The International Rice Research Institute

Annual Report 1967

The International Rice Research Institute was established jointly by The Rockefeller Foundation and the Ford Foundation in cooperation with the Republic of the Philippines. It was incorporated in 1960 and dedicated in 1962 when the research program began. This annual report, the sixth to be published by the Institute, presents a detailed account of the work done in 1967.

THE INTERNATIONAL RICE RESEARCH INSTITUTE

1960

The International Rice Research Institute
Annual Report 1967

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

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*Arrived during year.
†Left during year.
‡On study leave.

From fields planted to IR8 such as this one in the Province of Laguna, many Filipino farmers in 1967 were harvesting from 4 to 8 metric tons of rice per hectare — two to four times the yield of conventional varieties.

Director's Introduction

Undoubtedly, the most significant accomplishment of the Institute during 1967 was the widespread adoption of IR8 by farmers, not only in the Philippines and in other countries of South and Southeast Asia, but in many other rice-growing nations around the world. Although a specific project for farmer acceptance of a variety is not a direct activity of the Institute, it is nevertheless a distinct outgrowth of the Institute's program. As indicated in the 1966 Annual Report, the Institute produced an abundance of seed, prepared and distributed appropriate instructions for the culture and management of the new variety, and trained many extension workers in the techniques of modern rice production.

The most phenomenal change has occurred in the Philippines. In the province of Laguna, by December, 1967 over 52 percent of the rice farmers were growing IR8. Only 18 months earlier, Laguna farmers growing the variety could have been numbered on the fingers of one hand.

Admittedly, the province of Laguna is not typical of the Philippines in general. It has excellent soils for lowland rice culture; over much of its area year-round irrigation can be and is practiced; and in it are situated both the College of Agriculture (of the University of the Philippines) and The International Rice Research Institute. However, some 10 other provinces are moving fast in the adoption of the newest varieties and of the appropriate cultural practices that, together, allow farmers to double and even triple their previous grain yields. It is estimated that more than 200,000 hectares of IR8 were grown in the Philippines during the main (rain-fed or monsoon) crop season of 1967 and that, conservatively, the resulting additional net profit to Filipino farmers was ₱58,200,000 (US$15,000,000). Furthermore, the economy of the country obviously has been helped considerably through increased sales of fertilizer and of the products of other industries serving agriculture.

India got off to a late start in the multiplication and distribution of the IR8 variety. However, over 150,000 hectares were grown in 1967, and some estimate that at least one million hectares will be grown in the monsoon season of 1968. The Institute was partly responsible for the introduction into India of Taichung (Native) 1, which, in spite of its defects, has markedly increased rice yields on more than a million hectares of rice land.

In Pakistan, with the help of the Ford Foundation, significant progress is being made. The fastest spread is occurring in West Pakistan, where abundant sunshine and low disease incidence are conducive to high yields. Moreover, the farmers, accustomed by now to short wheats, seem to be accepting short rice avidly. Predictions are that about 500,000 hectares of rice area in West Pakistan will be planted to IR8 in 1968.

In East Pakistan, on the other hand, IR8 is beset, in the monsoon season, by problems of disease and deep water; and at that time of year IR5 seems to be doing better. In the dry season, however, IR8 is popular with the farmers. Even so, because of the unique wet-season difficulties, coupled with the greater conservatism of the East Pakistani farmer with respect to dwarf crops, the acceptance of IR8 is not yet up to early expectations. The year 1968 should give a clearer picture of the spread of this variety in East Pakistan.

A word might be in order, here, about the Institute's view of the position and role of IR8. The great contribution of IR8 is its high yield potential, which, of course, derives from its short stature, its vigorous tillering ability and its nitrogen responsiveness. These characteristics constitute a revolutionary new plant type, of which IR8 was the initial variety. The plant type is here to stay; varieties, however, will come and go, and IR8 soon will be out of date. New varieties are being developed that will retain the shortness, the yielding ability and the fertilizer responsiveness of IR8 but will possess greater disease resistance, improved grain quality, and desirable variations in crop duration to suit the different requirements of the various Asian countries.

