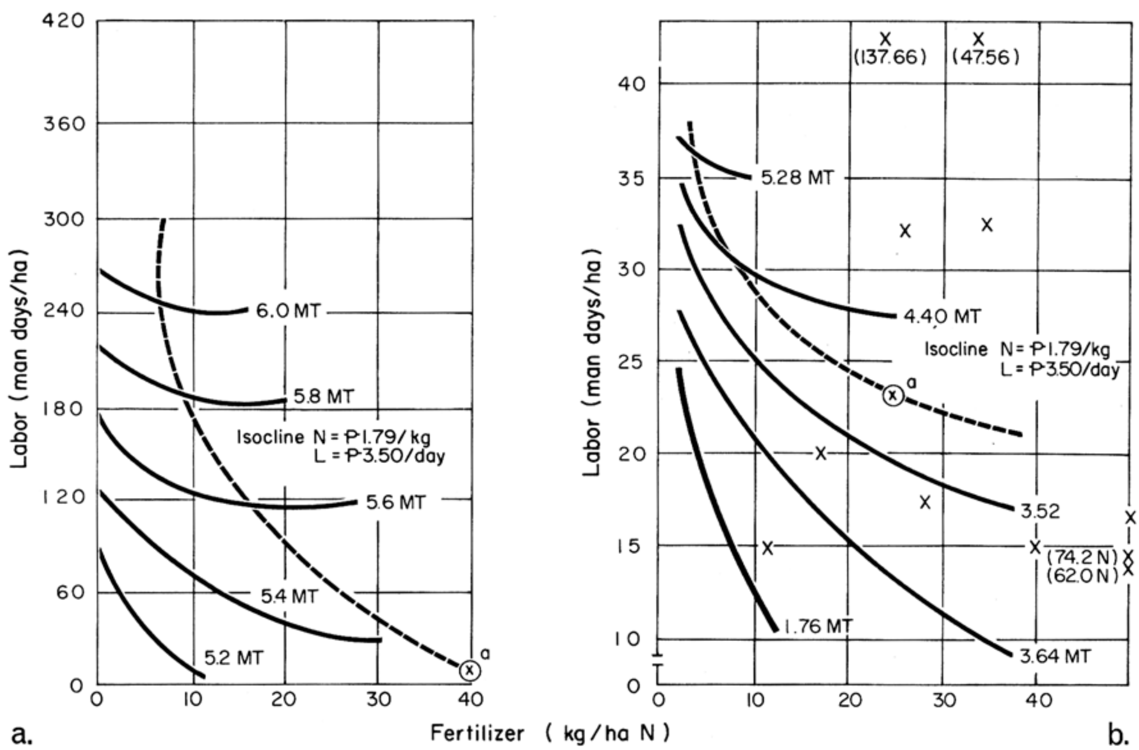


Fig. 7a. Yield isoquants and price isocline, 1965/66 dry season. Experimental data, Peta.

Fig. 7b. Yield isoquants and price isocline, 1965/66 dry season. Farm survey data, Intan.

mechanization cost required to obtain this yield.

The work on this topic was initiated in 1964, and initial results were reported in the 1965 Annual Report. The research has involved: (1) experimental work conducted at the Institute, and (2) a survey of 12 farms located in Calauan, Laguna. The first phase of this work (1964/65 and 1965/66) focused on the period between planting and harvest. It was hypothesized that there would be a positive interaction between labor inputs (for weeding and other crop-care activities) and other inputs such as fertilizer. That is to say, increased use of labor in this period would result in better cultural practices such as weeding, insect and disease control, timely irrigation and drainage, all of which alone or in combination would affect fertilizer response.

Response to fertilizer was negligible during the two wet seasons. In order to study the interaction effects between fertilizer and labor in the dry seasons, square root functions were fitted to both the experimental and the farm survey data. The estimating equations are shown below. Figures shown in parentheses are standard errors.

(Experimental)

$$Y = \underset{(981.89)}{2826.45} + \underset{(7.86)}{3.52X_1} - \underset{(7.05)}{13.35X_2} + \underset{(178.77)}{8.62\sqrt{X_1}} + \underset{(98.20)}{209.16\sqrt{X_2}} - \underset{(5.67)}{6.86\sqrt{X_1X_2}} + \underset{(198.34)}{1831.47X_3}$$

$$R^2 = .824$$

(Farm Survey)

$$Y = -\underset{(7649.40)}{12231.12} + \underset{(221.30)}{296.56X_1} - \underset{(66.88)}{198.88X_2} + \underset{(2189.88)}{847.00\sqrt{X_1}} + \underset{(1821.16)}{5496.48\sqrt{X_2}} - \underset{(71.28)}{707.08\sqrt{X_1X_2}}$$

$$R^2 = .946$$

where:

Y = yield in kg/ha rice
X_1 = labor from transplanting to harvest in man-days
X_2 = fertilizer in kg/ha N
X_3 = seasonal effect (1965 = 1, 1966 = 0)

The variety used in the experimental plots was Peta, while the variety on all but one of the case study farms was Intan. (One farm had BE-3.) Both of the equations show a negative interaction term for labor and fertilizer. The significance of this can be seen more clearly by examining Figs. 7a and 7b. Two sets of *isoquants* were constructed based upon these two equations. An isoquant shows all possible combinations of fertilizer and labor inputs to achieve a specific output level. For example, on the experimental plots in the 1965 dry season, a yield of 5.4 m tons of rice could be obtained by using approximately 130 man-days of labor and no fertilizer or 27-man-days of labor and 30 kg N.

The next step was to draw an *isocline* or a line showing the optimum combinations of fertilizer and labor at specified prices for these two inputs. The isocline shown for each of the two figures is based upon a price of ₱1.79 (US\$.46)/kg N and ₱3.50 (US\$.90)/man-day of labor. For example, the optimum combination of inputs required to achieve 5.4 m tons based on the experiment results would be approximately 33.5 kg N and 27 man-days of labor (the point of intersection of the isocline with the 5.4-ton isoquant). The isocline would shift to the left if one were to choose a lower price per man-day of labor, but the slope would still be negative.

Figures 7a and 7b for experimental and farm survey data show the same basic pattern in spite of the fact that observed yield and labor input levels differ greatly. The backward slope of the isoclines reflect the negative interaction between fertilizer and labor. The optimum path of yield increase is achieved by increasing labor inputs and at the same time decreasing fertilizer inputs.

The highest profit level (where the added return just equals the added cost) is shown at point *a* in each figure. In Fig. 7b, the X's indicate the current points of operation for the 12 survey farms.

The negative interaction between fertilizer and labor is the result primarily of lodging in the Peta and Intan varieties. The hypothesis of a positive interaction between labor inputs and fertilizer, therefore, must be rejected for these varieties. However, a positive response to increased labor inputs was observed throughout the entire range of observations in the dry season (35 to 420 man-days/ha on experimental plots, and 14 to 138 man-days/ha for survey farms). This contrasts with wet-season experimental results where no positive response was obtained for labor inputs in excess of 140 man-days.

The negative interaction between fertilizer and labor can be explained in part as a consequence of physical response relationships. Both nitrogen application and weeding encourage the production of dry matter in the rice plant. If the build-up of dry matter is too rapid in the tall-stemmed varieties, they will lodge even before heading. Withdrawing of nitrogen or weed control up to a point retards this build-up of dry matter and therefore may result in higher yields. Since the build-up is much less in the short, stiff-strawed varieties, one would not expect to find the same negative interaction between factor inputs.

The experimental phase of this study was redesigned in the 1966 wet season. The new design involved the following treatments: (a) 2 varieties, (b) 5 levels of land preparation, (c) 6 weeding treatments, and (d) 6 levels of fertilizer. Thus, there were 360 possible treatment combinations. Standard IRRI insect, pest control and water management practices were followed. The preliminary results for the 1966 wet season are summarized in Figs. 8a and 8b. Only two levels of weeding are shown. The two single harrowing and two double harrowing treatments were combined since yields for these treatments did not differ significantly. Results for IR8 and BPI-76 are shown separately in Figs. 8a and 8b. With the lowest level of land preparation (no harrowing) the two varieties respond almost identically. However, with improved land preparation, yields for IR8 exceed those for BPI-76 by approximately 1 m ton. The advantage of weeding is pronounced when land preparation is inadequate. With IR8 there is some tendency for positive interaction between fertilizer level, weeding level and land preparation.

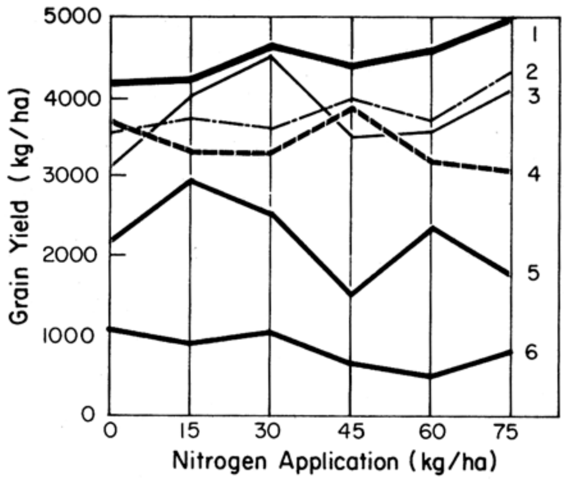


Fig. 8a. Effects of harrowing and weeding on yield of IR8 with varying levels of nitrogen (IRRI wet season, 1966).

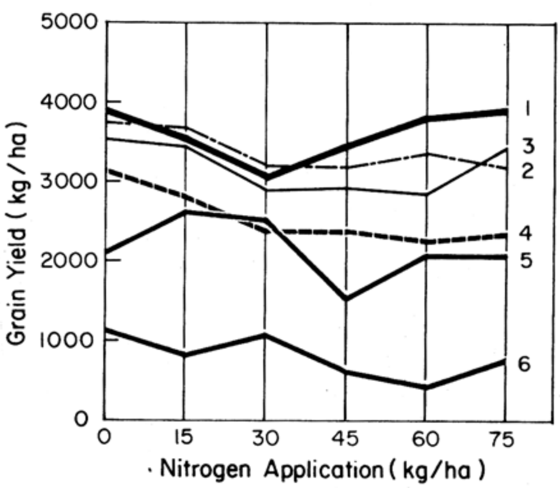


Fig. 8b. Effects of harrowing and weeding on yield of BPI-76 (non-seasonal) with varying levels of nitrogen (IRRI wet season, 1966).

Rice Supply, Demand, and Price Behavior

A large share of the department's total effort in the previous year (1965) was devoted to the

Table 10. Estimated short-run price elasticities of rice and corn hectarage and marketed surplus in postwar Philippines.

Region	Price elasticity of hectarage*	Average marketed proportion†	Price elasticity of marketed surplus (low estimates)*
	Rice		
Ilocos (2)‡	.11 to .23**§	.37	.30 to .62
Cagayan Valley	neg‖	.40	neg
Central Luzon (2)	.13 to .55**	.65	.20 to .85
Southern Tagalog (2)	.19 to .64**	.50	.38 to 1.28
Bicol (2)	.38** to .41**	.49	.78 to .84
Eastern Visayas (1 & 2)	.15 to .35	.43	.34 to .81
Western Visayas (2)	.09 to .58	.51	.18 to .96
Northern & Eastern Mindanao (2)	.21 to .22	.54	.39 to .41
Southern & Western Mindanao (2)	.25 to .34	.44	.57 to .77
	Corn		
Ilocos (1, 2, & 3)	.04 to .08	.24	.17 to .33
Cagayan Valley (2)	.17	.36	.47
Central Luzon	neg	.26	neg
Southern Tagalog (1, 2, & 3)	.30 to .60	.34	.88 to 1.76
Bicol (1 & 3)	.16 to .29	.38	.42 to .76
Eastern Visayas (2)	.50** to .67**	.27	1.85 to 2.48
Western Visayas (1 & 2)	.42* to .49	.19	2.21 to 2.58
Northern & Eastern Mindanao	neg	.40	neg
Southern & Western Mindanao (1 & 2)	.11** to .13	.38	.28 to .34

* The elasticities of hectarage and of marketed surplus are with respect to expected product price in the first-trial regressions and with respect to expected relative product price in second- and third-trial regressions.
† Rice, 1959-60; corn, 1954-55.
‡ The figures in parentheses after each region refer to the regression trials from which the price elasticity ranges were taken.
§ One asterisk indicates that the coefficient is significant at the 40-percent level; two asterisks, the 20-percent level.
‖ neg indicates that all estimated price coefficients are negative.

issue of rice supply and demand and price behavior. The first phase of this work has been completed and a summary of the results is shown in Table 10, which also includes the supply estimates obtained from the cooperative project on corn. The supply estimates in the second column of the table show the percent change in hectarage for a 1-percent change in price. For example, in Central Luzon a price change of 10 percent is estimated to bring about a change in hectarage ranging from 1.3 percent to 5.5 percent. The range in hectarage coefficients affects the range in estimates obtained by fitting several equations with minor changes in the independent variables. The price elasticity of marketed surplus is calculated by dividing the price elasticity of hectarage (column 2) by the average marketed surplus (column 3). It is apparent that a change in hectarage due to a change in price will be accompanied by a considerably larger change in the amount of marketed surplus. This is an important consideration for a developing economy since the growth in the urban industrial sector depends on the transfer of food from the agricultural sector.

In the second phase of the supply response work the model has been formulated to take into account the effect of changes in yield as well as hectarage, and the effect of the interaction of these two variables on rice production. The revised model is shown in block diagram in Fig. 9. Rice production is a function of hectarage times yield. The hectarage is in turn influenced strongly by the price of rice and the price of competing crops. The price of inputs and technology may also influence hectarage, but their influence has not been readily discernible in the analysis conducted for the Philippines. In cases of severe crop damage, weather can reduce harvested hectarage. The connecting arrows in Fig. 9 are therefore represented by dotted lines. The major factors influencing rice yields are technology, weather and hectarage. Prices to date appear to have had little direct influence on yields. This undoubtedly is due at least in part to: (1) high marginal propensity to consume among rice farmers, (2) low rate of return and high risk on investment in inputs such as fertilizer, or (3) combination of these two factors.

The model illustrated in Fig. 9 can be formulated in the following set of equations:

(1) $Q = YH$
(2) $Y = f(P_r, P_a, P_f, T, W, H)$
(3) $H = f(P_r, P_a, P_f, T)$

where:

Q = quantity of rice produced
Y = yield per hectare of rice
H = hectarage of rice harvested
P_r = price of rice
P_a = price of alternative crops
P_f = price of factor inputs
T = technology
W = weather

Equation 1 is an identity which states that the quantity of rice produced is equal to hectarage

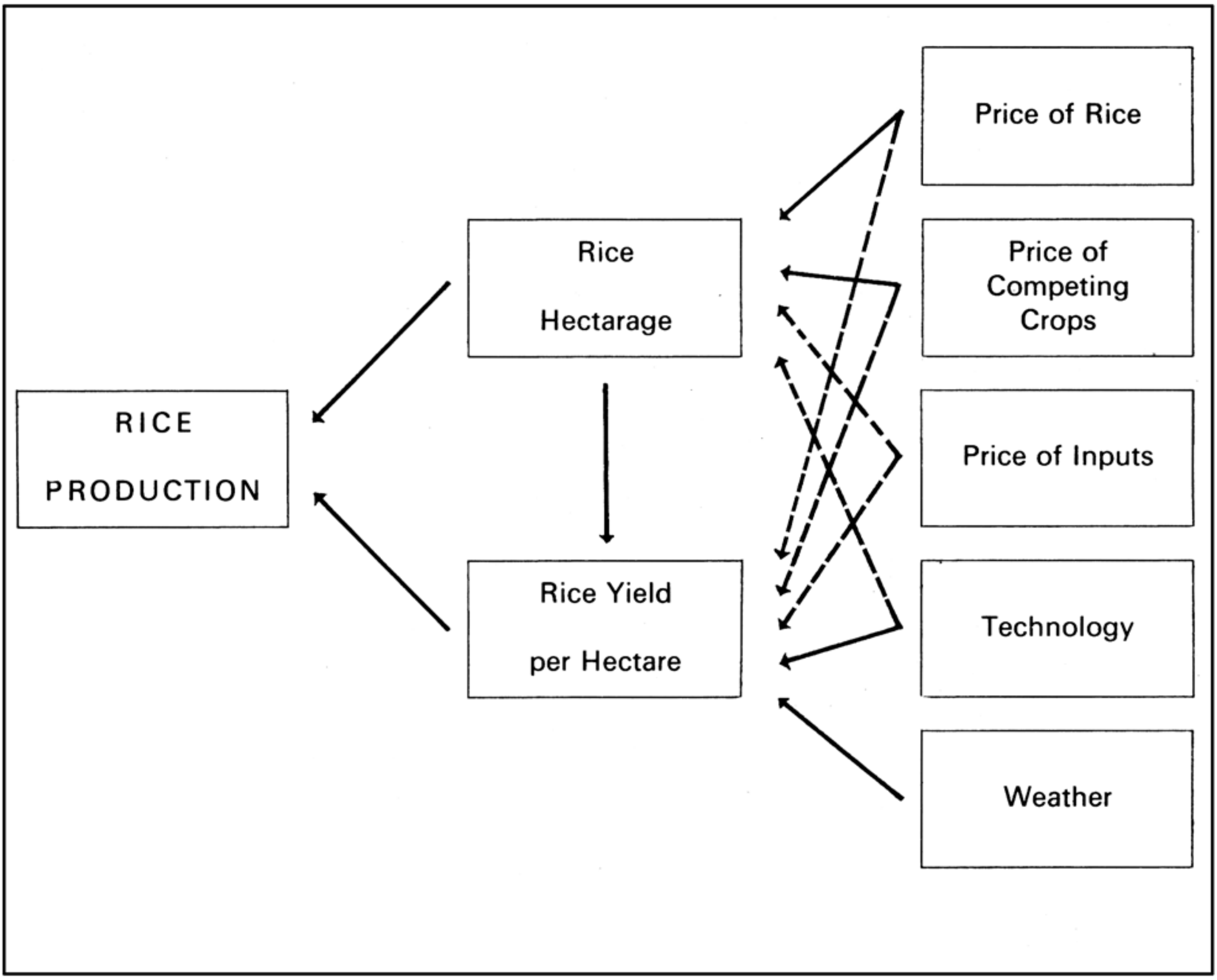


Fig. 9. Model of rice production and price relationships.

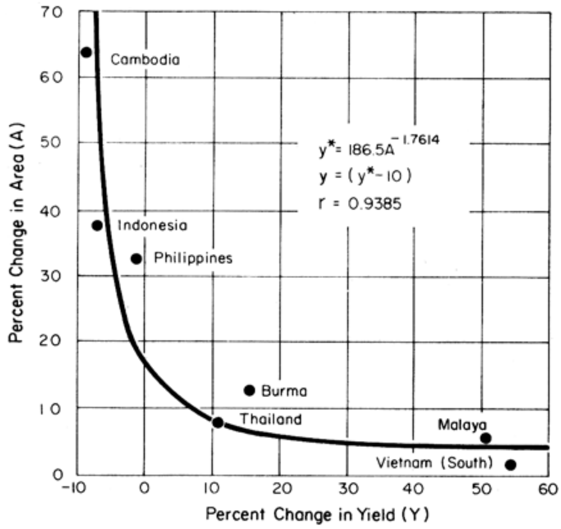


Fig. 10. Interaction of rice area and yield changes, 1949/50-1953/54 to 1959/60-1963/64.

times yield per hectare. Equations 2 and 3 show yield and hectarage as a function of certain variables. The first step, using Equation 3, is to estimate the effect of a price change upon hectarage. The second step, using Equation 2, is to estimate the effect of a change in price and a change in hectarage upon yield. Finally, the estimates of change in hectarage and yield are multiplied together to determine change in production. The first phase of this study focused on Equation 3 of this model (see Table 9). Work is now underway to estimate the short-run effect of hectarage, weather and other variables upon yield (Equation 2). Figure 10 (and Fig. 5 in the 1964 Annual Report) indicates that for Southeast Asian countries (and for the regions of the Philippines) hectarage and yield are inversely correlated. For example, from Fig. 10 it can be seen that no country in Southeast Asia that has undergone rapid expansion in hectarage in the last decade has increased its rice yields. Conversely, two countries with relatively stable hectarage have experienced sharp yield increases (Taiwan could also be included in this latter group).

Estimating equations based upon Equation 2 are being computed for each region of the Philippines. Properly including the effects of weather in these equations is a most difficult task. Stream flow data (provided by the Hydrology Division, Department of Public Works, Philippine Government) is being used as the basic source of data on water availability. Preliminary results from Central Luzon based upon fitting several minor variations of Equation 2 gave an estimated value for the coefficient of hectarage with respect to yield ranging from a low of —.43 to a high of —.85. The coefficient for hectarage was in all instances statistically significant at the 5-percent level while the coefficient for price was not significant. This indicates that the price elasticity of hectarage shown in Table 9 is likely to be higher than the price elasticity of total production. As a consequence, the price elasticity of marketed surplus may, in fact, be lower than the estimates in Table 1.

Statistics

As in previous years, the Department of Statistics was engaged in the following activities: (a) consultation and analytical services for research workers; (b) instruction on statistical techniques; and (c) research on the theoretical and experimental problems related to rice research.

The statistical research was primarily aimed at providing the research workers with statistical techniques for the planning, analysis and interpretation of results obtained from experimental and farmer's fields. Some of these studies are continuing projects with the aim of deriving consistent estimates and providing checks on the accuracy of estimates from previous years. Examples are those on sample size and sampling methods in rice research. New techniques are described below with reference to: (1) principal component analyses of agronomic characteristics and sensory tests on rice, (2) methods of describing the canopy of rice plants, (3) combining experimental data from several locations, (4) distributions of rice yields, and (5) new findings concerning the collection of rice statistics from farmer's paddy fields. In cooperative projects, variability studies were made of data from household food consumption surveys, and least-cost rations with rice bran as one of the feed ingredients in pork production were derived.

Table 1. Characteristics and percent variation (PV) accounted for by each principal component (Z) by experiment.

Description	Z_1			Z_2			Z_3			Total variation (%)
	X ( )*		PV	X ( )		PV	X ( )		PV	
I. *Variety x Nitrogen x Spacing experiment*†										
a] Variety x Nitrogen‡	Yield, g	(.42)	53	No. of panicles	(.60)	30	% sterility	(.83)	11	94
	No. of spikelets	(.45)		No. of tillers	(.58)					
	No. of filled grains	(.45)								
	Wt. of straw, g	(.43)								
	Height, cm	(.43)								
b] Variety x Spacing	Yield, g	(.45)	56	No. of panicles	(—.45)	26	% sterility	(.90)	12	94
	No. of spikelets	(.38)		No. of tillers	(—.49)					
	No. of filled grains	(.38)		Height, cm	(.43)					
	Wt. of straw, g	(.46)								
c] Variety x Nitrogen	Yield, g	(.46)	52	No. of panicles	(—.47)	29	% sterility	(.89)	13	94
x Spacing	No. of spikelets	(.37)		No. of tillers	(—.49)					
	No. of filled grains	(.36)		Height, cm	(.37)					
	Wt. of straw, g	(.45)								
II. *Nitrogen x Shading experiment*§										
a] Chianung 242,	Total weight of grains, g	(.43)	51	No. of empty grains	(.53)	35	No. of degenerated spikelets	(.98)	11	97
shaded throughout	Total no. of grains	(.46)		Wt. of empty grains, g	(.52)					
	No. of filled grains	(.44)		% sterility	(.55)					
	Wt. of filled grains, g	(.42)								
	Length of panicle, cm	(.43)								
b] Chianung 242,	Total weight of grains, g	(.39)	57	No. of empty grains	(.48)	28	No. of degenerated spikelets	(.99)	11	96
no shading	Total no. of grains	(.43)		Wt. of empty grains, g	(.47)					
	No. of filled grains	(.41)		% sterility	(.57)					
	Wt. of filled grains, g	(.38)								
	Length of panicle, cm	(.40)								
c] Taichung (Native) 1,	Total weight of grains, g	(.44)	55	No. of empty grains	(.60)	30	No. of degenerated spikelets	(.98)	11	96
shaded throughout	Total no. of grains	(.43)		Wt. of empty grains, g	(.57)					
	No. of filled grains	(.44)		% sterility	(.52)					
	Wt. of filled grains, g	(.44)								
	Length of panicle, cm	(.41)								

d] Taichung (Native) 1, no shading	Total weight of grains, g (.45)	54	No. of empty grains (.58)	32	No. of degenerated spikelets (.99)	11	97
	Total no. of grains (.44)		Wt. of empty grains, g (.57)				
	No. of filled grains (.45)		% sterility (.55)				
	Wt. of filled grains, g (.45)						
	Length of panicle, cm (.42)						
e] Chianung 242 and Taichung (Native) 1, five shadings	Total weight of grains, g (.41)	51	No. of empty grains (.53)	27	No. of degenerated spikelets (.81)	10	88
	Total no. of grains (.43)		Wt. of empty grains, g (.52)		Panicle number (.47)		
	No. of filled grains (.43)		% sterility (.50)				
	Wt. of filled grains, g (.41)						
	Length of panicle, cm (.37)						

* The figure in ( ) refers to the weight attached to the standardized variable X.
† Source of experimental data: Department of Plant Physiology, IRRI, 1964 dry season.
‡ Reported in the 1965 Annual Report.
§ Source of experimental data: Lamin, J. A Study on some of the factors that influence the yield of the rice plant. M.S. thesis, 1966.

Principal Component Analysis

Relative variabilities of 66 agronomic characteristics of rice were given in previous reports. Attempts to extend these variability studies to the multivariate case have been made. Thus, the theoretical background of principal component analysis in rice research was presented in the 1965 Annual Report (pp. 319-322) with an experiment on variety x nitrogen interaction. With the same eight characteristics (X_i's) the application of this technique was extended to studies on variety x spacing, and variety x nitrogen x spacing interactions (Experiment I). The structure of the variety x spacing experiment with spacings at 10 x 10, 25 x 25, and 50 x 50 cm was similar to that of the variety x nitrogen experiment.

In addition, data on a nitrogen x shading study for two varieties, Chianung 242 and Taichung (Native) 1, also were utilized. Each variety had two replicates, three levels of nitrogen (0, 60 and 120 kg/ha) and two or five shading treatments (Experiment II). Nine characteristics were observed on a panicle basis for the two shading treatments, while 10 characteristics were used for the five treatments. The average per panicle was used for the latter experiment.

The results are summarized in Table 1. For Experiment I, yield, number of spikelets, number of filled grains, and weight of straw are common to Z_1; number of panicles and number of tillers to Z_2; while sterility is identified with Z_3. Height appeared in Z_1 for a] and in Z_2 for b] and c]. Z_1 accounted for 52 to 56 percent of total variation, Z_2 from 26 to 30 percent, and Z_3 from 11 to 13 percent, or a total of 94 percent for the first three principal components.

Sterility appears to be a very important single defining contrast. The correlation between number of spikelets and number of grains ranges from 0.86 to 0.91. Similarly, the correlation between number of panicles and number of tillers is 0.96 to 0.97. In subsequent analyses, only one of these characteristics may be retained, number of grains or spikelets in Z_1 and number of panicles or tillers in Z_2. The X_i's appear to segregate themselves in importance to each Z_i in a rather consistent manner.

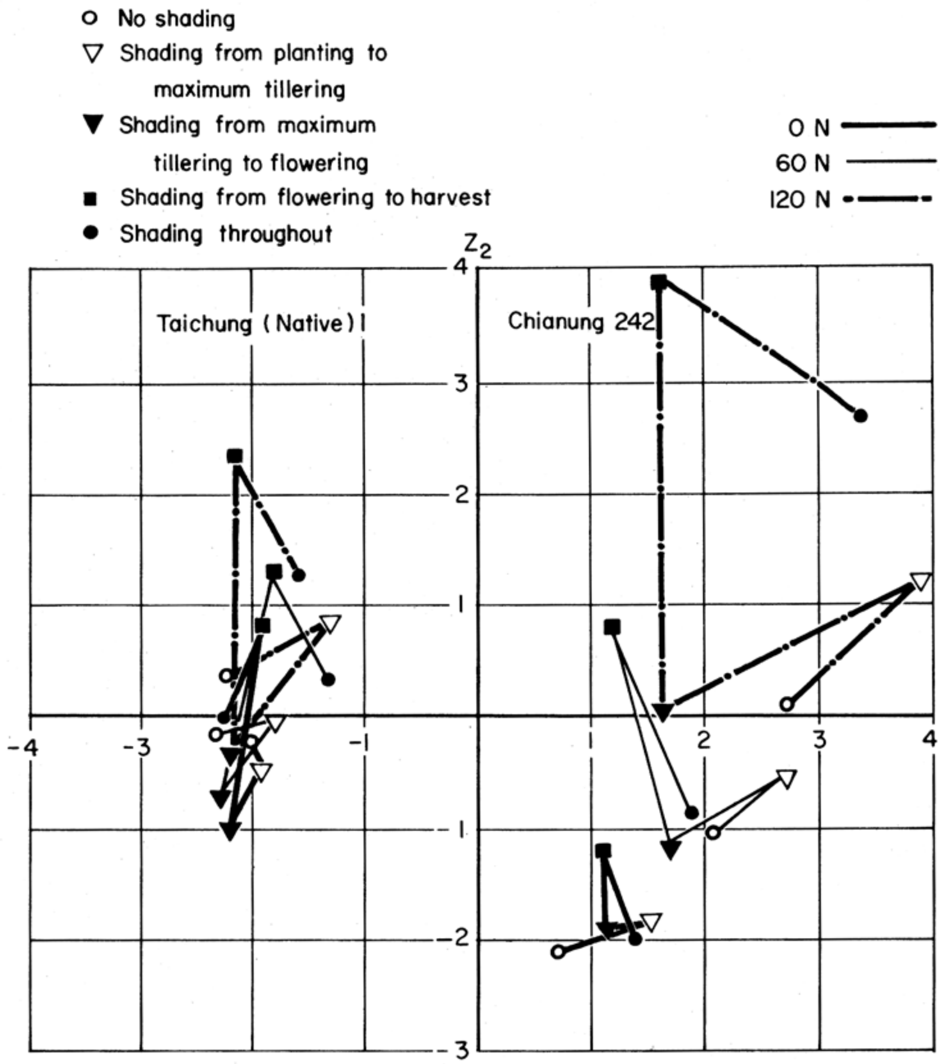


Fig. 1. Nitrogen x shading interaction by variety on the Z_1 and Z_2 axes.

For experiment II, total weight of grains, total number of grains, number of filled grains, weight of filled grains, and length of panicle are highly associated with Z_1; number of empty grains, weight of empty grains and sterility with Z_2; and number of degenerated spikelets with Z_3. For the two shading treatments (a, b, c, d), the total percent variation accounted for by Z_1, Z_2 and Z_3 ranges from 96 to 97 percent. Again, only three principal components are enough to account for most of the variations. The consistency of the X_i's within the Z_i's also is highly evident.

Results from the correlation analyses show that total number of grains is highly correlated with number of filled grains which in turn is correlated with weight of filled grains. Length of panicle is also correlated with these three variables. Likewise, high correlations between number of empty grains, weight of empty grains, and sterility were found to exist. These results were consistent for the two varieties. Note that Chianung 242 is an indica panicle-weight type while Taichung (Native) 1 is an indica panicle-number type.

A combined analysis was attempted in order that panicle number might be included. The results are shown in Experiment II e] and Fig. 1. The distribution of the variables by principal component is again consistent as compared to the four analyses except for the addition of panicle number in Z_3. The weight of panicle number in Z_1 is —0.26.

Another method which can be utilized by research workers is to present the pairs of principal component on the Z_iZ_j plane. An example was given in the 1965 Annual Report and another is given in Fig. 1. Five shading treatments were included to show the shift of the principal component from one shading treatment to another and likewise from 0 to 120 kg/ha N level by variety. The points are mean values of eight plants for each interaction. Increasing N level is associated with increasing Z_2's, while the reaction to the shading treatment is rather irregular. Note that Taichung (Native) 1, a panicle-number type, is associated with negative Z_1's whereas Chianung 242, a panicle-weight type, with positive Z_1's.

Data obtained from sensory tests on rice from the University of the Philippines College of Agriculture Department of Home Technology were used in the analyses. Eight characteristics were evaluated by scores from a judging scale. Each of two groups consists of eight varieties with BPI-76 as a standard. The test was replicated three times and the panel consisted of six judges.

Table 2 shows the variables (X_i's) in each component (Z_i). Flavor and color are the dominating characteristics in Z_1; tenderness and gloss in both Z_1 and Z_2; and aroma in Z_1 and Z_3. Flavor, color, tenderness and gloss appear to be the most important characteristics. The judges recorded very consistent scores of the varieties through time.

Note that 70 to 79 percent of the total variation was accounted for by the first three principal components. These results indicate that for sensory tests, one will need more components to explain a major portion of the variation. This is in contrast to the results obtained for the agronomic characteristics where the first three principal components accounted for an average of about 95 percent of the total variation. For groups I and II, aroma and color are correlated with flavor, tenderness and cohesiveness with gloss, and off-aroma with off-flavor.

The correlation matrix of the variables will serve as a guide to the research worker in his selection of the plant or sensory characteristics. Presently, the consistency of these matrices is under study. An IBM 1620 computer was utilized in the analyses; the program is available and will be supplied on request.

Table 2. Characteristics and percent variation (PV) accounted for by each principal component (Z) by groups. Sensory tests on rice.*

Description	Z_1			Z_2			Z_3			Total variation (%)
	X ( )†		PV	X ( )		PV	X ( )		PV	
Group I	Aroma	(.42)	32	Tenderness	(.54)	23	Off-aroma	(—.55)	15	70
	Flavor	(.46)		Gloss	(.57)		Off-flavor	(—.58)		
	Color	(—.40)		Cohesiveness	(.44)					
Group II	Flavor	(.46)	42	Off-aroma	(.62)	21	Aroma	(—.67)	16	79
	Tenderness	(.42)		Off-flavor	(.62)		Cohesiveness	(.41)		
	Color	(—.42)								
	Gloss	(.42)								

* Source of experimental data: Oñate, B. T. and L. U. Oñate. Principal components in sensory tests on rice. Philippine Journal of Food Technology. 1966.

† The figures in ( ) refer to weights attached to the standardized variable X.

Table 3. Test of azimuth preference of four varieties. IRRI, July, 1966.

Variety	Days after trans-planting*	Nitrogen level (kg/ha)	No. of rows	No. of leaves	Probability ($\chi^2 \geqslant \chi_c^2$) Within rows			Pooled total		Heterogeneity
CP 231 dw x Rexoro	22	0	3	261	.08	.94	.09	.14	.02	.73
Tainan 3	25		3	455	.11	†	†	†	†	.02
IR8	28		3	435	†	.49	.10	†	.02	.08
Rodjolele	30		3	716	.07	.03	.08	.04	.02	.24
CP 231 dw x Rexoro	32	120	3	413	.06	†	.04	.02	†	.38
Tainan 3	34		3	604	.18	†	.04	†	†	.78
IR8	36		3	450	†	.04	.15	†	†	.69
Rodjolele	39		3	455	†	†	.04	†	†	.18

* Seedlings were 21 days old when transplanted.
† Probability is less than 0.01.

Methods of Describing the Leaf Canopy of Rice Plants

The leaf canopy of rice plants may be described by the position of the leaves in terms of azimuth directions and also by means of the cumulative frequency distribution of leaf angles.

These methods were applied to describe the canopy of four rice varieties, namely: CP 231 dw x Rexoro, Tainan 3, IR8 and Rodjolele. Data were obtained from the lodging demonstration plots of the Varietal Improvement Department, from seedlings transplanted July 6, 1966, spaced 30 cm between rows and 25 cm between plants in a row, and under two nitrogen levels, 0 and 120 kg/ha N.

Azimuth directions

Leaves within NW and NE, NE and SE, SE and SW, SW and NW are defined to be in the direction of the cardinal points N, E, S and W, respectively. Table 3 contains the techniques in testing azimuth preference and the consistency of the data at time of sampling. Total chi-square (χ^2) indicated preference for a given azimuth direction. The heterogeneity χ^2 showed that there is consistency in azimuth preference among rows except Tainan 3 at 0 N.

IR8 at 114 days after transplanting showed no preference for any azimuth direction.