In the meantime, the spread of IR8, in Malaysia, Ceylon, and even Mexico (where it is highly acceptable) continues and could be cited in detail. Perhaps, however, it is sufficient to state that the variety is being grown in more than 60 countries throughout the world, is being intensively multiplied in the principal tropical countries of South Asia, and is now gaining rapid acceptance in several countries of Latin America.

In late 1967, the Institute named its second rice variety when the genetic line first known as IR5-47-2 was designated as IR5. The newer variety is slightly taller than IR8 but has greater resistance to the bacterial blight and tungro virus diseases. The initial pure seed of this variety is being produced at the Institute and, along with that of IR8, no doubt will continue to be multiplied extensively until the anticipated better varieties appear during the next few years.

The Agronomy Department continued its program along lines similar to those reported last year. It intensified its studies of direct seeding methods. As a result, the highest yield ever obtained at the Institute—10,341 kg/ha—occurred in a direct-seeded field of IR8.

A group of the newest varieties were tested under upland conditions and compared with several standard recommended Seedboard upland varieties of the Philippines. The truly phenomenal yield (for an upland crop in the monsoon season) of 6,191 kg/ha was obtained with IR5. This was about 50 percent higher than the yield obtained with Palawan, one of the recommended Seedboard varieties. Actually, the yield of IR5 in this experiment topped, by about two metric tons, any previous yield of rice under upland culture obtained on IRRI's experimental plots during the past 5 years. Naturally, such a yield could not have been obtained without an excellent distribution of rainfall during the growing season. The variety IR8 produced the next highest yield, with a recorded 5,678 kg/ha.

The chemical weed control work of the Agronomy Department was continued, and further studies of "Daxtron", or "Pyriclor" (its new name), point out that compound's potentiality as a good selective herbicide of low cost. Unfortunately, the company producing this herbicide has not been able to place it on the market because of manufacturing difficulties. Several promising new chemicals appeared during 1967, and the results of their experimental use are presented later in this report. It is predicted that within the next few years chemical weed control for flooded rice will be so much perfected that farmers who wish to do so may eliminate handweeding completely.

The Plant Pathology Department continued to screen varieties and genetic lines for resistance to the principal diseases. In cooperation with the Varietal Improvement Department, it discovered several lines that have high resistance to bacterial blight and to the tungro and grassy stunt virus diseases, and a broad spectrum of resistance to the many races of rice blast disease. The superior yields obtained by IR5 over IR8 in many instances during the monsoon season demonstrated the importance of disease resistance. Certain of the crosses with TKM-6 from India are producing some dwarf lines that have resistance to the several virus diseases, to bacterial blight, and even to rice stem borers.

During the next two or three years, the Institute undoubtedly will release several new varieties that will combine this high disease resistance not only with good plant type, but with improved grain shape, size and eating and cooking qualities. In fact, the work has progressed to the point where several promising lines, selected from single-row plantings, were planted for the first time in December, 1967, in multiple-row yield trials.

Although the Entomology Department continues to find diazinon the best chemical for the control of stem borers and leafhoppers, it is still seeking a systemic insecticide that will give better control of the brown planthopper, which is the vector of the grassy stunt virus disease and which causes serious direct injury as well.

As mentioned earlier, the entomologists, by crossing TKM-6 from India with IR8 and other similar new dwarf varieties, have developed dwarf rice varieties that have considerable resistance to the rice stem borers. Probably, a variety with complete immunity to these insects never will be developed; but, as pointed out in the 1966 Annual Report, chemical control is greatly facilitated by having a degree of resistance in a variety. For example, when Rexoro, a highly susceptible variety, is grown in large fields, it is impossible to obtain effective control of the stem borers with diazinon; but when IR8, a moderately susceptible variety, is grown, diazinon provides good insect control.

The Chemistry Department has found over 100 varieties of rice from the world collection that have a grain protein content of more than 13.5 percent in several successive plantings (the average value for rice is about 8 percent). Because these hundred-odd varieties came from a collection of 8,500, the high protein content, of course, could be simply a matter of chance. Work on the selected varieties is continuing in order to ascertain whether there are among them any that possess a genetic character for high protein. Furthermore, these initial, high-protein varieties are being studied to determine the distribution of the essential amino acids, in the hope of finding some varieties that consistently have a lysine content in the protein of over 4 percent.