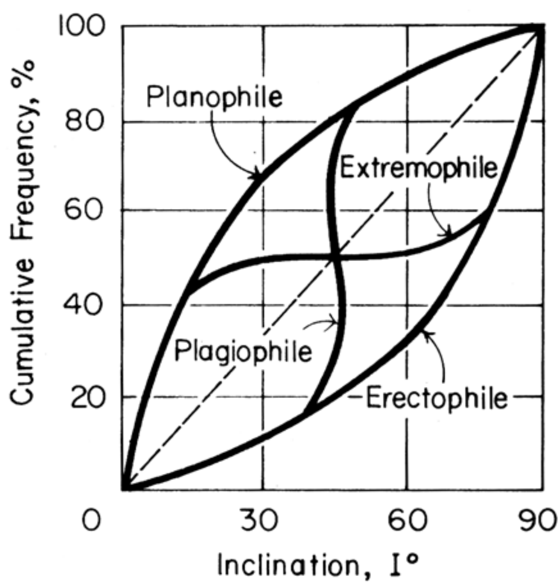


Fig. 2. Four types of canopies.

Angle of inclination

Cumulative leaf angle frequency distribution is represented by plotting the cumulative frequency of occurrence of the inclinations against inclination which ranges from 0° for a horizontal leaf to 90° for a vertical one. According to this technique, four types of canopies are evolved. Horizontal leaves are most frequent in planophile canopies while vertical leaves are most common in erectophile canopies. The leaves in plagiophile canopies are most frequently at some oblique inclinations, whereas those in extremophile canopies are least frequent at oblique inclinations (Fig. 2).

Two measurements are taken on the same leaf blade. One is the angle of inclination of the main blade (I_1) and its length (L_1), measured from the collar to the point where the blade begins to curve. The other is the angle of blade openness measured from collar to tip (I_2). The length of the tip (L_2) is measured from the point where the blade begins to curve to the tip (Fig. 3). The average angle of inclination ($\bar{I}$) is the weighted average of I_1 and I_2. Thus,

$$\bar{I} = W_1 I_1 + W_2 I_2$$

where

$$W_1 = L_1/(L_1 + L_2)$$
$$W_2 = L_2/(L_1 + L_2)$$

and

$$W_1 + W_2 = 1.$$

The cumulative frequency distribution of leaf angles for the four varieties is shown in Fig. 4. All varieties exhibited erectophile canopies at about 30 days after transplanting and at both nitrogen levels. At harvest, IR8 assumed an almost erectophile canopy whereas Tainan 3 tended to become plagiophile in shape. The response of CP 231 dw x Rexoro and Rodjolele may be considered as falling between those exhibited by IR8 and Tainan 3. About 100 leaf measurements are sufficient to produce a smooth cumulative frequency curve.

These simple methods of describing the leaf canopy of rice plants by azimuth directions and leaf angle distribution may be utilized in studying the reactions of rice varieties under varying treatments and environmental factors.

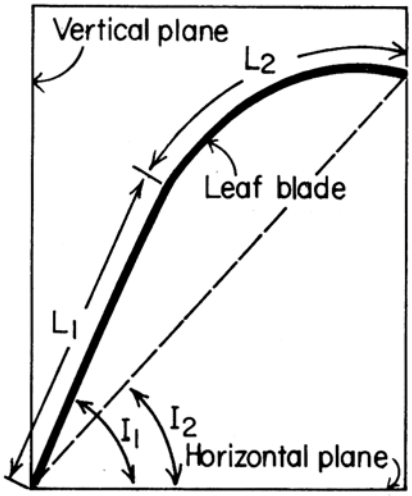


Fig. 3. Components in the measurement of leaf angle.

Combining Data from Rice Stem Borer Experiments over Several Locations

The screening technique for estimating stem borer incidence was recommended as a more efficient method than the purely random case, and the relative efficiency of this technique was presented in the 1965 Annual Report with data from the APC-IRRI Stem Borer Control Applied Research Plots. The technique was also applied to the BPI-IRRI Applied Research Plots. Experiments were conducted at several locations throughout the country with a 4 x 4 Latin square as the basic design. Two varieties with and without gamma-BHC constituted the treatments. The data on percent dead heart, percent white head, and grain yield for all locations can be analyzed by using a combined analysis of variance (ANOV) (Table 4). In the model, location (L) is assumed to be random and variety (V) and insecticide (I) as fixed. The differences in the degrees of freedom for the four ANOV's were due to the different numbers of locations included in each analysis. The results imply that the degree of infestation (dead heart and white head) and the grain yield vary with location. The effect of insecticides (I), averaged for all locations and varieties, differs significantly.

As in previous studies, grain yield was found to be highly correlated with percent dead heart

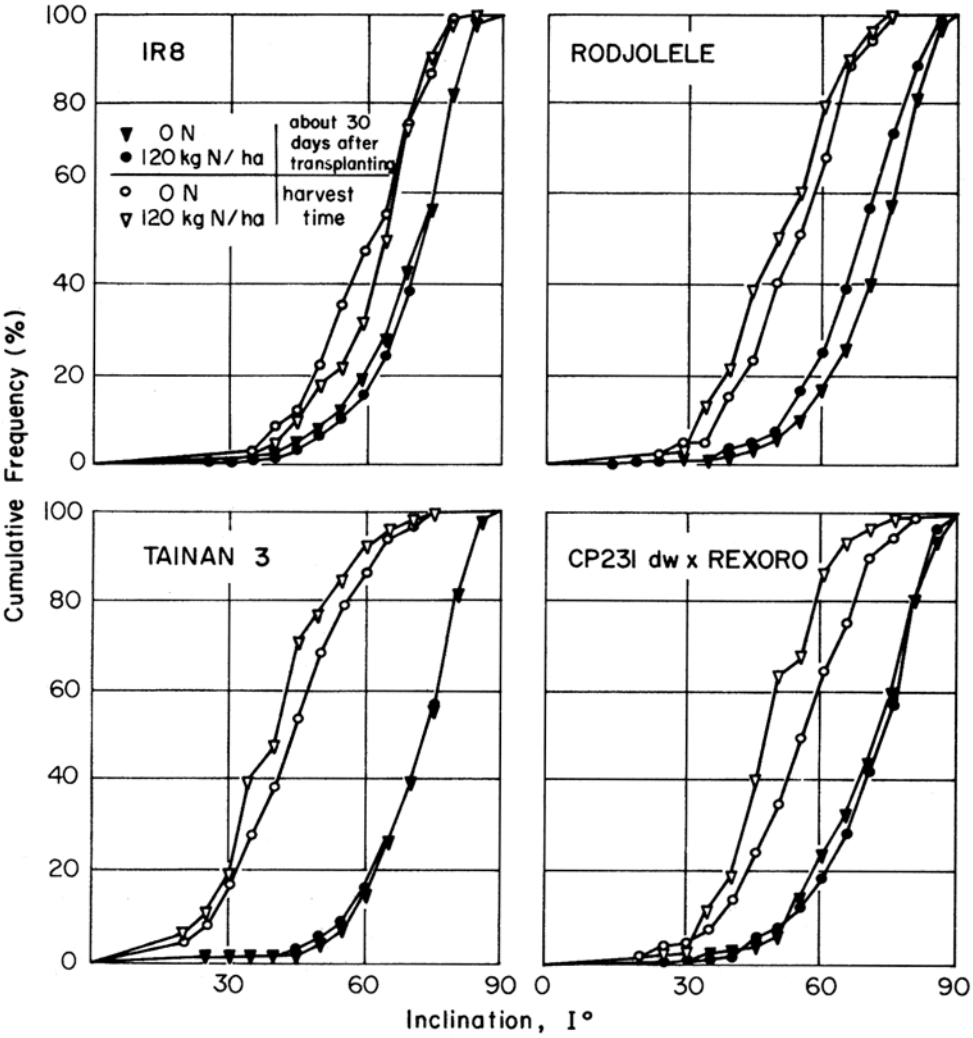


Fig. 4. Cumulative frequency distribution of leaf angles of four rice varieties.

and percent white head. The reduction in yield potential was about 2 percent for each percent increase in white head. In addition, a quadratic relationship pooled within locations was derived as

$$\hat{Y} = 3599 - 76.93X + .64X^2$$

or

$$P(\hat{Y}) = 100 - 2.14X + .02X^2$$

where

$\hat{Y}$ is grain yield in kg/ha,
X is percent white head,

and

$P(\hat{Y})$ is percentage of total production for X percent incidence of white head.

This correlation may be utilized in a covariance analysis as an aid in the interpretation of the results. If the percent white head is used as the independent variable, then one can test for the equality of grain yields in the different locations with the level of incidence assumed equal for all locations (Table 5). Eighteen locations were included in the analysis.

Significant F-value for testing adjusted L-means implies that not all the differences in the yield for the locations are due to the differences in percent white head. These differences may be explained partly by the environmental factors. The test for the adjusted I-means also gave a significant result which implies that the increase in yield of the treated over the control is not primarily due to the effect of the treatment (gamma-BHC) on stem borer incidence. The

Table 4. Combined ANOV for percent dead heart (DH), percent white head (WH) and grain yield (kg/ha). BPI-IRRI Applied Research Plots, wet season, 1965.

SV	% DH (2nd DH count)		% DH (3rd DH count)		% WH		Grain yield	
	DF	MS	DF	MS	DF	MS	DF	MS(000,000)
Total	*415*		*319*		*383*		*335*	
Location (L)	25	128.1**	19	130.1**	23	208.1**	20	12.0**
Treatment (T)	3	245.8**	3	240.1**	3	329.8**	3	20.3**
Variety (V)	(1)	0.1	(1)	3.7	(1)	61.6	(1)	30.1*
Insecticide (I)	(1)	733.9**	(1)	715.7**	(1)	905.7**	(1)	30.0**
V x I	(1)	0.5	(1)	1.1	(1)	21.9	(1)	0.01
L x T	75	23.2**	57	13.9**	69	20.5**	60	1.7**
L x V	(25)	13.2**	(19)	6.6**	(23)	20.8**	(20)	4.1**
L x I	(25)	53.0**	(19)	30.1**	(23)	31.4**	(20)	0.6**
L x V x I	(25)	3.4	(19)	4.9**	(23)	9.8	(20)	0.4
Rows within L	78	4.3	60	5.0**	72	7.0	63	0.3
Columns within L	78	8.7**	60	4.4**	72	2.9	63	0.3
Pooled error	156	4.5	120	2.1	144	7.0	126	0.3

* Significant at 5% level.
** Highly significant.

Table 5. Covariance analysis for grain yield in kg/ha (Y) and percent white head (X). BPI-IRRI Applied Research Plots, wet season, 1965.

SV	DF	SS			Deviations from regression			
		YY	XY	XX	DF	SS	MS	F
Total	287	423,052,527	—622,703	7931				
Location (L)	17	230,902,641	—357,606	4031				
Treatment (T)	3	79,778,947	—254,665	1074				
Variety (V)	(1)	(48,917,589)	(—87,990)	(158)				
Insecticide (I)	(1)	(30,858,368)	(—166,874)	(902)				
V x I	(1)	(2,990)	(199)	(14)				
L x T	51	55,382,530	—13,516	1071	50	55,211,959	1,104,293	
L x V	(17)	(39,343,161)	(—1,498)	(299)				
L x I	(17)	(8,549,924)	(—3,855)	(602)				
L x V x I	(17)	(7,489,445)	(—8,163)	(170)				
Rows within L	54	15,578,233	3,202	524				
Columns within L	54	15,994,240	830	318				
Pooled error (E)	108	25,415,936	—948	913	107	25,414,952	237,523	
E x L	125	256,318,577	—358,554	4944	124	230,315,145		
Testing adjusted L-means					17	204,900,193	12,052,952	50.74**
(L x T) + I	52	86,240,898	—180,390	1973	51	69,747,968		
Testing adjusted I-means					1	14,536,009	14,536,009	13.16**

** Highly significant.

possible effects of treatment on the fertility of the soil may explain this result. The adjusted means of the other factors and interactions may be tested.

Other variables such as the physical and chemical properties of the soil and the weather conditions can also be used in a covariance analysis to explain the behavior of the yielding performance. These models may be used in testing the performance of new rice varieties grown in several locations of any country.

Distributions of Rice Yields

In predicting field crop yields there is a tendency to overestimate crop production and productivity. Information on the distribution of crop yields according to fertilizer levels, soil classes, etc., are important in correcting this element of overestimation.

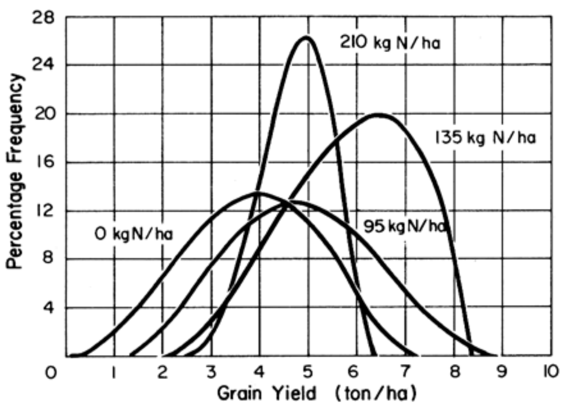


Fig. 5. Estimated percentage distribution of grain yield of Milfor-6(2) at selected nitrogen levels. IRRI dry season, 1962-1966.

Yield data for three varieties, namely: Milfor-6(2), Chianung 242, and PI 215936 from experimental fields at the Institute from 1962 to 1966 dry and wet seasons, accumulated by nitrogen levels, were used to derive probability distributions. The grain yields of Milfor-6(2) for the dry season were used as a model (Fig. 5). These distributions were derived by using the method of moments, and the trends for the other two varieties follow that of Milfor-6(2). Note the changes in the kurtosis and skewness of the curves as the nitrogen level is increased from 0 to 95, 135 and 210 kg/ha. Thus, the mean, median, and mode will also change. The data for the wet season are being analyzed.

Most of the data suggest Pearson's Type I function which is described as:

$$f(x) = k(1 + x/a_1)^{m_1} (1 - x/a_2)^{m_2}$$

where

a_1 and a_2 are roots of the quadratic term of the integral derived from the differential equation of the density function (intercepts on the X-axis),

and

k, m_1 and m_2 are functions of the differential equation parameters.

As may be noted in Fig. 5, the values of a_1 (lower limit on X-axis) and a_2 (upper limit on X-axis) are finite. The m coefficients were positive, giving rise to the bell- or bowl-shaped curves.

Because of the contrast among the estimated distributions, the study of decision-making under risk in rice farming should not only be based on expected yields and variances but upon skewness as well. Use of the mode or median in forecasting may be preferred, since in the former the probability of coming close to the observed values is maximized, and in the latter there is an equal chance of under- or over-prediction.

The yielding potentialities of four varieties are shown in Fig. 6. For comparative purposes, data for IR8 in the dry season of 1966 from 295 experimental plots are included in this presentation. First and second order models were considered and the analyses of variance show that a reduction in the experimental error is achieved with the use of a quadratic term. A cubic term will not improve the fit.

Considering all inputs for the production of IR8, a cost function was constructed with the following components: (a) fixed cost: seedbed preparation, land preparation, transplanting, land rent, irrigation fee, seed, insecticides (material and labor) and weeding; and (b) variable cost: fertilizer (material and labor), harvesters' share (1/6), cleaning and drying (3 man-day/ton), interest (1 %/month) and sacks (₱1.20/sack). The relationship of the return function and the cost function is indicated in

Fig. 7. Maximum net returns are obtained at the given nitrogen level at ₱15 and ₱25/cavan (44 kg) of rough rice. The optimum yields are obtained at about 130 and 170 kg N for P15 and ₱25/cavan of rough rice, respectively.

With these distribution functions as background, the farmer may attempt to control variability of income during a number of crop years and resources will be allocated on the basis of information such that the probability is low for the occurrence of a loss. A resource Q may be partitioned into

$$Q = Q_A + Q_B$$

such that

$q = Q_A/Q$ is the proportion allocated to variety A with variance σ^2_A.

and

$(1 - q) = Q_B/Q$ is the proportion allocated to variety B with variance σ^2_B.

If varieties A and B are planted in sequence or at the same time, then the variance of the total $(T = A + B)$,

$$\sigma^2_T = \sigma^2_A + \sigma^2_B + 2\,\varrho\sigma_A\sigma_B,$$

is a minimum if

$$q = 1/[1 + (\sigma^2_A - \varrho\sigma_A\sigma_B)/(\sigma^2_B - \varrho\sigma_A\sigma_B)]$$

where

ϱ = correlation coefficient of varieties A and B.

Estimates of these parameters are obtained from distributions of rice yields.

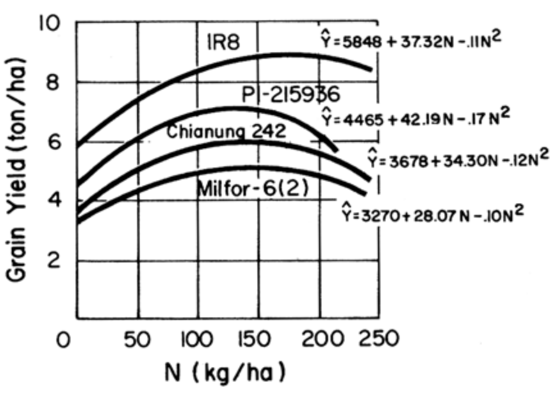


Fig. 6. Yielding potential of different varieties. IRRI dry season, 1962-1966.

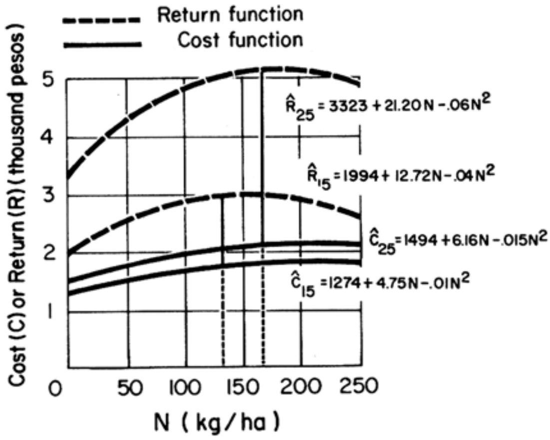


Fig. 7. Costs and returns to nitrogen fertilization of IR8 at alternative prices of rough rice.

In the farmers' paddy fields in the province of Laguna, Philippines, one of the most popular sequences is variety Intan in the wet season (A), followed by the same variety in the dry season (B). The estimated minimum σ^2_T for this sequence with two levels of nitrogen is given in Table 6. These variances may be used to evaluate the risk or uncertainty in obtaining certain levels of productivity.