The Agricultural Engineering Department during 1967 designed, constructed and tested a new type of mechanical thresher which, with its promise of low investment and operation costs, should be of decided value in South and Southeast Asia, where farm incomes are low. Threshing in those regions is now done largely by hand or by animal treading.

The Agricultural Economics Department has produced considerable data to support the contention that the new varieties, such as IR8, under low levels of management perform as well as the traditional tall, tropical varieties, and at high management levels do much better. Under top management, the profits from IR8 are about twice those obtained from the traditional tall varieties.

Useful data are now being collected from Philippine farmers who have started to grow IR8. These studies will be completed in 1968 and should provide valuable information on factors influencing the acceptance of technological innovations in agriculture.

Staff Changes

Dr. Ian MacRae, the soil microbiologist, resigned in April, 1967, and in October was replaced by Dr. Tomio Yoshida of Japan.

Dr. Randolph Barker became the Institute's agricultural economist on July 1, 1967.

Dr. Peter R. Jennings, the plant breeder and head of the Varietal Improvement Department, left the Institute in May to take on new duties as The Rockefeller Foundation's rice specialist in Latin America. Dr. Gurdev S. Khush joined the Institute as a plant breeder in August, 1967, and Mr. Henry M. Beachell took over as head of the Varietal Improvement Department when Dr. Jennings left.

Mr. Edward A. Jackson resigned as Editor, at the end of August, and has not yet been replaced.

Dr. Francis C. Byrnes, head of the Office of Communication, left the Institute at the end of November to accept new responsibilities in Colombia, in connection with the new Institute of Tropical Agriculture. His replacement is being sought.

Trustees

In January, 1967, the Board of Trustees elected two new members, Dr. B. P. Pal, Vice-President and Director-General for Research of the Indian Council of Agricultural Research, and Dr. M. O. Ghani, Vice Chancellor of the University of Dacca, East Pakistan.

The resignation of Mr. P. N. Thapar, Vice Chancellor of the Punjab Agricultural University of India, was accepted, as his term of appointment had ended on December 31, 1966.

Finances

The major portion of the operating costs of the Institute were shared equally by the Ford and Rockefeller Foundations. The sum received during 1967 from the two foundations for the operation of the Institute's central program, including the value of the salaries, perquisites and travel for certain staff members assigned to the Institute by The Rockefeller Foundation, amounted to $1,429,750. Other funds received by the Institute during 1967 are listed below.

1. From the Ford Foundation for support of rice research and for the training of scientists and extension workers in several countries, as follows:

a) East Pakistan	$140,724
b) West Pakistan	$127,500
c) Ceylon	$ 95,000
d) Philippines	$ 79,160

2. From The Rockefeller Foundation, $40,000 for partial support of research on the improvement of the protein and the essential amino acid content of the rice grain, and $10,000 to support the training at the Institute of four research fellows from India.

3. From the United States Agency for International Development, a

total of $102,253.05, $95,407.62 of which was in support of the research project entitled, "The Farm and Equipment Power Requirements for Production of Rice and Associated Food Crops in the Far East and South Asia". The remaining funds were applied to the Institute's training program.

Although the Institute entered into a contract with U.S. AID for a rice research program in India, none of the funds had been released by December 31, 1967.

4. From the National Science Foundation, Washington, D.C., $17,250 in support of the research project entitled, "The Description and Preservation of the World's Germ Plasm".

5. From the National Science Development Board of the Republic of the Philippines, $10,179.49 toward the research project, "Insecticide Residue Problems of Rice Production with Emphasis on Gamma-BHC".

6. From the Esso Research and Engineering Co., $3,450 in support of fertilizer research.

7. From the Bio-Products Dow Chemical International, $1,535.97 toward the weed control research program.

8. From the Imperial Chemical Industries, Ltd. of the United Kingdom, $5,000 in support of research on minimum tillage techniques and on the use of non-selective herbicides for tropical rice production.