Table 6. Estimated minimum σ^2_T for two nitrogen levels in the wet and dry seasons. Variety Intan, Laguna, Philippines, 1965.*

Fertilizer application† (WS-DS)	r	q	(l-q)	σ^2_T(000)
O - O	.8	.443	.557	332
	.2	.486	.514	367
O - w	.8	.826	.174	616
	.2	.584	.416	425
w - O	.8	.315	.685	572
	.2	.453	.547	385
w - w	.8	.706	.294	668
	.2	.552	.448	452

* Data were collected in conjunction with the Crop and Livestock Survey of the Philippine Bureau of Agricultural Economics.

† O - no fertilizer
w - approximately 10 kg/ha N.

Experience in crop cuttings indicated that 1-sq m cut gave a bias of up to 11 percent while the 9-sq m cut gave an upper limit of about 4 percent bias in the estimation of productivity of rough rice per hectare. With the present variability in the farmer's paddy field, the sampling unit must be at least 9 sq m so that the bias will not exceed 4 percent.

Data from the interview method in three barrios showed that there was an average underestimation of 3 percent. Survey data from the province of Laguna, Philippines, for crop year 1966 (July 1, 1965 to June 30, 1966) were collected to explain the components of this negative bias (Table 7). Generally, the farmer's production report, including landlord, tenant, and harvester shares, and seeds, will account for 96.2 percent of total production. Usually, the unreported components of production related to other expenses, gleaning, heaping or "paulo", and extra shares given to friends and relatives account for 3.8 percent of total production. The degree of the bias will depend on the type of culture (Table 7). These adjustments, if applied to the current production figures, will have relevance to agricultural policies on imports and on the economic analysis of production and consumption.

Three types of responses on hectarage from a sample of 826 rice farmers were obtained, namely: those giving direct hectarage (22%), those giving hectarage via seed rate (74%), and those giving local units (4%). As a follow-up to the 1966 survey, the possible biases in reporting hectarage are presently being investigated.

Data from the 1965 survey were also utilized in deriving simple but efficient estimation procedures such as univariate and multivariate ratio estimators. The experiences to date on the use of this more efficient estimation procedure can be found in Table 8.

These findings will be relevant to the possible

Table 7. Components of rice production in percent, by culture, Laguna, Philippines, 1966.*

Culture†	Total production‡ (000 cavans)	Total production‡ (%)	Reported§	Unreported components: Other expenses‖	Gleaning	Heaping	Extra shares to relatives and friends¶
I 1st crop, L, I	(741)	100	96.4	1.5	0.6	1.0	0.5
II 2nd crop, L, I	(246)	100	95.8	1.4	0.7	1.4	0.7
III 1st crop, L, NI	(137)	100	94.9	3.1	0.5	0.8	0.7
IV 2nd crop, L, NI	(1)	100	99.7	0.3	—	—	—
V Upland	(34)	100	98.0	—	1.0	0.6	0.4
Provincial total	(1,159)	100	96.2	1.6	0.6	1.1	0.5
Total with standing crop	(1,433)						

* The data were collected in conjunction with the Philippines Bureau of Agricultural Economics Annual Crop and Livestock Survey for Crop Year 1966.

† L means lowland; I, irrigated; and NI, non-irrigated.

‡ Does not include standing crop.

§ Includes landlord, tenant, and harvester shares and seeds. Previously reported as total production.

‖ Includes irrigation fees and other accounts payable.

¶ Includes weeder and thresher shares.

Table 8. Relative efficiencies of ratio estimators for rice farms, selected provinces, Philippines, 1960-1965.

Province	Characteristic	Concomitant variable	Estimator*	Relative efficiency† (%)
Laguna‡	Production	Area (sample)	sub-strata	142 to 695
			strata	136 to 618
		Area (list)	sub-strata	1163 to 11683
			strata	568 to 3681
	Area	Production (sample)	sub-strata	287 to 1243
			strata	191 to 1087
		Production (list)	sub-strata	366 to 2116
			strata	147 to 2540
		Number of farms (list)	strata	729
		Production (list) + No. of farms (list)	strata (multivariate)	749
	Carabaos	Number of farms (list)	sub-strata	362 to 854
			strata	213 to 348
Abra§	Production	Area	strata	682
		Number of farms		426
Bulacan§	Production	Area	strata	6670
		Number of farms		2000
Pampanga§	Production	Area	strata	3830
		Number of farms		1290
Tarlac§	Production	Area	strata	6180
		Number of farms		2810
Zambales§	Production	Area	strata	3500
		Number of farms		4740

* Univariate separate ratio estimator unless specified.
† X-only estimator as basis of comparison.
‡ David, I.P. Development of a statistical model for agricultural surveys in the Philippines. M.S. Thesis. May 1966. UPCA Library. Tables 6.4 to 6.8 and Table 6.11.
§ Oñate, B. T. Estimation of palay production with the 1960 agricultural census as the sampling frame. Phil. Stat. *13*(3): 114-131. Sept. 1964. Tables 3a to 3c.

adjustments of figures on rice production, hectarage, and productivity.

Since most of the agricultural surveys utilize the farm household as the basic frame, there will be understatements of the number of livestock and poultry because non-farm households are not included in this frame. The count for livestock and poultry can be incorporated into the listing operation which is a general requirement of most surveys. In urban areas, these counts can be obtained from other national surveys on the demographic and social conditions of the population. These two sources will generally correct these understatements. For example, in the Philippines 1960 agricultural census the percentage of livestock and poultry reported by the non-farm households to the total number ranged from 18 for carabao, 30 for hog and almost 21 percent for chicken. For the 1966 survey for Laguna, the understatements of this livestock and poultry were 16, 42 and 30 percent, respectively.

These results are of special relevance to procedure and methodology for the coming 1970 World Census of Agriculture.

Cooperative Projects

Food consumption surveys

Variability studies of data from household food consumption surveys of the Philippines were undertaken in cooperation with the Food and Nutrition Research Center (FNRC). These studies attempted to evaluate the variabilities of data by food and by nutrient groups in eight regions and also data collected in the municipality of Morong, Rizal. Some of the pertinent findings are as follows:

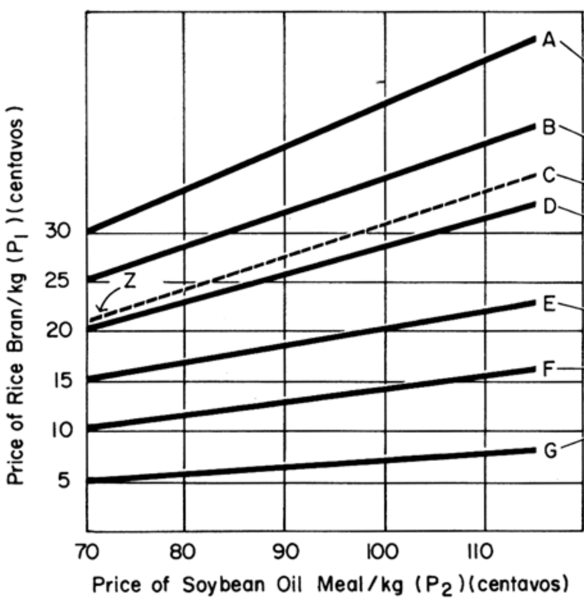
1. The household food consumption survey (HFCS) is a subsample of the Philippine Statistical Survey of Households (PSSH). Precise per capita consumption estimates can be derived from subsamples of national household surveys. Eight of the ten regions have been surveyed. Estimates of per capita consumption of rice and the other food groups are given for the eight regions. A lower limit national daily per capita estimate of 265 g of rice from these regional estimates is higher than the current national per capita estimate of 217 g used by the National Economic Council in the assessment of supply and demand situation for rice.

2. The 1959 survey in metropolitan Manila indicated that there exists no difference in rice consumption between the 3-day and the 5-day weighing methods. Tests also showed that rice consumption in the 1958 dry season was the same as in the 1959 rainy season for the comparable 3-day survey.

3. The Morong survey demonstrated that on the average there exist no differences between the weighing and the 24-hour recall methods in either household, per capita, or per consuming unit for all food and nutrient groups. Also, within a survey week, no differences were detected between sampling dates and between days within sampling dates. In the comparison of methods, sampling dates, and interaction means, statistical precision is increased in the use of the consuming unit as the universe of discourse.

4. Ratio estimators with number of members

Fig. 8. Least-cost rations for pork production: Rice bran and soybean oil meal combination.*



Price ratio P_1/P_2	Mixtures (100 kg basis) Rice bran (RB)	Soybean oil meal (SOM)	Vitamin and minerals premix †
0.43	71.1	24.5	4.4
0.36	74.3	21.3	4.4
0.31	76.3	19.3	4.4
0.28	77.8	17.8	4.4
0.21	81.6	14.0	4.4
0.14	85.8	9.8	4.4
0.07	90.4	5.2	4.4

* Source of experimental data: Oñate, B. T., J. A. Eusebio and E. U. Quintana. Least Cost Ration: Surface production and substitution rates of rice bran and soybean oil meal rations for growing hogs. Phil. Agric. 50(2). 1966.
† 3.4 kg macro-mineral (Ca, P, Na, Cl); 1 kg vitamin-mineral premix.

in household as concomitant variable will result in considerable gain in precision in the estimation of total rice consumption in households. The average gain in statistical efficiency is about 425 percent in selected urban and rural strata. Estimates of the components of variance are given for each food and nutrient group. These estimates will be used in a multivariate procedure of obtaining the optimum number of days, number of households and number of barrios.

5. The regional estimates on rice consumption and other food groups may be used in the assessment of supply and demand of food on the national level. For example, the improved estimates of rice production must be incorporated into the supply side. In addition, future HFCS should utilize the 24-hour recall method and the survey conducted for only one day. However, quality control checks in a time series must be instituted on a small sub-sample for testing the performance of the weighing and recall methods and the equality of consumption between two days of the week. For additional statistical precision, ratio estimators may be incorporated into the estimation procedures for totals.

Least-cost ration: rice bran and soybean oil meal rations for growing hogs

The experimental data on gain in weight of hogs collected by the UPCA Department of Animal Husbandry from feeding experiments using rations with different combinations of rice bran and soybean oil meal and containing protein ranging from 12 to 18 percent were utilized to estimate a Cobb-Douglas production function of the form:

$$\hat{Y} = 1.368X_1^{0.436}X_2^{0.351}$$

where

$\hat{Y}$ is the biweekly gain in weight in kg,
X_1 the amount of rice bran (RB) in kg,

and

X_2 the amount of soybean oil meal (SOM) in kg.

This equation may be written in the form

$$X_1 = [\hat{Y}/1.368X_2^{0.351}]^{(1/0.436)}$$

which shows the combination of feeds (RB, SOM) that can be used to produce a given gain in weight ($\hat{Y}$). The cost of the ration for any given gain per pig is a minimum when the substitution rate is inversely equal to the feed price ratio. Thus,

$$dX_1(RB)/dX_2(SOM) = 0.804X_1/X_2 = P_2/P_1$$

or substitution rate of X_1(RB) to X_2(SOM) = P_2(Price of X_2)/P_1(Price of X_1). This relationship was utilized to derive the least-cost rations for pork production with rice bran and soybean oil meal as the basic feed ingredients. These least-cost rations are given in Fig. 8 for actual ranges of market prices of rice bran and soybean oil meal. As an example, the Z in the figure indicates that if the price of rice bran is ₱0.22 and that of soybean oil meal is ₱0.70 or a ratio of 0.31, then the least-cost ration will be described by letter C. Thus, farmers can easily use this chart in mixing their own feeds with rice bran as the major ingredient.

Miscellaneous

The Department was involved in more than 1,500 consultations with the Institute staff and scholars, and with research workers from the University of the Philippines College of Agriculture, the Philippine Bureau of Plant Industry and Agricultural Productivity Commission, the AID Spread Project in Bay, Laguna and in Mayantoc, Tarlac, Institut Pertanian in Bogor, Indonesia, and the ECAFE Lower Mekong Basin Project, Thailand. More than 1,500 analyses were performed with an average of four variables and an average sample size of 105 observations. Interpretation of results was a basic part of these services.

The statistician taught four courses in statistics at the University of the Philippines Graduate School, three at the University of the Philippines College of Agriculture, Los Baños and one at the University of the Philippines Statistical Center in Manila.

A total of 600 copies of the manuscript "Statistics in Rice Research" has now been distributed to agricultural research workers in 15 countries. Parts I, II and III of this manuscript are undergoing revisions so that suggestions from these research workers may be incorporated in the text before publication.

Experimental Farm

The Experimental Farm provides a field labor force for other Departments of the Institute, and is responsible for seed multiplication and combatting weeds and pests on the station. This year a substantial quantity of IR8 seed was produced for distribution in the Philippines and to the rice-growing countries throughout the world.

Multiplying IR8 seed was one of the responsibilities of the experimental farm during the year. The photograph shows the harvested crop being brought in for threshing.

Seed Production

Since it was clear that the demand for seed of the new variety, IR8, would far exceed supplies, as much land as possible was devoted to multiplying the meager quantities of seed available. Land normally used for experimental purposes was converted to seed production. Some of this land, however, could be used only on the condition that little or no fertilizer was applied; as a consequence some areas received suboptimal amounts of nitrogen fertilizer and hence did not yield as well as could normally be expected. To make maximum use of what seed was available, the seedlings were grown in raised seedbeds and transplanted 1 plant/hill. Thus, from 2 cavans (88 kg) of seed, nearly 14 ha were planted. From this area, 77.1 tons of extremely clean seed (14% moisture) were harvested, giving an average yield of 5.6 ton/ha.

The distribution of this seed has been described in the Varietal Improvement section of this report. The bulk of it was sent to various public and private organizations in the Philippines. In addition, however, the Experimental Farm supervised the distribution of 2 kg samples, free of charge, to 2,359 Filipino farmers. According to the addresses given by these farmers, IR8 seed has now been distributed to growers in 48 of the 56 provinces in the Philippines.

Seed was also produced, either for multiplication or for eating quality tests, of 7 Institute selections (IR52-18-2, IR14-149-3, IR6-53-2, IR9-60, IR5-47-2, IR3-66, and IR3-36), 5 indica varieties (Peta, Milagrosa, Azucena, Mangarez, and BPI-76), 3 ponlai or japonica varieties (Chianung 242, PI 215936, and Fujisaka), and a United States hybrid. A total of 22.1 ha was used for seed production; 6 ha of this were still to be harvested at the year's end.

The Experimental Farm collaborated with the Agronomy department in experiments on farmers' fields; the results are described in the Agronomy section of this report.

Over 64 ha of rice were planted in connection with experiments and demonstrations conducted by other departments. The area planted (in ha) for each department was as follows: Agronomy, 28.4; Varietal Improvement, 19.7; Entomology, 8.3; Plant Physiology, 2.4; Plant Pathology, 2.1; Communication, 2; Agricultural Engineering, 1.4.

Rat Control

The electric fence described in the 1965 Annual Report was further modified and improved. Whereas formerly the chicken wire was mounted on the levees, it is now erected in the water 75 to 100 cm from the levees; and instead of electrifying the chicken wire itself, the charge is carried by 2 strands of wire running along the top of the netting. This latter modification has been made possible by using plastic insulators to support the charged wires, rather than by insulating the bamboo posts with plastic or rubber sheets. The rats, wet after swimming to the fence, climb the netting and are either killed or thrown back when they encounter the electrified wires at the top.

Rat infestation of the fields has been kept to a minimum, although some experimental plots have suffered some damage. From January 1 to December 14, 1966, 25,436 rats were killed by the electric fence, an increase of some 5,000 over the previous year.

A safety device for the fence, cutting off electricity and either lighting a bulb or starting a buzzer when the fence is accidentally touched by people or large animals, has been tested successfully.

Office of Communication

Through publications, exhibits, films, training programs, and related activities, the communication program emphasized increased rice yields as realistic goals for rice-producing countries. The world-wide publicity generated by the mass media incident to the release of the new rice variety IR8 tended to obscure temporarily the fact that profitable increases in rice production depend upon proper management as well as improved varieties. These management systems, in turn, require technically competent extension workers, adequate information and instructional materials, available technical inputs, and some means of financing these investments. Most countries usually lack one or more of these essentials.

While the public read glowing accounts of the "miracle rice", as it was called by the press, Institute informational efforts tried to de-emphasize the miracle and to focus the attention of responsible government officials and the public on the total range of factors upon which the solution of rice problems depends.

One of the major communication themes related to the cost-benefit return ratios associated with the appropriate use of fertilizers and the control of insects and weeds. At the same time, the office worked closely with personnel of national agencies in the Philippines on expanding programs of local applied research or field tests of new varieties and cultural practices and on training and establishing an effective corps of rice production specialists.

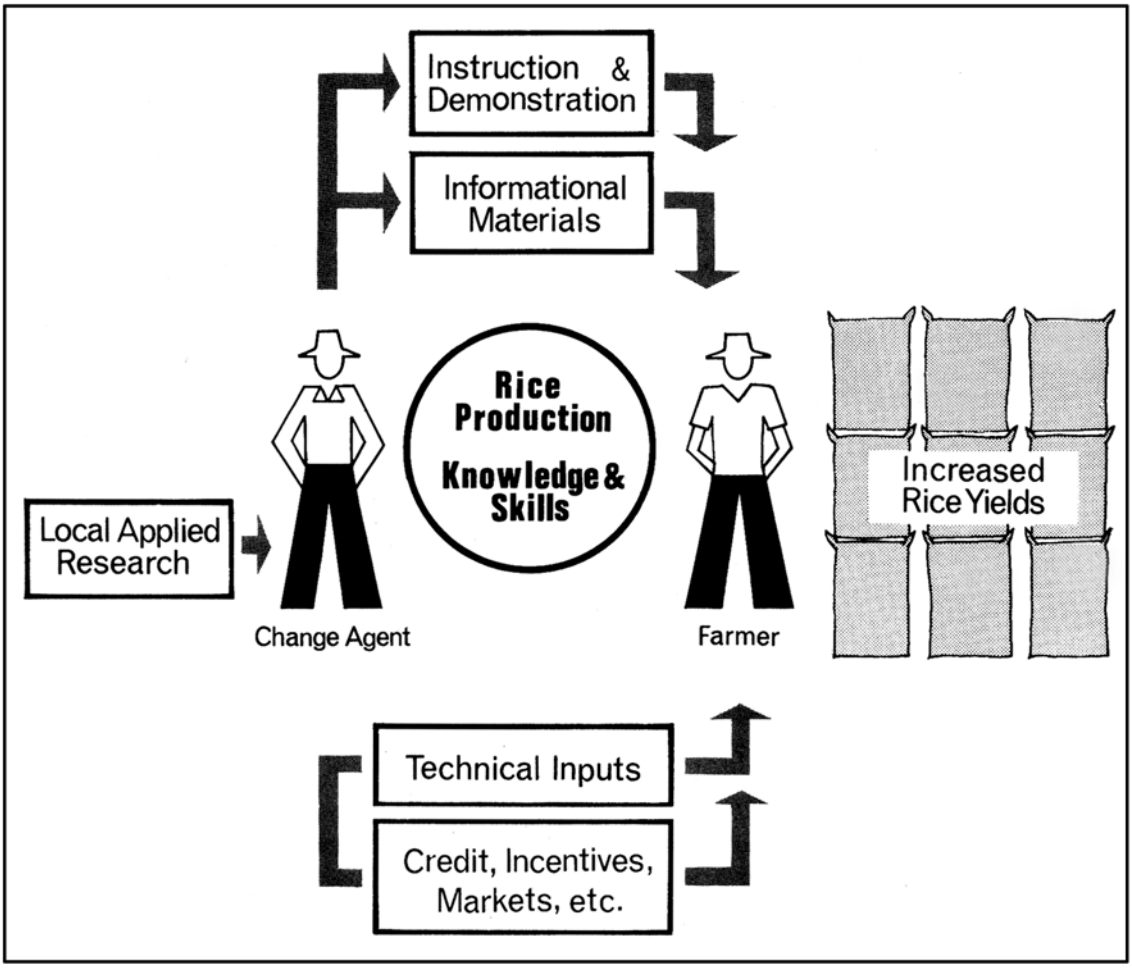


Fig. 1. Factors associated with increasing the farmer's ability to raise rice yields.

Many of the factors associated with the farmer's ability to increase rice yields are outlined in Fig. 1. At any point in time, the farmer's rice yield is a function of his rice production knowledge and skills and the availability of technical inputs, plus such other factors as credit, markets, incentives, and land ownership-tenancy arrangements.

Research progress, such as a new insecticide or variety, outdates the farmer's knowledge and skill and necessitates instruction and information. These programs are the responsibility of national extension services with hundreds or thousands of such local workers, identified in Fig. 1 as the "change agent." As the local worker is responsible for teaching, advising, and helping the farmer, it seems reasonable to argue that he should be able to grow rice at least as well as the farmer. If he can not, he may have difficulty in winning and holding the farmer's confidence and little hope of teaching him new practices. It is difficult for one to teach what he does not know.

Similarly, if the change agent does not have the means of testing new practices and varieties in the local environment, he runs the risk of teaching, demonstrating, or advocating the adoption of something that may not succeed locally. He needs to establish ways to validate his messages if such a mechanism does not already exist and operate effectively in his country.

Thus the Office of Communication continued to stress, in its cooperative work with national agencies, the importance of employing and supporting competent change agents and associating their field activities with a system of applied research to test the local suitability and adaptability of new practices.

As in other years, two basic orientations guided the staff in its work to support the mission of the Institute: (a) To work with and through national agencies, public and private, in such ways as to help build and strengthen these, and (b) to define the objectives of communication activities and materials in terms of the desired changes in the behavior of the audiences addressed.

Significant activities of the year toward achieving the objectives of the office are presented below in five categories: (a) Dissemination of information; (b) training in rice production and communication; (c) applied research on rice; (d) communication research, and (e) consultation and liaison.

Personnel changes during the year included the addition of a graphic designer-production coordinator to assist with the publication and exhibit programs, and three research assistants to help with the applied research and rice production training programs.

Dr. Arthur A. Muka, extension entomologist at Cornell University, arrived in late 1965 and continued with the office until September. During this time, he helped supervise applied research activities on the control of the rice stem borers, instructed the photographers in special techniques for making photographs of insects, and assisted them in producing a set of identification slides of important rice insects.

Dissemination of Information

Publications

Reporting for duty late in 1965, the new editor assumed direct supervision of the Institute publication program.

One of the major changes was a shift in editorial approach and format of *The IRRI Reporter,* a bi-monthly publication started a year earlier. Under the new procedure, the editor writes the major articles appearing in the publication, these being semi-technical in nature to serve a wide range of scientists, educators, administrators, and extension workers. In some articles, he integrates and interprets the results of related research projects of the Institute, while in others, he may present material on a particular rice problem or research objective.

Despite efforts to condense and shorten the 1965 Annual Report, the total number of pages was 360. The editing, illustrating, proofing, and supervising of the production of the 3,000 copies through a commercial printer occupied much of the editorial staff's time for 6 months.

Continuing the policy of encouraging scientists to publish the results of their research through the established professional journals, the editors processed some 40 manuscripts. Reprints were purchased for circulation to interested scientists.

Four technical bulletins were published and editorial work begun on two others.

Another series of publications, technical papers, was started—these to report developments in research methodology, transient items of research results, and miscellaneous matters of immediate interest to rice research and extension workers. Two technical papers were published.

Editors completed work during the year on galley and page proofs for the book based on the symposium of the major insect pests of the rice plant. This book, of approximately 700 pages, will be published in 1967 by The Johns Hopkins Press.

Addition of a photo-direct process for making offset plates increased the efficiency and productivity of the printing operation and reduced the amount of work sent to contract printers.

Informational materials

Informational materials produced included a film, instructional sheets to accompany the release of the IR8 seed, and a rice production manual, the latter being prepared and published by and through the Rice Information Cooperative Effort.

Work begun in mid-1965 on the film, "Harvest of Energy," was completed in time for a special presentation before the International Rice Commission at New Delhi. This 26-

minute, color film was designed to depict the potential of the rice plant as an efficient converter of solar energy into calories for man.

Through picture and narration, the film outlines how plant breeders, through selection and cross-breeding, produce the short, stiff-strawed varietal types. It also illustrates the problems of insect, disease and weed control, water and fertilizer management, and other practices necessary to help the rice plant realize its genetic capabilities. The film features several time lapse and special closeup photographic sequences.

Produced as the Institute's special contribution to the International Rice Year of the Food and Agriculture Organization, the film will serve a variety of informational and educational roles in many countries. After the initial distribution in early 1967, prints may be ordered through the Institute.

Planting and cultural practice instructions for the IR8 seed released by the Institute were printed in English and Tagalog and placed inside the package of seed in a heavy, printed envelope. These instructions also were released to the press and formed the basis of leaflets and brochures prepared by government agencies and private growers who multiplied the seed.

When the IR8 was officially named in late year, press releases and photographs were distributed to the agricultural press throughout the world.

A STUDY IS NOW UNDERWAY TO DETERMINE the experiences of the some 2,300 farmers who came to the Institute and received 2-kg bags of IR8 seed, along with instruction printed in English and Tagalog.

Throughout the year, reporters, photographers, and motion picture film producers came to the Institute in a steady stream to obtain information about IR8 and other activities. Among the internationally circulated media carrying information about the new rice and related topics were the *National Geographic, Saturday Review of Literature, LIFE International, TIME,* Associated Press and United Press International, and *FREE WORLD.*

Several new agricultural films, produced by such sponsors as the Japanese fertilizer industry, an insecticide manufacturer, and the United Nations, featured work of the Institute.

Working closely with the Institute scientists, the staff of the RICE project completed the manuscript for a rice production manual for agricultural extension workers. The Department of Agricultural Information and Communications, University of the Philippines College of Agriculture, published a limited edition of this comprehensive text while printing and financing arrangements were being made for large-scale production and distribution of the manual within the Philippines. With minor adaptations it is expected that the manual will serve similar purposes in other countries, and 200 copies were sent to East Pakistan in October for use in short courses.

In addition to the manual, the RICE staff produced 21 press releases and feature stories for Philippine newspapers and magazines.

Displays and visitors

Other communication activities were directed to the development of materials and procedures for the efficient handling of the ever-growing number of visitors.

With the employing of a graphic designer, work moved ahead rapidly on the design and construction of exhibits and displays for use in the halls and auditorium.

The series of display plots close to the Institute headquarters was continued, while another series was placed along the national highway at the back of the experimental farm. At the suggestion of the Institute, the governor of Laguna Province had the road widened to permit vehicles to park along the display site, and, in addition, built a concrete sidewalk along the length of the entire display area.

This location now permits the display of a wide range of rice-growing problems and potentials, including symptoms of various diseases and insects, the response to fertilizer, and the differences in varietal types.

At the same time, design and management of the plots provide useful demonstration experience for the rice production trainees.

Training in Rice Production and Communication

Demands for and activities associated with training in rice production and communication increased rapidly during the year with more agencies, countries, and organizations becoming interested in enrolling personnel or in supporting the training efforts. At the same time, some national agencies made notable progress toward institutionalizing their rice extension programs and in-service development activities.

Philippine agency establishes network of rice specialists

When the first group of 10 employees of the Agricultural Productivity Commission (APC), the national extension organization, completed training at the Institute in June, 1965, 9 of these were assigned to provincial posts. There they were allocated some rice land and assigned five extension workers for a year of training. At the end of that year, in May-June, 1966, these 45 workers came to the Institute, in two groups, for 2 weeks of special testing and refresher training.

At the completion of these two courses, the APC established a network of regional and provincial rice production specialists, staffing this organization with these "first" and "second" generation trainees. Generally, those who had trained at the Institute for 6 months to a year were placed in the regional posts.

Establishing this network, however, helped to dramatize some of the problems yet to be solved if an extension program is to be truly effective in a developing country. One of the major problems has been a lack of finances to increase the salaries of the specialists so that they will not be tempted to take more attractively paying commercial positions, and to provide them with the minimum of materials and travel funds necessary to carry on their work.

Concurrently, some of the specialists were borrowed to serve on specific inter-agency rice "crash" programs; some found it difficult to acquaint co-workers and superiors with the nature of their new role. The lesson here seems obvious; it is not enough to train people to perform a new role in an organization—the organization must be guided in how to make maximum use of people prepared to carry out roles new to the organization.

Second year-long class begins in June

Encouraged by the successful performance of the first group of trainees, several agencies requested a similar program for selected members of their staffs. After several months of discussing the possibilities with representatives of various agencies, and interviewing some 60 candidates for training, the second class was launched in June, 1966.

Unlike the previous class in which all of the trainees came from the APC and were financed by the Institute, the 29 members came from several agencies and all but two were financed by sponsors other than the Institute. Philippine agencies enrolling persons included the APC, Bureau of Plant Industry (BPI), College of Agriculture, Tarlac College of Technology, and several private or semi-private groups—United Church of Christ, CAT Planters Cooperative, Philippine Seed Corporation, and the Tiruray Cooperative. Financial sponsors included the Agency for International Development, Rice and Corn Production Coordinating Council, Agricultural Development Council, Asia Foundation, provinces of Laguna and Tarlac, Bicol Development Planning Board, and the private sponsors. Out-of-country enrollments included one each from the Sudan, Nigeria, Pakistan, and India.

This course was similar to that conducted in 1965 in that it emphasized learning practical paddy skills, the science of rice culture, rice problem diagnostic skills, applied research and field demonstration techniques, and the principles of effective communication. At the end of the first 6 months, the trainees were placed, in teams of two, in practical production situations throughout the Philippines. Here, under close supervision, they will make all of the management decisions incident to growing a crop of IR8 under field conditions.

Rice production short courses in East Pakistan

During a visit to East Pakistan in September, the rice production specialist helped organize a series of 2-week short courses for agricultural extension workers. Two members of the Office of Communication staff went to East Pakistan to help teach the first course for 60 persons, and two others from the Institute performed similar roles for the second course immediately following. Their Pakistani co-workers conducted a third course.

Subjects emphasized in these courses were the practical field skills, particularly in land preparation, rice problem diagnostic skills, and cultural practices appropriate to growing IR8 and similar short, stiff-strawed, nitrogen-responsive varieties.

Orientation and briefing on tropical rice culture

Throughout the year, various United States agencies posting agriculturists abroad sent these to the Institute for a short orientation on the problems and possibilities in tropical rice culture. Some persons came for only a day, while others spent up to a week. Because of the limited numbers in each case, usually one or two persons, the instruction or briefing was tutorial in nature.

At the same time, the staff cooperated with the College of Agriculture in helping organize and conduct short courses underway there for Philippine agencies and such groups as the International Voluntary Services.

Applied Research on Institute Results

Applied research or field testing under a wide range of Philippine conditions, begun in 1965 with the BPI, was expanded to include cooperative work with the APC. Most projects involved the rice production specialists who had trained at the Institute.

RICE PRODUCTION TRAINEES LEARN FIRST-HAND some of the problems associated with lodged rice when they harvest their applied research plot to learn about the influence of spacing on plant growth. Immediately behind them are plots established along the national highway opposite the area where the provincial governor has widened the road and provided a sidewalk for farmers to view the demonstrations.

Three new research assistants, employed in late 1965, helped to prepare the plans, package the materials, conduct visits to the field sites, and process the resulting samples and materials. The Department of Statistics analyzed the data.

Recognizing the value of these systematic field tests of new research findings before recommending them to farmers, the two agencies took positive action to build such efforts into their continuing operations. Each agency stationed a man at the Institute for the second 6 months of the year for on-the-job training in carrying on certain of the operations. By the end of the year, both agencies had assumed administrative responsibility for the programs in 1967, with the Institute supplying the plans and necessary materials.

Coordination of Institute and APC operations was facilitated when that agency designated one of the former trainees as a liaison officer between the two organizations.

Stem borer control plots

Early in 1965, the Institute and the BPI agreed to conduct a series of field tests on new methods of stem borer control. These projects, conducted in 16 provinces during the wet and dry seasons, test under widely differing environmental conditions the effectiveness of new chemicals and methods of application.

Trials in all provinces follow a common plan including specific varieties, treatments, and cultural practices. Quantitative data from the tests are analyzed to establish a basis for realistic recommendations for farmers.

Results of the first series of plots in the 1965 wet season included yield increases as great as 1,982 kg/ha as the result of using lindane granules to control stem borers. This represented an increase of 110 percent over the non-treated plots and a cost: benefit ratio of more than 4:1 at current prices of the insecticide and paddy rice.

In the second series, during the 1966 dry season, protected plots yielded as much as 3,376 kg/ha more than those not protected. This indicates the relative seriousness of the stem borer in the dry season. Data from the third series of trials (1966 wet season) are now being processed.

Uniform rice variety trials

Beginning with the 1966 dry season, APC graduates of the rice production training program established uniform rice variety trials in 10 provinces to obtain specific data on the adaptability of a number of new rice selections and varieties to the prevailing environments. Success of these trials led the APC to establish a second series in 25 provinces during the 1966 wet season.

Uniform rice fertilizer trials

Data obtained from the first series of plots managed by APC personnel in the 1966 dry season indicated clearly that significant increases in rice yields can be obtained when a nitrogen-responsive variety is fertilized properly. The results from any given test will show which fertilizer treatment can be expected to produce the greatest amount of grain per hectare. Economic analyses, in addition, indicate which treatment is most likely to return the highest monetary benefit.

With the increased availability of seed, IR8 was used in establishing more than 40 uniform fertilizer trials in the 1966 wet season. In addition to recording the yields from the 10 fertilizer treatments used, the APC personnel responsible for the plots also noted the incidence of disease and other problems with the new variety. After processing and analyzing, the data will be useful in formulating fertilizer practices in specific areas.

Aerial application of lindane and other field activities

Among several isolated field activities of the year was a test of the feasibility of rice stem borer control through minimum applications of lindane granules from the air. For this test, in cooperation with the BPI and the manufacturer of the gamma benzene hexachloride used, four contiguous areas of 10 hectares each were established. The first area received one early application of lindane, the second a late application, while the third was treated twice: early and late. The fourth area served as a control. The low incidence of stem borer infestation in the area made it difficult to obtain conclusive data.

In another field trial, personnel of the office cooperated with the owner of a large irrigated farm in Central Luzon in re-establishing rice culture there during the dry season. By determining that the principal problem was stem borer control, the staff was able to introduce appropriate cultural methods and to supervise the owner's labor force in producing yields, on several hectares each, of the order of 4.5 and 7.5 m ton/ha with Milfor-6(2) and IR8, respectively.

Communication Research

Research activities, although limited in scope and volume, are designed to accomplish these objectives: (1) to provide some data useful in evaluating the efficiency and effectiveness of Institute programs in publications, training, international symposia, and the like; (2) to document some of the principal variables and processes involved in social and technological change associated with rice cultivation and production; (3) to provide research topics and guidance for a limited number of research scholars engaged in master's programs in scientific publication, agricultural extension, education and training, or communication strategy; and (4) to interest social scientists in the work of the Institute and the related problems of effecting changes in tropical rice culture.

Because of the limited staff, most of these objectives are pursued through the work of other persons and organizations. This approach includes cooperative research projects with local institutions and individuals or providing an operational base, some local financing, and administrative support for research by universities and research organizations of other countries.

The principal topics in which the present staff has been most interested in studying, in addition to research on Institute publication and training, are the institutional or organizational variables associated with social and technological change, and the social, cultural, economic, and psychological variables associated with the acceptance and use of new rice technology by farmers, landowners, and others at the farm or community level.

Related topics of interest are ways to increase the effectiveness of training programs for rice extension workers, the problems of cross-cultural adjustment, particularly for persons being trained, outside their own country, the selection, training, and administration of overseas technical assistance personnel, and scientific information processing, storage, and retrieval.

Because of the continuing inability to fill the position for a social science research assistant, research efforts were limited to thesis projects of research scholars of the Institute and graduate students at the College of Agriculture, working under the guidance of the communication specialist. One study was completed and three new ones launched.

Effects of demonstrations on knowledge, understanding, attitude

The completed study attempted to assess the effects of field demonstrations on the knowledge, understanding, and attitudes toward the choice of a rice variety and the use of fertilizers on the rice crop. Unlike most diffusion studies, the emphasis was upon the educational influence of the demonstration rather than the actual change in or adoption of practices.

In this study, "knowledge" appraisals were based on the ability of farmers to state or recall specifics, while responses to "how" and "why" questions provided much of the data for assessing "understanding."

Sixty farmers in each of two physically separated communities (barrios) were interviewed twice—before and after demonstration plots had been grown and harvested in each barrio. The demonstration variables included a locally grown rice variety, a rice variety new to the area and different in plant type (Milfor-6(2)), and three levels of ammonium sulfate fertilization.

Between the first and second interviews (during which time the demonstrations were conducted), no significant increases in knowledge of rice varieties were found, but knowledge of fertilizers increased significantly among non-users of fertilizer. Understanding of rice varieties and fertilizers increased significantly, especially among farmers who usually have high yields.