9. From the Pittsburgh Plates Glass Co., $2,000 to support trials of azide on rice in six Asian countries.

10. From the Monsanto Company, $1,000 in support of the chemical weed control research program.

11. From the Stauffer Chemical Company, $5,000 toward the general research program of the Institute.

12. From the International Minerals and Chemicals Corp., $10,000 toward the support of soil fertility studies.

13. From the International Business Machines Corp., $7,000 for the preparation of a rice variety catalogue.

Crop Weather—1967*

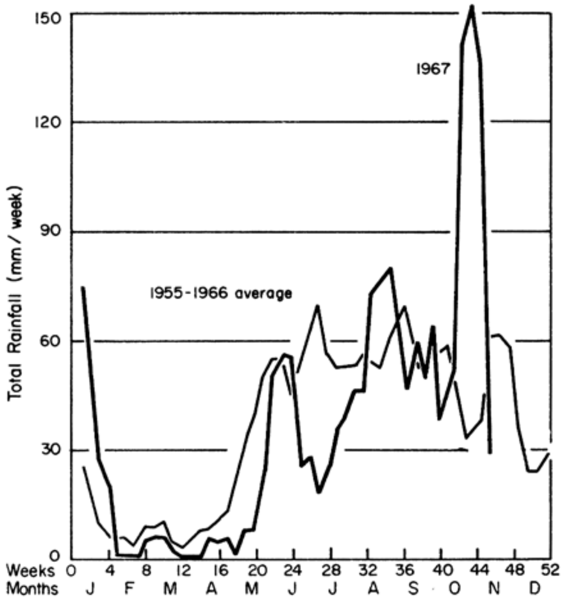


Fig. 1. Annual rainfall curve (3-point moving average) for College, Los Baños, Laguna.

The weather during the 1967 crop year was relatively normal compared to recent averages. Figures 1 and 2 show the curves for rainfall and solar radiation recorded at the weather station of College, Laguna, about 700 meters from the Institute farm. The 1966 data were included in computing the recent averages of rainfall and solar energy. From January through November 30, 1967, rainfall amounted to 1,771 mm compared with 1,773 for the 12-year mean of 1955-1966. Rainfall during January 1967 was much higher than for either January 1966 or for the long-term average. Since little rice is in the field in January, these differences had no practical significance for the rice crop of the area. During May, the amount of rainfall received was 26 mm compared to 441 mm during the same month in 1966 and 183 mm for recent averages (average value for May 1965 through 1966). As a result of the more open weather, the solar energy for May 1967 was higher by 2,827 g-cal cm^{-2} per month than for May 1966, but was lower than the values for the 12-year mean of 1955 to 1966. Although the total solar energy received during the ripening period (April to May) of the 1967 dry season crop was higher by 701 g-cal cm^{-2} than the previous year, it was considerably lower than the long-term average.

The amount of solar energy received during August 1967 was low compared to the recent average but this has little practical significance since most of the wet season crops were at the tillering stage (Fig. 2), when light plays a less important role in final yield.

One of the significant aspects of the 1967 crop weather was the higher rainfall received during August and September. This had a direct bearing on the growth of upland rice which depends largely on rainfall. During the reproductive stage of the crop (September to October), upland rice received higher rainfall which contributed substantially to the high yields (5,817 to 6,191 kg/ha) obtained in replicated experiments. Solar energy values for September to October this year were also higher than for 1966.

The other significant item about the 1967 crop weather was the severe typhoon named "Welm-

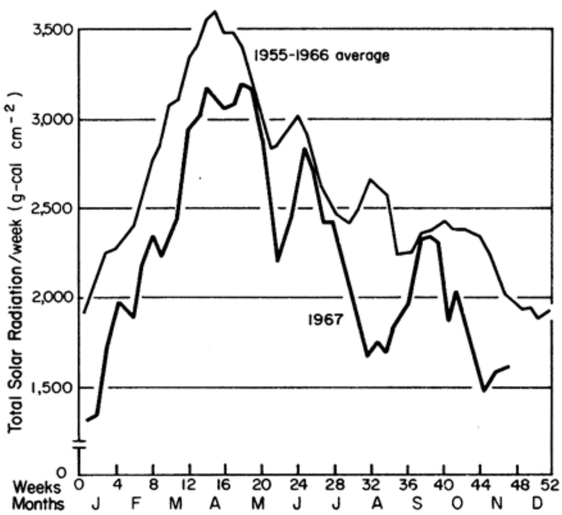


Fig. 2. Annual solar radiation curve (3-point moving average) for College, Los Baños, Laguna.