Generally, knowledge of rice varieties correlated with understanding of rice varieties among high yield farmers. Knowledge of fertilizer was associated with users and non-users in one barrio but only with users in the other.

At the second interview, the number of farmers willing to change rice varieties had increased as well as the number who were willing to change the kind and rate of fertilizer application.

Because of the research focus on the dynamics of demonstrations *per se,* these two demonstrations were placed in barrios with a minimum prior exposure to extension activities and workers. Other than placing explanatory signs in the dialect, no efforts were made to focus attention on the demonstrations or to use them in other instructional or motivational activities.

Most farmers were aware of the demonstration and many had talked with the local farmer cooperators to get information about the fertilizer, other cultural practices, and the new variety. Farmers claimed that they would understand a demonstration most if the demonstrator notifies them before establishing it, explains the variables, shows methods which they can follow, and establishes numerous demonstrations.

Frequent adverse reactions to the typical research plot-sub-plot design of the demonstration suggest that, if possible, demonstrators should avoid changing the size or configuration of existing paddies. Farmers see additional levee construction as tedious, expensive, and wasteful of land. Moreover, a complicated plot design makes it difficult for them to concentrate on the significant variables.

It is also clear that, to be effective, the extension worker needs to supplement a local demonstration with field days and meetings and to use, particularly in the Philippine culture, means to make it more personal—that is, identify it with significant local persons.

The fact that 84 percent of the farmers in one barrio and 51 percent in the other identified the demonstration and out of them 27 percent in the first and 63 percent in the second said they talked with the cooperator to get information about the demonstration indicates the potential of demonstrations in extension teaching. However, only 2 to 3 percent of the farmers mentioned the demonstration as a source of information. Obviously, those who talked with the cooperator identified him as the source of information.

These results parallel the findings of research on the use of static graphic training aids and motion pictures in changing levels of knowledge, understanding, and attitude.

Analysis of the qualitative data recorded in response to probes to assess understanding and attitudes provides insight into the way these farmers think about rice varieties and fertilizers. The most frequently expressed reason for growing a chosen local variety was the high yielding characteristics the farmers perceive it to have. Some grow a particular variety because it is early maturing.

These farmers believe that: (a) some varieties easily recover from attacks of pests and diseases, (b) some are more resistant to drouth and flood, and (c) some are more adapted to the soil and season. While some want non-lodging varieties, a number prefer those that lodge. According to them, when a rice crop lodges, it bears heavy panicles and so the yield is high. Obviously, they were thinking about lodging at maturity.

These farmers see fertilizer as one of the major factors responsible for increased yields. Many noted the differences in color, height, and size of hills in the demonstration plots. Although some farmers wanted to use fertilizers in the season of the demonstration, none was available locally.

With respect to variety-fertilizer interaction, the farmers claim that high-tillering varieties should be spaced wider in fertile soils. They also believe that if a given rice variety is planted continuously in the same paddy the soil will become more depleted than when two varieties are planted alternately.

Other studies underway

One of the three studies underway represents an attempt to identify those factors (vocabulary, knowledge, skills) which rice specialists agree are important to the rice extension worker, and to develop and test an instrument or test capable of assessing or measuring these factors in individual workers. Such an instrument would be useful to employers as well as those concerned with conducting and evaluating in-service training programs.

The other two studies focus on various aspects of the diffusion of information and seed of the new rice variety IR8. One study relates to the some 2,000 farmers who each obtained 2 kilograms of seed from the Institute, while the other is a case study of a private individual's approach to seed multiplication and cultural practice supervision of several hundred farmers under a management contract arrangement.

Consultation and Liaison

Each year the numbers of persons—landowners, farmers, industrial representatives, government workers—coming to the Institute to discuss rice production problems increase. Significant amounts of staff time, particularly of the rice production specialist and his research assistants, were spent with such visitors. Besides supplying them with information, the staff encouraged them to consult with their local representatives of Philippine government agencies and provided them with the names and addresses of trained personnel in their own provinces or regions.

Similarly, large numbers of letters inquiring about rice problems and seeking help or information reach the office each year. In the process of answering these, national, regional, and provincial agricultural workers are provided copies of the letters.

Other cooperative activities included furnishing persons and materials to the College of Agriculture in connection with various rice production short courses, reviewing material submitted by commercial firms for use in advertising and promotion, and trying to stimulate governmental and private concern for the design, production, and use of more adequate training and reference materials about rice culture.

Work progressed in Taiwan on the training materials project to the extent that at year's end the original Chinese manuscript had been reviewed and expanded, translation was underway, and a rice specialist from the United States employed to report in January to assist in the next phases of the project.

At the request of the Rice and Corn Production Coordinating Council, the office furnished suggestions on the content and organization of various training programs being planned for council representatives in the provinces. The United States Agency for International Development inquired frequently about rice cultural practices, availability of chemicals, and use of informational materials for its SPREAD projects. The office cooperated with AID and the College of Agriculture in preparing a series of instructional materials on rice stem borer control—slides, films, flip charts, posters, and printed handouts.

Library and Documentation Center

International Bibliography

The 1965 Supplement to the *International Bibliography of Rice Research* was published in 1966. Consisting of 261 pages including indexes, the supplement contains 1,986 references to scientific rice literature, the main bulk of which appeared in journals printed in 1965. References missed in the 1964 and 1963 supplements are also included. An additional 87 serial titles, mostly Japanese, were scanned and searched in the compilation. The coverage is world-wide and the format follows the previous supplements. It is classified according to subject matter and features an author and a manually produced keyword index. A list of 101 rice literature translations to English is included. This number represents the total number of translations obtained in 1966. The listing of translations, started in 1964, will be a regular feature of all future supplements.

A quinquennial author, specific-subject, and geographic index is nearing completion.

A marked increase in demand for copies of the bibliography supplements necessitated the printing of more copies, the press run being increased from 500 to 700. Inquiries regarding the bibliography have been received from the rice-cropping areas of South and Southeast Asia and Latin America, and also from libraries and documentation centers in Europe.

Reference and Circulation

Requests for information and photocopying services were processed from 36 countries, with requests from India, Japan and Australia being most numerous. Increasing numbers have been received from Hungary, Great Britain and West Germany.

Rice breeding and genetics continue to outrank all other subject requests. As in previous years, many of the requests were for Japanese literature. When translations are available, these are sent. In some cases, only English abstracts and summaries were supplied.

Circulation statistics within the Institute totalled 20,411. Figures on direct-library use are not available as the library operates an open stack system. Increasingly, reference questions are received and answered by telephone.

Library Holdings

In 1966 the library acquired copies of dissertations on rice completed in United States universities from 1951 to 1966. A few theses were acquired from India. In Indian universities, where copying facilities are not available, the theses were sent to the Institute for copying. In some instances, when loan was not possible, only the summaries were acquired.

Some gaps in the periodical holdings were filled. Single issues of important journals were obtained through the facilities of the United States Book Exchange. Some rice literature originating from Russia and the Chinese mainland was added to the collection. As sources become better known, the acquisition of these materials will become less of a problem.

Twenty-five new exchanges were established, 23 new subscriptions were placed, and 52 additional serial titles were received as gifts, bringing the total number of serial titles being received to 1,437. A few of these serial titles, however, are not being retained in the library's permanent files but are discarded at year's end.

The new monographic materials, totalling 2,230 books, pamphlets, reprints and translations, brought the over-all collection of monographs to 17,259. Card production totalled 25,000.

Other Library Activities

In 1966, the library started a newspaper clipping file of rice news items. Inasmuch as the library does not expect to retain voluminous files of back issues of newspapers, foreign as well as local, the clipping was started and will continue in conjunction with its indexing services.

Table-of-contents routing continued and the monthly listing of new acquisitions of books, serial titles, translations, and reprints was more widely distributed.

Now part of library routine is the contribution of master cards of the library's book acquisitions to the union catalogue of scientific holdings of libraries in the Philippines. This catalogue is maintained by the library of the National Institute of Science and Technology. During the year, a list of the serial holdings of the library was copied for inclusion in the union list of serials—a service which will enable researchers to ascertain the location of serials and to avoid duplication of acquisitions especially of the more expensive scientific periodicals. The use of the library facilities and services will be subject to the rules and regulations of the participating libraries.

To make the library's translations of foreign language rice literature more generally known, copies of translations were regularly sent to the National Agricultural Library, U.S. Department of Agriculture, which, in turn lists these in the *Bibliography of Agriculture* to make them more readily accessible to rice scientists. Copies of these translations have been acquired by the U. S. Department of Commerce and listed in their widely distributed publication entitled *Technical Translations*.

The library continued to take charge of the purchase and the distribution of books to research scholars.

Bindery

The bindery output during the year was as follows: periodicals, 771 volumes; theses, 285 volumes; field books, 56 volumes; IRRI Annual Report, 97 volumes; booklets, 805 pieces; reprint file boxes, 43 pieces; slide boxes, 20 pieces; albums, 12 pieces; reprint pamphlets, 276 pieces; reprint folders, 56 pieces.

International Activities

The activities of the Institute that are undertaken in support of or in cooperation with other rice research centers represent an increasingly important part of the total program. They have as their ultimate goal bringing science to bear on the rice shortages facing most Asian countries through: (a) identification of factors limiting production; (b) testing, throughout Asia, new findings of the Institute and other research centers; (c) improving the proficiency of young rice scientists through additional training; (d) supporting travel of Institute staff and scientists of other Asian centers on study tours; (e) organization of symposia and work conferences on topics of general importance in rice production; and (f) cooperative participation of the Institute in national rice research projects of various Asian countries.

Several of these activities were established at the same time as the Institute's program was being organized at the Research Center in the Philippines. Among these, the training program has continued essentially on the same basis and at the same level initially undertaken. Others have been altered appreciably as their objectives were realized or as other more extensive projects took their place. Thus, the emphasis on international conferences or symposia was greatest at the start when identification of major research problems and means of attack were being sought. Likewise, small cooperative projects of limited objective and grants-in-aid originating at the Institute have been reduced in number as more comprehensive undertakings have been agreed upon. During the past year the efforts in certain of these approaches were sharply increased through additional financing and assignment of Institute rice scientists to work at cooperating centers. Such has been the case in both East and West Pakistan where the Ford Foundation has made separate grants to assist in acceleration of rice research. In other situations, in India and Thailand, for example, the cooperative projects of The Rockefeller Foundation with the host country have expanded notably in the area of rice research.

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The Training Program

One of the most productive of the Institute's international activities and certainly the most personally gratifying to the scientists, student and teacher alike, has been the training program. Under this program, young scientists from many countries come to the Institute to study and work in their fields of specialization. All come from rice research or teaching centers and are expected to return to the same post or a similar one to continue their careers. They have been nominated for training by officials of their home institution and selected after careful examination of academic records. A personal interview is given in which the nature of the work which the candidate intends to do following his return, and the assistance which the Institute might be able to offer, are both considered. English language proficiency is determined and in certain cases the individual is provided with additional training in this area.

The research scholar is the most junior participant in the training program. He normally holds the Bachelor of Sciénce degree and comes to the Institute for a period of 6 months to 2 years. Those who stay for more than a year are usually candidates for the Master of Science degree at the University of the Philippines College of Agriculture. Such degree candidates conduct thesis research at the Institute under the direction of one of its scientists. Non-degree scholars are also expected to conduct a research project. After consultation with his adviser, the

A visiting scientist from Colombia crossing IR8 with a tall variety from his own country.

A Dutch research scholar and a Filipino research assistant make leafhopper counts in the screenhouse.

scholar outlines his problem, conducts the indicated research, and prepares a report on his results. Upon the successful completion of his work he receives a certificate from the Institute stating the nature of his training and the duration of study.

The research fellow is the more experienced participant in the training program and usually holds the M.S. or Ph.D. degree. He is not a degree candidate, but instead carries out a research program in some special field. He is usually at the Institute for about a year, although the duration of his residence may be longer or shorter depending on his particular requirements. In many respects, he acts as a temporary junior member of the research staff. His research results are summarized upon completion and in many instances are published as a joint contribution with the senior adviser.

Research scholars from Pakistan and Taiwan at work in the seed store.

By special arrangements, periods of residence of less than six months may be undertaken. Characteristically, such programs are arranged to allow the individual to study a particular technique or plant material not available at his home station. Such persons are not present merely as observers, however, but invariably participate in some way in research activities of the Institute.

In 1966 a total of 105 persons studied and worked in the training program for part or all of the year. They came from 13 Asian countries plus Nigeria, Sudan, United States, United Arab Republic, Panama, and Germany. Most of those from countries other than the Philippines came under grants made from funds provided to the Institute by the Ford Foundation, although some came under the sponsorship of FAO, USAID and other agencies. Within the Philippines significant financial support came from a variety of agencies interested in the training of extension rice production specialists.

Research scholars

Ninety-four persons studied in this program in 1966. The largest number for any particular subject were participants in rice production training, an activity of the Office of Communication, which is designed to teach prospective extension specialists the skills and science of rice growing. Thirty persons were enrolled in this course which calls for 6 months work and study at the Research Center, followed by a similar period of application of rice growing and field research techniques in an extension environment.

During the year, 30 scholars completed their studies in various fields, 20 of them having received the Master of Science degree. The scholars' theses and special problem research dealt with subjects in each department of the Institute.

The scholars' names, home institutions, and special research problems are as follows:

Agronomy

ABDUL MUTTALIB AKHANDA,† *agronomical assistant,* East Pakistan Agricultural Institute, Dacca, East Pakistan. Major research: Weed control techniques for upland rice.

R. SESHADRI AYYANGAR, *instructor,* Osmania University, College of Agriculture, India. Major research: Iron and manganese relationships in rice soils.

A. J. M. ENAMUL HUQ CHAUDHURY, *agronomical assistant,* Dacca, East Pakistan. Major research: Fertilizer studies in flooded soils.

PIYA DUANGPATRA, *junior instructor* and *researcher,* Agronomy Department, Kasetsart University, Thailand. Major research: Phosphorus fertilizers and soil fertility.

DONG SOO KIM, *junior agricultural research technician,* Crops Experiment Station, Office of Rural Development, Korea. Major research: Weed control and direct seeding.

BASILIO MABBAYAD,* *instructor,* College of Agriculture, University of the Philippines. Major research: Tillage and planting methods.

ABDULLAH PRAWIROSAMUDRO,* *assistant agronomist,* Cereals Research Institute, Bogor, Indonesia. Major research: Spacing and planting methods.

VICENTE RACHO,† *soil technologist,* Bureau of Soils, Philippines. Major research: Nitrogen balance and utilization by flooded rice.

ERASMO G. SAGARAL, *vocational agriculture teacher,* Central Mindanao University, Philippines. Major research: Herbicides for upland rice.

VISHNU PRASAD SHARMA, *assistant manager,* Department of Agriculture, HMG/N Nepal. Major research: Rice fertilizers and fertilizer response.

GERONIMO SIMSIMAN,† *instructor,* Department of Soils, College of Agriculture, University of the Philippines. Major research: Nitrogen sources and placement.

AGAPITO TAURO, *agronomist I,* Bureau of Plant Industry, Philippines. Major research: Weed control in transplanted rice.

AKIN WILLIAMS, *rice agronomist,* Federal Department of Agricultural Research, Nigeria. Major research: Water management and environmental influences on flooded rice.

SABUROU MATSUMOTO, *assistant in agronomy* at Tokyo University of Agriculture, Japan. Major research: Irrigation practices and direct seeding.

Agricultural Economics

NARCISO DEOMAMPO, *instructor I,* College of Agriculture, University of the Philippines. Major research: Effects of the quality of land preparation, fertilizer, and methods of weed control on the yield of lowland rice.

RAYMUNDO FONOLLERA,† *instructor,* Mindanao Agricultural College, Philippines. Major research: Labor and land resources in Philippine agriculture: Trends and projections.

SAWART PONGSUWAN, *third grade economist,* Land Policy Division, Department of Land Development, Ministry of National Development, Bangkok, Thailand. Major research: The response of Thai rice farmers to rice.

ARKOM SOOTHIPHAN,† *instructor,* Department of Agricultural Economics, Kasetsart University, Thailand. Major research: Income ceilings under alternative rice production technologies.

NA MIN SOO,* *lecturer,* Department of Economics, Yonsei University, Korea. Major research: Income ceilings in northeast Asian countries.

Agricultural Engineering

ANTERO S. MANALO, *research assistant,* The International Rice Research Institute, Philippines. Major research: Design, development and evaluation of performance of a commercial size rough rice dryer.

Chemistry

NATIVIDAD RAMOS, *instructor,* College of Agriculture, University of the Philippines. Major research: Study of physicochemical, cooking and eating properties of Philippine waxy rice varieties of different gelatinization temperatures.

* Completed training.
† Completed Master of Science degree.

Communication

ENRIQUE ALCONABA, *plant pest control officer*, Bureau of Plant Industry, Philippines. Training in rice production, applied research and communication.

EDUARDO P. ALMOJUELA, *farm management technician*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

ERNESTO G. ANDRES, *farm management technician*, team leader, Agricultural Productivity Commission, Philippines. Training in rice production, applied research and communication.

RENATO V. BARDON, *farm management technician*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

DAN C. BERDIN, *farm management technician*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research and communication.

FIDEL V. CABELLO, *farm management technician*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

ARNULFO M. CADA, *farm management technician*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

DAVID Z. CANET, *city agriculturist, president*, Naga City Employees Cooperative Credit Union, Inc., Philippines. Training in rice production, applied research, and communication.

MARCELO A. CARAAN, *farm management technician*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

JAIME B. CARBONELL, *agricultural engineering services division representative*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

DIOSDADO V. CASTRO, *extension instructor*, College of Agriculture, University of the Philippines. Training in rice production, applied research, and communication.

EDDIE C. CHU, *officer-in-charge*, Applied Research Station, Agricultural Productivity Commission, Philippines. Area of research: Diffusion of information about, and seed of, a new rice variety.

DOMINADOR A. CORPUZ,* *agriculturist*, Philippine Seed Corporation, Philippines. Training in rice production, applied research, and communication.

FELINO G. CINENSE, *technical assistant*, Philippine Rural Reconstruction Movement, Philippines. Training in rice production, applied research, and communication.

ROGELIO V. CUYNO, *extension instructor*, College of Agriculture, University of the Philippines. Major research: Development of a measuring instrument to assess the rice production competency of agricultural change agents.

MARCELO P. ELESANGO, *plant pest control officer*, Bureau of Plant Industry, Philippines. Training in rice production, applied research, and communication.

ANDRES V. FORONDA, *assistant instructor*, Tarlac College of Technology, Philippines. Training in rice production, applied research, and communication.

CIRIACO G. GIBRALTAR, *agricultural extension officer*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

ANTONIO G. ICO, *farm management technician*, Agricultural Engineering Services Division, *representative*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

MOHAMMAD RAFIQUAL ISLAM, *district agricultural officer*, Directorate of Agriculture, Pakistan. Training in rice production, applied research, and communication.

ROGELIO C. LABRADOR, *farm management technician*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

MIGUEL MALLARI, *head*, CAT-Planters Cooperative on Rice, Tarlac, Philippines. Training in rice production, applied research, and communication.

BRUNO A. MANGUBAT, *farm management technician*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

RODOLFO F. MATA, *assistant instructor*, Tarlac College of Technology, Philippines. Training in rice production, applied research, and communication.

JULIAN P. MOLANO, *plant pest control officer*, Bureau of Plant Industry, Philippines. Training in rice production, applied research, and communication.

MUSTAFA MAHMOUD OBEID,* *inspector of agriculture*, Department of Agriculture, Khartoum, Sudan. Training in rice production, applied research, and communication.

MAURICE OKEREKE, *agricultural officer*, Rice Production and Extension, Ministry of Agriculture, Enugu, Eastern Nigeria. Training in rice production, applied research, and communication.

J. CARLOS R. PAUA, JR., *rural youth officer*, Agricultural Productivity Commission, Philippines. Training in rice production, applied research, and communication.

TEJ PRATAP SINGH, *student*, Allahabad Agricultural Institute, India. Training in rice production, applied research, and communication.

ALFREDO T. SUENAN,* *farmer*, Tiruray Cooperative, Philippines. Training in rice production, applied research, and communication.

MELITON D. VERMAN,* *student*, Tiruray Cooperative, Philippines. Training in rice production, applied research, and communication.

LEOPOLDO VILLEGAS,† *instructor*, College of Agriculture, University of the Philippines. Major research: Effects of a field demonstration on level of knowledge, understanding and attitudes of farmers about choice of a rice variety abd use of fertilizers.

* Completed training.
† Completed Master of Science degree.

PAUL R. WALTHER,* *agricultural missionary,* United Church of Christ, United States. Training in rice production, applied research, and communication.

Entomology

SHAMSUL ALAM, *assistant entomologist,* Directorate of Agriculture, Dacca, Pakistan. Major research: Population dynamics of leafhoppers and planthoppers and stem borers.

SANG HEE BAE,† *research technician,* Department of Entomology, Institute of Plant Environment, Korea. Major research: Studies on some aspects of the life history and habits of the brown planthopper, *Nilaparvata lugens* (Stal) Delphacidae, Homoptera.

MANOLA PADILLA, † *junior plant entomologist,* Bureau of Plant Industry, Philippines. Major research: Mating habits and sex attractions in striped rice stem borer, *Chilo suppressalis* Walker.

CARLOS R. VEGA, *research assistant,* The International Rice Research Institute, Philippines. Major research: Studies on sex attraction of striped borer moths (*Chilo suppressalis* Walker).

T. YESU DAS, *research assistant,* Agricultural University of Andhra Pradesh, India. Major research: Varietal resistance to stem borers.

Plant Pathology

FE DIVINAGRACIA,† *agronomist I,* Bureau of Plant Industry, Philippines. Major research: Inheritance of resistance in rice to Philippine races 1, 3, and 12 of *Piricularia Oryzae* Cav.

SHIH-PAN-YU HSIEH,† *assistant,* Department of Plant Pathology, Taiwan Provincial Chung Hsing University, Taiwan. Major research: Stem rot of rice in the Philippines.

HEI-TI-HSU,† *research assistant,* Department of Plant Pathology, Taiwan Agricultural Research Institute, Taiwan. Major research: Relation between chemical constituents of rice leaves and resistance to the blast disease.

SHIH-TIEN HSU,† *assistant,* Department of Plant Pathology, Taiwan Provincial Chung Hsing University, Taiwan. Major research: Nutritional requirements *in vitro* of *Xanthomonas Oryzae* (Ishiyama and Uyeda)-Dowson and its effect on host plant resistance.

MOHAMMAD QUAMARUZZAMAN, *research assistant,* Division of Mycology and Plant Pathology, East Pakistan Agricultural Research Institute, Dacca 5.

CESAR VON CHONG,* *plant pathologist,* Estación Experimental Agropecuaria, Ministerio de Agricultura, Comercio e Industrias, Panama. Major research: Further studies on the physiological races of the rice blast fungus, *Piricularia oryzae* Cav., in the Philippines.

GERD FRANCK, *attendant,* Laboratory of Phytopathology, Hohenheim, Germany. Major research: Bacterial leaf streak disease of rice.

Plant Physiology

SU BONG AHN, *senior technician,* Crop Experiment Station, Korea. Major research: Photoperiod and growth analysis of rice varieties.

NGUYEN THI DIEM,* *assistant chief,* Soil Fertility Section, Soil Service, Directorate of Agricultural Research, Vietnam.

JAMALUDIN BIN LAMIN,† *plant physiologist,* Department of Agriculture, Kuala Lumpur, Malaysia. Major research: Environmental factors affecting the yield components.

RANJIT MULLERIYAWA,† Ceylon. Major research: Some factors influencing bronzing—a physiological disease of rice in Ceylon.

YOUNG DAE PARK,* *research worker,* Department of Agricultural Chemistry, Office of Rural Development, Korea. Major research: Effect of silica application on the rice plant.

Soil Chemistry

GLORIA CRUZ, *senior soil technologist,* Legaspi Soils Laboratory, Bureau of Soils, Philippines. Major research: A correlation study of available phosphorus on air-dry soils and wet soils with the yield of lowland rice.

TAWIN KRUTKUN, *instructor,* Department of Agronomy, Kasetsart University, Thailand. Major research: Influence of internal drainage on the chemical changes of four flooded soils and the growth of rice.

TZE-SHUN LEE, *junior specialist,* Taiwan Agricultural Research Institute, Taipeh.

PAIBOON PRABUDDHAM, *instructor,* Department of Agronomy, Kasetsart University, Thailand. Major research: Influence of the duration of submergence of the soil prior to transplanting on the growth and yield of rice.

Soil Microbiology

CHING MING CHIOU,† *technician,* Laboratory of Soil Microbiology, National Taiwan University, Taiwan. Major research: Microbiological studies on two soils of Taiwan associated with a physiological disorder of rice.

S. M. MOSARAFF HOSSAIN, *assistant soil microbiologist,* Department of Agriculture, East Pakistan. Major research: Nitrification in flooded soils.

SALVADOR SALANDANAN,† *soil technologist I,* Bureau of Soils, Philippines. Major research: Nitrogen transformations in flooded soils.

SOMSAK VANGNAI,† *instructor,* Department of Soils, Kasetsart University, Thailand. Major research: Microbial transformations of sulfur in soil.

Varietal Improvement

ZAINUDDIN HARAHAP, *assistant rice breeder,* Cereals Research Institute, Indonesia. Major research: Breeding behavior of dormancy in rice seed.

CHENG-CHANG LI,† *project technician,* Taichung District Agricultural Improvement Station, Taiwan. Major research: Inheritance of the basic vegetative phase and photoperiod sensitivity in rice.

* Completed training.
† Completed Master of Science degree.

PENG-TU LIU,† *project technician,* Kaohsiung District Agricultural Improvement Station, Taiwan. Major research: Inheritance of lodging resistance in rice.

MOHAMMAD MOAFIEZAD, *in charge and breeder,* Rasht Rice Research Station, Iran. General rice breeding.

NUR MOHAMMAD MIAH, *assistant botanist,* Agricultural Research Institute, Dacca, Pakistan. General rice breeding.

D. C. PUROHIT, *assistant economic botanist,* Agriculture Department, Rajasthan, India. General rice breeding.

SEVERINO A. RAYMUNDO, *research instructor,* College of Agriculture, University of the Philippines. General rice breeding.

JUSTINO TEPORA,† *instructor,* College of Agriculture, University of the Philippines. Major research: Inheritance of resistance to *Piricularia oryzae* (Philippine Races 15 and 20) in rice.

KALLUTLA VENKATA SUBBANA, *research assistant,* A.P. Agricultural Research Institute, India. General rice breeding.

SHENG-TIAN YEN, *junior specialist,* Taiwan Agricultural Research Institute, Taiwan. Major research: Inheritance of short plant stature in varietal crosses.

Statistics

SUANG BOONYAKOM, *senior staff member,* Cooperative Department, Faculty of Economics and Business Administration, Kasetsart University, Thailand. Advanced training in statistics.

ISIDORO P. DAVID,† *instructor,* College of Agriculture, University of the Philippines. Major research: Development of a statistical model for agricultural surveys in the Philippines.

SUTJIHNO, *assistant-in-charge,* Statistical Division, Coordinated Bureau for Research Institutes, Indonesia. Major research: Multivariate methods in rice research.

LILIA A. VARGAS, *agronomist I,* Bureau of Plant Industry, DANR, Philippines. Major research: Variance-covariance of characteristics in rice research.

Research fellows

Eleven research fellows from Japan, Taiwan, India, Pakistan, and the United Arab Republic conducted investigations in fields which included plant physiology, entomology, plant pathology, agronomy and biochemistry. Four of them were post-doctoral fellows. All are identified by name, home institution, and research interest as follows:

MR. MOHEB RAGHEB AYAD, *assistant researcher,* Ministry of Agriculture, U.A.R., is working on identification of physiologic races of rice blast.

MR. JIRO HARADA, *graduate student* (Doctoral Course), Department of Agronomy, Faculty of Agriculture, Tohoku University, Japan, is working on the biochemical studies on the internode elongation of the rice plant.

MR. MUN HUE HEU,* *assistant professor,* the Department of Agronomy, Seoul National University, Korea, completed two years of intensive participation in the rice breeding program.

DR. MERVYN KAMRAN, Pakistan, is conducting a 2-year study on the biological control of rice stem borers.

MR. CHENG CHANG LI,† *project technician,* Taichung District Agricultural Improvement Station, Taichung, Taiwan, is working on the genetic analysis of the components of growth duration and the inheritance of quantitative characters.

MR. KUNIO MORIYA,* *graduate student,* Kyushu University, Japan, spent a year in studying the quantitative characters in rice and the maintenance of genetic markers.

DR. P. NARAYANASAMY, *assistant lecturer in Mycology,* Research Institute, Coimbatore 2, South India, is working on sources of tungro virus.

MR. M. N. PRASAD,* *junior plant breeder,* The Rockefeller Foundation field program, India, completed 1 year of intensive participation in rice breeding.

DR. KANTHADAI RAGHU,* *pool officer,* Division of Microbiology, Indian Agricultural Research Institute, New Delhi 12, India, is working on the fate of pesticides in submerged soils.

MR. NAMBRATTIL SETHUNATHAN, *senior fellow* on "Studies on Plant-Microbe Interrelations" at University Botany Laboratory, Madras-5, India, is working on pesticide residues.

MR. JUN'ICHI YAMAGUCHI,* *graduate student,* Hokkaido University, Japan, is working on photosynthesis and respiration of the rice population.

* Completed training.
† Completed Master of Science degree.

Advanced study in the United States

Financial assistance to permit advanced study in the United States was continued for a number of individuals in 1966. Certain of these students were from the Institute's junior staff while others were from other countries and were identified among the research scholars and fellows of the Institute. Their names, country of origin, field of interest, and institutions attended in the United States were as follows:

Scholarships

MUNSHI SIDDIQUE AHMAD, Pakistan, plant breeding, Texas A&M University.

GLORIA B. CAGAMPANG, Philippines, biochemistry, Purdue University.

ISAAC CAGAMPANG, Philippines, agronomy, Purdue University.

RUBY UY CASTRO, Philippines, chemistry, University of Pennsylvania.

WILDREDO G. ESPADA, Philippines, agronomy, Ohio State University.

CHEN-SENG HUANG, Taiwan, genetics, Louisiana State University.

ADELINA JAVIER, Philippines, chemistry, University of Illinois.

RHODA S. LANTIN, Philippines, soil chemistry, Iowa State University.

ABRAHAM B. MEDINA,† Philippines, biology, Bowling Green State University.

LETICIA MENDIOLA, Philippines, biochemistry, Rutgers University.

LUCILA PARIAL, Philippines, rice breeding, Texas A&M University.

REBECCA C. PASCUAL, Philippines, nutrition, Purdue University.

TRUONG DINH PHU,‡ Vietnam, soil science, University of Illinois.

IFOR B. SOLIDUM,† Philippines, personnel management, University of Kentucky.

Travel grants

RUBEN B. ASPIRAS, Philippines, soil chemistry, University of Wisconsin.

ARIFIN DJAMIN, Indonesia, entomology, University of California.

VIVIAN BRIONES, Philippines, chemistry, Pennsylvania State University.

DR. C. T. LEWIS, England, chemoreception in insect pests of rice, (Sabbatical study) University of Hongkong.

† Completed Master of Science degree.
‡ Completed Ph.D. degree.

Cooperative Research

Cooperative studies carried out in 1966 were largely in continuation of projects started earlier. Most were studies originating from work done at the Institute and requiring extension to different environmental conditions for further evaluation. Some, however, were established to study problems of importance in areas other than the Philippines or in subjects of significance to rice sciences but not under study at the Institute.

The cooperative project between Taiwan and the Institute on the control of suffocation disease was concluded in 1966. Earlier studies had shown that true suffocation disease is caused by toxic reduction products in the soil and had distinguished between the diseased condition arising from this cause and that due to virus. Field experiments in 1966 showed that commercial manganese dioxide at 2 to 4 ton/ha of active ingredient markedly reduced the severity of the disorder and substantially increased yield by preventing acute soil reduction.

Cooperative blast nurseries established at six stations located from Luzon to Mindanao, Philippines, and including about 750 selected varieties, identified some 75 rice varieties showing high resistance at all stations. These varieties offer good sources of resistance for breeding blast resistant varieties. The results are summarized in the Plant Pathology section of this report; brief report on the results has been sent to the cooperating stations and to the Director of the Philippines Bureau of Plant Industry.

A series of international uniform blast nurseries included cooperative projects in 20 countries and at 50 stations. About 250 rice varieties were tested and an account of the results is given in the Plant Pathology section. Many resistant varieties for various regions of Asia were identified. Results also showed different groups of races in each region. The 1964-1965 results of similar cooperative studies were published in the IRC Newsletter in 1966.

Studies on the "penyakit merah" disease were conducted cooperatively with the Department of Agriculture, States of Malaya, Malaysia. Results further confirmed that this disease is caused by a virus. When the plants were protected from the virus, yields of 4 to 5 tons were obtained as compared to 0.3 to 1.2 tons for unprotected plots (see Plant Pathology section).

Two reports were prepared during the year from studies on the nutrition and enzyme activity of the *Piricularia* organism by the group at the Academia Sinica, Taiwan, supported by a small grant from the Institute.

Preliminary results of the animal feeding study to determine the (comparative) nutritive value of rice at the United States Naval Research Unit No. 2 (NAMRU-2), Taipei, Taiwan are given in the Cereal Chemistry section of this report.

A fertilizer experiment was conducted during 1966 wet season at Bangkhen, Thailand, using eight NPK treatments and three varieties of rice. Grain production of IR8 was threefold higher than that of a local variety, at least partly because the damage due to virus was less severe with IR8. Increased yields due to nitrogen application were measured.

Cooperative fertilizer tests were initiated with the All-India Coordinated Rice Improvement Project, Rajendranagar, during the 1966 dry season. These were intended to test the relative nitrogen responsiveness of different varieties. Results will be reported jointly at a later date.

Cooperative soil fertility experiments conducted with the Maligaya Rice Research and Training Center are reported in the Agronomy section of this report.

A study on sources and rates of fertilizer phosphorus for flooded rice was conducted in the Philippines and in Thailand. Experiments were conducted simultaneously during the 1966 wet season in Bulacan, Philippines, and in cooperation with the Rice Department of the Ministry of Agriculture, at Khonkaen, Thailand. The responses to added phosphorus were consistent for all urea-ammonium phosphate fertilizers (TVA-materials). With both nitrogen and phosphorus applied, IR8 produced more than double the grain yield obtained with nitrogen alone. All of the TVA materials performed equally well in increasing the grain yield of rice but superphosphate appeared slightly superior. This series of tests will be continued to evaluate these phosphorus sources under a wide range of soil conditions.

Cooperative research in agronomy was carried out at Central Mindanao University and in several field locations in Laguna. Institute scientists were either cooperators or advisers on studies of the methods, rates and timing of nitrogen application using the IR8 variety. The results indicated that yields of about 6,000 kg/ha were produced with applications of urea made at maximum tillering and at panicle initiation. No differences were observed between nitrogen broadcast and that incorporated in the relatively acid Musuan soils. Nitrogen rates above 60 kg/ha did not produce significantly higher yields.

Cooperative research on the growth performance of rice plants under different crop seasons in Taiwan has been extended to June, 1967. Results will be reported following completion of the second harvest.

A cooperative project on the rice gall midge is being carried out with Mr. Somporn Patanakamjorn at the Kasetsart University, Thailand. This insect does not occur in the Philippines, but is quite serious in several other countries of Asia. Some basic progress has been made in this project by obtaining data on seasonal fluctuations in gall midge population in affected areas of Thailand. Eggs have been obtained and healthy plants infected in laboratory experiments preliminary to mass rearing studies. Gall midge infestations were recorded on certain wild grasses, but definite identification of the species is still to be established.

Numerous tests of rice selections from the Institute's breeding program were conducted in other Asian countries. Some of these results are summarized in the Varietal Improvement section of this report. For others, publication of the results awaits the joint decision of the Institute's scientists and the cooperators abroad.

The Institute does not conduct active research on the morphology and classification of paddy soils but has contributed substantial financial support to Kyoto University's Center for Southeast Asian studies. An interim review of the results was presented by Dr. K. Kawaguchi in July, 1966, giving chemical data and notes on profile characteristics of soils in Thailand, Malaysia and Ceylon.

Under a 3-year grant to genetic researchers in Taiwan, Dr. C. H. Hu of Chung-Hsing University has studied inter- and intra-specific hybrids in the "*O. officinalis* complex" and hybrids between taxa of the "*O. officinalis* complex" and the "*O. sativa* complex". Pairing data indicated chromosomal differentiations in the C genome, homoeologous pairing between the B and C genomes, and non-homologous pairing at pachytene in two hybrids. Dr. S. C. Hsieh of Taiwan Agricultural Research Institute tested a number of crosses to individual races of the blast fungus. In the majority of cases, a single dominant gene controlled resistance to a specific race. No linkage was detected between the genes controlling resistance to race 4, 13 or 22 and a number of marker genes, except the phenol reaction gene (*Ph*). A gene for dwarfness (d_{42}) was added to linkage group II. Some phases of the above studies are being continued after the Institute grant expired in 1966.