*The general climatic and soil environment at the Institute was described in the 1965 Annual Report and the crop weather for 1966 was described in the 1966 Annual Report.

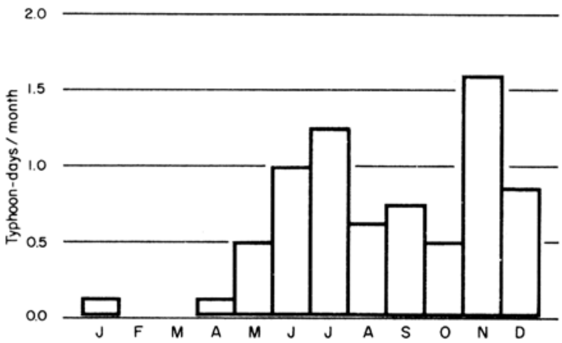


Fig. 3. Average frequency of typhoon days within 150 miles of Los Baños, Laguna (1959-66).

ing" (max. velocity, 125 km/hr) which occurred on November 3 and 4 and destroyed many rice crops which were nearing maturity. Typhoons of this magnitude have not occurred at this site in recent years (1959-1966). Grains in the panicles of the standing rice crop were desiccated or were shattered in the field with resultant increased floret sterility. The varieties which lodged just before the typhoon suffered smaller shattering losses from high wind velocity than the unlodged plants. The other typhoon, called "Trining", which struck on October 17, was comparatively mild (max. velocity, 47 km/hr). The average frequency of typhoons at Los Baños from 1959 to 1966 is shown in Fig. 3.

Although the total rainfall received during November this year was similar to that in 1966, the total solar energy was considerably lower and tended to reduce the grain yield of varieties that matured in November.

Plant Physiology

Physiological studies, particularly on the carbohydrate accumulation pattern and tillering ability of rice plants, were continued to provide a better understanding of the high-yielding ability of certain rice varieties. Further investigations also were conducted on the phenomena of photoperiodism in rice and on the elongation of the rice plant internodes.

The problems of high salinity in rice areas where the soil is affected by sea water or where precipitation is too low as compared to evaporation, and of zinc deficiency of the rice plant, also received the Department's attention during the year.

Carbohydrate Accumulation and Nitrogen Response in Rice Varieties

Experiments were conducted to (1) determine if any differences in the process of carbohydrate accumulation exist between high- and low-nitrogen responsive varieties, (2) understand the relationship between carbohydrate accumulation and plant type, (3) estimate the contribution of the carbohydrate accumulated before flowering to grain carbohydrate, and (4) compare the process of carbohydrate accumulation during the dry and wet seasons.

Four varieties differing in plant type were grown in the field at 0 and 100 kg/ha N in the wet season and at 0 and 150 kg/ha N in the dry season. The nitrogen, starch and sugar contents of the plant samples were determined every 2 weeks after transplanting. The plants were supported with bamboo sticks whenever there was danger of lodging.

High vs low nitrogen responsive varieties

Table 1 shows the grain yield and nitrogen response of the four varieties in the dry season. IR8 showed the highest nitrogen response and gave the highest grain yield. Chianung 242 and Peta also responded to nitrogen application. Bengawan responded negatively to nitrogen even in the dry season. Peta and Bengawan would have yielded much less had the plants not been supported to prevent them from lodging.

The changes in the total sugar and starch contents of the leaf sheath plus culm of the four varieties followed a similar pattern (Figs. 1 and 2) at successive growth stages. The sugar and starch contents started to decrease after transplanting, then increased and reached the maximum at around flowering time, and finally decreased sharply. The total sugar content of Chianung 242, a japonica variety from Taiwan, was remarkably low as compared to those of the other varieties, which were indicas.