Continued assistance was given to Dr. Man-emon Takahashi of Hokkaido University (Japan) in a genetic analysis of marker genes in indica and japonica testers. Eight F_2 populations of indica x japonica hybrids were grown at the Institute to provide comparative data. The F_2 data obtained at Sapporo and Los Baños verified the validity of the *C A P* system of complementary genes in controlling anthocyanin pigments in both racial groups, though strains may differ in other genes of a modifying nature. New inhibitor genes which interacted with the purple leaf gene (*Pl*), purple pericarp gene (*Prp*), and colored apiculus gene (*P*) were found. Being added to the known list of marker genes were duplicate genes controlling floral glume development, a new mutant gene for brittle culm, and an additional nodal color gene. Data on the distribution of 11 marker genes in four linkage groups were added to the known groups in indica testers.

Dr. H. I. Oka and associates at the National Institute of Genetics, Misima, Japan, continued to explore the genetic mechanisms involved in producing isolating barriers in inter- and intra-specific hybrids. Data indicate the presence of restricted recombination among progeny lines obtained from *O. sativa* x *O. glaberrima* hybrids, lowered pollen and embryosac fertility, and F_1 weakness phenomena. In *O. sativa* x *O. perennis* subsp. *barthii* hybrids, embryo deterioration shortly after fertilization followed by endosperm collapse appears to be the main incompatibility barrier.

The Institute continued to support a project at the Institute of Botany, Academia Sinica (Taiwan) in developing alien additional lines by repeated backcrossing of interspecific hybrids to the *O. sativa* parent. Among the three interspecific crosses, viable progenies were only obtained in the *sativa* x *australiensis* cross. The third backcrossing has produced 16 plants each containing one chromosome from *australiensis*. These 16 plants can be grouped into seven morphologically different types.

International Travel

Short observational tours of the Institute and of rice-growing areas of Japan and Taiwan were arranged for a number of Asian rice workers. Mr. R. B. M. Abassi and Mr. Mohammed Shafi of West Pakistan paid a 5-day observational visit to the Institute in May. In April Messrs. Busin Bin Ismail, Chee Sek Pan, Goh Khek Boon, K. Kanapathy, A. Mutalib and Dr. K. G. Singh of Malaysia came to observe the work of the Institute and, following a tour of Central Luzon, travelled to Taiwan to observe rice research and commercial production. In October, Dr. A. Alim together with Messrs. M. R. Talukdar, Sirajul Haq, and A. Halim of East Pakistan observed the Institute's program for a week and then travelled to Japan to observe work at several rice research centers. Dr. H. I. Oka of the National Institute of Genetics, Misima, Japan, spent 4 weeks at the Institute (October 26 to November 21) in continuation of his studies on rice genetics.

The senior staff of the Institute travelled extensively on missions related to both the research and training programs. Trips were made within the Philippines and internationally, but because of the number and frequency of the former, only those trips made abroad are recorded here. On occasion, it was possible for staff members to visit distant rice-growing areas while enroute on home leave. Such trips are also mentioned here.

The plant pathologist travelled to Malaysia and Thailand in February to discuss "penyakit merah" experiments to be carried out in Malaysia in 1966 and to review recent results in Thai rice research centers. In May, he travelled extensively in India to observe rice diseases there. In August, he attended the IRC Eleventh Working Party Meeting on Rice Production and Protection in the United States and visited rice-growing areas in Colombia. In August-September, he toured Japan and Korea and attended the Eleventh Pacific Science Congress. In October, he went to Thailand to inspect virus diseases of rice and in November he visited Taiwan on a similar mission. In December he travelled to India to attend the Symposium on Plant Pathology.

The associate plant pathologist visited Japan and Korea in August and September when he attended the Eleventh Pacific Science Congress and observed the work at a number of rice research centers.

In August the associate physiologist went to India to inspect nutritional disturbances of rice and in September attended the Eleventh Pacific Science Congress in Tokyo and cooperative projects in plant physiology in Korea.

The statistician participated in the Conference of Asian Statisticians (COAS) held in Bangkok in June. In Tokyo, in August and September, he served as participant in the Pacific Science Congress and later attended the Regional Commission Meeting on Agricultural Statistics in Asia and the Far East conducted by the FAO.

In March the associate agronomist visited the Central Rice Research Institute, Cuttack and the All-India Coordinated Rice Improvement Project in Hyderabad, India. Returning from home leave, he also visited rice stations in Thailand and Malaysia. In August he attended the Eleventh Pacific Science Congress, Tokyo, and in September, attended the International Soil Science Conference in Aberdeen, Scotland. He also visited Rothamstead Experimental Station in the U.K., the Royal Tropical Institute, and various institutions at Wageningen in Holland.

The agronomist travelled to India during April and May to observe plantings of Taichung (Native) 1 and to attend the Indian Rice Research Workers' Conference in Hyderabad. In July he delivered papers at the International Rice Commission Working Party meetings at Lake Charles, Louisiana, and gave a talk to the research and development group of the Monsanto Chemical Company in St. Louis, Mo. Following the IRC meetings, he made brief visits to El Salvador and British Honduras to consult with private growers and government officials concerned with rice production. In August he presented a paper at the Eleventh Pacific Science Congress in Tokyo and made trips to outlying research stations, both government and industrial. In October he visited Taiwan to evaluate problems of rice production and to evaluate IRRI cultural recommendations at Chaiyi, Taichung and Taipei institutions. A tour of Malaysia and Thailand research stations was completed in November with one of the Institute's plant breeders. Observations were made of IR8 and other selections in the cooperative fertilizer tests in two Thailand locations.

The associate chemist presented an invitational paper at the Fourth International Cereal and Bread Congress in Vienna, Austria, in May and afterwards visited cereal protein chemists in Denmark, Netherlands and Belgium. He was chairman of a session at the Eleventh Pacific Congress symposium on problems in development and ripening of rice grains, Tokyo, in August and during this trip also visited rice chemists in Niigata, Osaka, and Tokyo.

In June, the associate plant physiologist attended the Rice Technical Working Group at Little Rock, Arkansas, and visited rice research centers in the United States. In August and September he attended the Eleventh Pacific Science Congress in Tokyo and visited experimental institutions in Japan, Taiwan and Korea.

The soil chemist attended the Eleventh Pacific Science Congress held in Tokyo, August 22 to September 2, 1966, and presented a paper entitled "Recent Advances in the Chemistry of

Flooded Soils". Enroute to Japan, he visited Taiwan to observe field experiments on the control of suffocation disease. The soil chemist also attended the 22nd Annual Sessions of the Ceylon Association for the Advancement of Science and presented the following papers: "Redox Equilibria in Flooded Soils"; "Carbonate Equilibria in Flooded Soils"; and "Some Practical Applications of the Chemistry of Flooded Soils". On his way back, he visited the Rice Department and Kasetsart University in Bangkok for consultations with Thai scientists.

In April, the agricultural engineer was a member of a Tractor Survey Team sent to Laos at the request of the U.S. State Department and the Royal Laos Government to consult on the use of tractors to increase rice production. In June he visited agricultural engineering centers in Europe and the United States to learn of their activities and to interview prospective staff for the AID-IRRI mechanization project. In September he attended a conference on "Mechanization and the World's Rice" in England sponsored by Massey-Ferguson as part of the FAO International Rice Year, 1966.

The head of the varietal improvement program visited Colombia in August to review the rice research program, and in September travelled to Coventry, England, to attend the conference on "Mechanization and the World's Rice". In December he toured Brunei and Sabah to observe materials from the Institute's breeding program and to review the rice research programs in those places.

The geneticist participated in the Fifth All-India Rice Research Workers' Conference held in May at Hyderabad. He also assisted in selecting lines from the cooperative breeding nurseries at Hyderabad and Cuttack. In June he visited the rice experiment stations of California, Texas and Arkansas and participated in the Eleventh U.S. Rice Technical Working Group Meeting. In early August he visited cooperative variety-fertilizer plots in Province Wellesley, northern Malaya, and discussed with Malaysian officials the seed distribution plan of IR8. During August he participated in the Rice Symposium and Divisional Meetings of the Eleventh Pacific Science Congress held in Tokyo. He also visited cooperative projects at Misima and Sapporo. In October he visited cooperative breeding nurseries in Taiwan.

The plant breeder attended the U.S.A. rice technical working group meeting held in Little Rock, Arkansas, the IRC working party meeting at Lake Charles, Louisiana, and the Eleventh Pacific Science Congress in Tokyo, Japan. Trips were made during the year to Malaysia and Thailand to observe experimental plots of IRRI lines being tested in those countries.

The Institute's editor attended the Eleventh Science Congress in Tokyo in August.

The communication specialist participated in a symposium on "Communication and Change" held at Michigan State University and in connection with this trip, interviewed several candidates for the position of consultant to the training materials project in Taiwan. Enroute, he conferred with officials of The Rockefeller Foundation's Agricultural Program in Mexico and inspected facilities for programmed learning instruction in California. In November, he spent 8 days in Taiwan reviewing the progress on the training materials project and making administrative arrangements for the arrival of the consultant in early 1967.

The assistant farm superintendent made a trip to Comilla, East Pakistan, in November to assist in conducting a 2-week Rice Production Training Program. The objective was to train Thana officers on techniques for obtaining best results with nitrogen-responsive rice varieties such as IR8.

In July the entomologist visited the University of Hongkong to discuss with Dr. C. T. Lewis the latter's studies on chemo-attraction in stem borer moths, and in August he visited Thailand to confer on cooperative studies of the rice gall midge.

In July the soil microbiologist attended the IX International Congress for Microbiology which was held in Moscow. Prior to the meeting, he visited laboratories of soil microbiology in Cairo, Paris, Montpellier, Aberdeen, Rothamsted, Denmark, the Netherlands and Prague. In December he travelled to Cuttack, India, to observe the work there in soil microbiology.

The farm superintendent visited Thailand in April to help develop a rat control program for the Bangkhen Experiment Station. In May to

July he spent about 6 weeks at Rajendranagar, India, to assist in developing the experimental fields of the All-India Coordinated Rice Improvement Project.

In February the assistant director met with AID and GOI officials in India to discuss possible contractual undertakings in rice research in that country. In March he travelled to Thailand to discuss a rice research project there with The Rockefeller Foundation and the Thailand Rice Department. In July he visited rice research centers in Ceylon, India, Egypt and Brazil. In November he returned to India to work out details of an AID contract with government officials of the United States and India.

At a conference held in February at the University of Hawaii the director gave a talk on "The challenge of agricultural production in the tropics". In February he visited various research centers in East Pakistan, and in May he attended a conference of research workers of the All-India Coordinated Rice Improvement Project. In May he travelled to Lima, Peru, to attend a symposium on the agricultural problems of the humid tropics of Latin America. In July he participated in the IRC Working Party Meetings, Lake Charles, Louisiana, and in August went to Malaysia to attend a special field day at which a campaign was inaugurated to introduce IR8 as a new variety. Later in August he attended the Eleventh Pacific Science Congress in Tokyo, and from mid-September to mid-October travelled extensively in Pakistan and India. In December he went again to India to receive an award from the President of India in recognition of his contribution to rice production in that country.

Publications and Seminars

Staff Publications

Plant Physiology

TANAKA, A. and K. KAWANO. 1965. Leaf characters relating nitrogen response in the rice plant. *Soil Sci. Plant Nutr. 11*(6): 251-258.

TANAKA, A. and K. KAWANO. 1966. Effect of mutual shading on dry matter production in the tropical rice plant. *Plant and Soil 24*(1): 128-144.

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JULIANO, B. O. 1965. Our daily rice. *Bull. Nutr. Found. Philippines 5*(7): 6.

JULIANO, B. O. 1966. Physicochemical studies of rice starch and grain. *Proc. 11th Pac. Sci. Congr. 6:* (Symp. Problems in Development and Ripening of Rice Grain): 16.

LUGAY, J. C. and B. O. JULIANO. 1965. Crystallinity of rice starch and its fractions in relation to gelatinization and pasting characteristics. *J. Appl. Polymer Sci. 9:* 3775-3790.

Varietal Improvement

AQUINO, R. C. and P. R. JENNINGS. 1966. The inheritance and significance of dwarfism in an indica rice variety. *Crop Sci. 6:* 551-554.

BEACHELL, H. M. 1966. The development of rice varietal types for the tropics. *Indian J. Gen. Plant Breed. 26:* 200-205.

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OU, S. H. and K. C. LING. 1966. Virus diseases of rice in the South Pacific. *Proc. 11th Pac. Sci. Congr. 6* (Div. Meet. Crop Hort. Sci.), Subcommittee on Plant Protect.

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MAI-THI-MY NHUNG and F. N. PONNAMPERUMA. 1966. Effect of calcium carbonate, manganese dioxide, and ferric hydroxide on chemical and electrochemical changes and the growth of rice on a flooded acid-sulfate soil. *Soil Sci. 102:* 29-41.

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DE DATTA, S. K., J. C. MOOMAW and R. S. DAYRIT. 1966. Nitrogen response and yield potential of some rice varietal types in the tropics. *Internatl. Rice Comm. Newslet. 15*(3): 16-27.

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Statistics

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Communication

BYRNES, F. C. 1966. Role shock: An occupational hazard of American technical assistants abroad. *Annals Amer. Acad. Pol. Soc. Sci. 368:* 95-108.

BYRNES, F. C. 1966. Some missing variables in diffusion research and innovation. *Philippine Soc. Rev. 45*(4): 242-256.

JACKSON, E. A. 1966. Tropical rice: the quest for high yield. *Agr. Sci. Rev. 4:* 21-26.

Seminars

The following topics were the subjects of seminars held at the Institute during 1966. Unless otherwise stated the speakers were staff members.

Some views on agricultural development. *Dr. F. F. Hill,* consultant, The Ford Foundation.

Fertilizer policy and India's food problem. *Dr. McClung.*

Maximum productivity of rice. *Dr. Vergara.*

Program on SEA studies. *Dr. S. Iwamura,* director, Kyoto University.

Varietal resistance to the major diseases of rice. *Dr. Ou.*

The agricultural revolution in Mexico and its world wide implications. *Dr. E. C. Stakman,* consultant, The Rockefeller Foundation.

Mathematics, engineering and agriculture. *Mr. Johnson.*

Microorganisms in paddy soils. *Dr. G. Rangaswami,* dean of agricultural science, Bangalore, Mysore, India.

The chemistry and physiology of silica in the rice plant. *Dr. Shoichi Yoshida,* National Institute of Agricultural Sciences, Japan.

Influence of grazing systems on pasture productivity. *Dr. W. K. Kennedy,* associate dean, College of Agriculture, Cornell University.

Water and Life. *Dr. Lorus J. Milne,* professor of Zoology, University of New Hampshire.

Iron problems of the rice plant. *Dr. Tanaka.*

The seasonal growth characteristics of irrigated cotton in a dry monsoonal environment. *Dr. W. R. Stern,* Commonwealth Scientific and Industrial Research Organization, Australia.

The physiology of cacao. *Dr. Raymond G. Lockard,* plant nutrition expert, United Nations.

Weed control in tropical rice: problems and prospects. *Dr. Moomaw.*

Classification of some Philippine soils. *Dr. Martin Raymundo,* assistant professor, Department of Soils, UPCA.

Goals, programs and problems in multiple cropping research. *Dr. Bradfield.*

The regional approach to development. *Dr. Ralph Allee,* associate, Agricultural Development Council, UPCA.

Pesticides, residues, regulations and anxieties. *Dr. Arthur A. Muka,* visiting scientist, IRRI.

The agricultural development organization and the rice problems in Laos. *Mr. Drilón.*

The rationale of new rice and corn program and status report of its progress. *Col. Osmundo Mondoñedo,* chairman and general manager, Rice and Corn Administration.

Physiological causes of variations in yield of wheat and barley. *Dr. Gillian Thorne,* crop physiologist, Rothamsted Agricultural Experiment Station, England.

The international wheat improvement program of The Rockefeller Foundation. *Dr. Charles Krull,* plant breeder, The Rockefeller Foundation, Mexico.

Some missing variables in diffusion research and innovation. *Dr. Byrnes.*

A preliminary study on the mechanism of carbohydrate translocation in the rice plant. *Dr. S. Aso and Dr. Y. Natori,* visiting scientists, IRRI.

The present activities of American type culture collection with special reference to the preservation of microorganisms. *Dr. Shuh-wei-Huang,* microbiologist, American Type Culture Collection.

Increasing rice production through the price support program. *Dr. Randolph Barker,* visiting scientist, UPCA.

Relation of some properties of rice starch and protein to eating quality preferences for milled rice in Asia. *Dr. Juliano.*

Search for rice stem borer parasites. *Dr. M. Kamran,* research fellow, IRRI.

The population growth estimates. *Dr. Mercedes Concepcion,* acting director, Population Institute.
Climate and soils in arid Australia, *Mr. Jackson.*
Potentialities of food preservation in the Philippines. *Dr. C. S. Pederson,* visiting professor, UP Cornell (UPCO).
Nitrogen response of rice varieties under three management practices. *Dr. De Datta.*
Control of submersed aquatic weeds in California rice. *Dr. Donale E. Seaman,* plant physiologist, University of California.
The extension service in a developing economy. *Commissioner Francisco F. Saguiguit,* Agricultural Productivity Commission.
The genetic basis of wide adaptability and yielding ability in rice varieties. *Dr. Chang.*
Variability studies of data from household food consumption surveys. *Dr. Oñate.*
Evaluation of the phosphorus fertility status of rice soils, and responses to phosphate in rice. *Dr. N. P. Datta,* head, Department of Soils, Indian Agricultural Research Institute.
Preliminary report on the studies of the rice fertility trials of the UNSF. Soil fertility project in the Philippines. *Dr. H. F. Chu,* soil fertility expert, United Nations Special Fund.
Nationalism and ideology. *Miss J. D. Constantino,* assistant to the president, Development Bank of the Philippines.
Some effects of mineral nutrient deficiencies on chloroplasts. *Dr. J. J. Possingham,* Commonwealth Scientific and Industrial Research Organization, Australia.
USAID rural development program in Laguna and Tarlac. *Dr. Ernest E. Neal,* deputy director, United States Agency for International Development.
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