A heavy application of nitrogen tended to lower both the total sugar and starch contents of Peta, Chianung 242 and Bengawan. However, IR8, a high-nitrogen-responsive variety, maintained relatively high total sugar and starch contents even when subjected to high nitrogen levels. The varietal difference in carbohydrate accumulation as affected by nitrogen application was more marked in starch than in total sugar content.

Generally, the low starch or low carbohydrate content (total sugar plus starch) of the leaf sheath plus culm was associated with high nitrogen uptake and with a high proportion of leaf blades to leaf sheaths plus culm. An example of this relationship is shown in Fig. 3. This suggests that when the rice plant absorbs nitrogen actively and tends to produce more leaf blades, the photosynthetic products are preferably used for synthesizing protein and producing leaf blades and other tissues. As a result, the carbohydrate content tends to be lower. This relationship, however, does not explain the high starch and/or carbohydrate content of IR8 when grown at high nitrogen levels.

Carbohydrate accumulation vs plant type

As shown in Table 2 and Fig. 4, Peta and Bengawan are tall, leafy and high tillering; IR8 is short, moderately leafy and high tillering; and Chianung 242 is moderately tall, less leafy and

Table 1. Grain yield and nitrogen response of four varieties,* 1967 dry season.

Variety	Grain yield (kg/ha)		Nitrogen response	
	0 kg/ha N	150 kg/ha N	Yield increase over 0 kg/ha N	Yield increase (%)
IR8	5307	8203	2896	54.6
Peta	6644	7459	815	12.3
Bengawan	6482	6223	—259	—4.0
Chianung 242	5414	6610	1196	22.1

*Transplanted January 5, 1967.

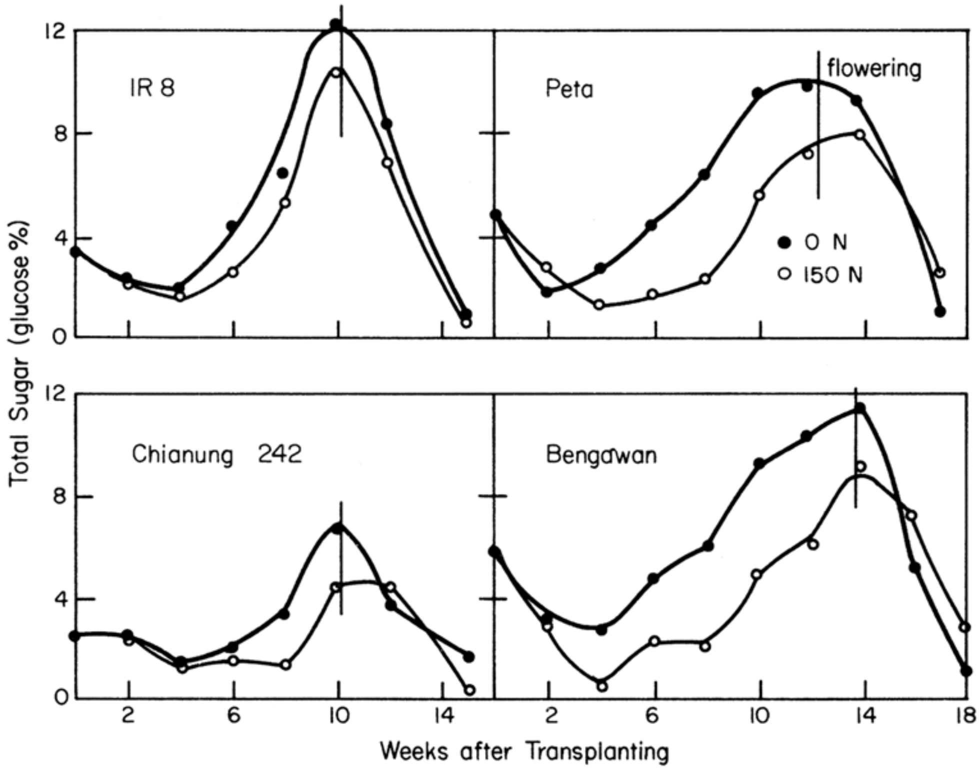


Fig. 1. Total sugar content of the leaf sheath plus culm of four varieties at successive growth stages, 1967 dry season.

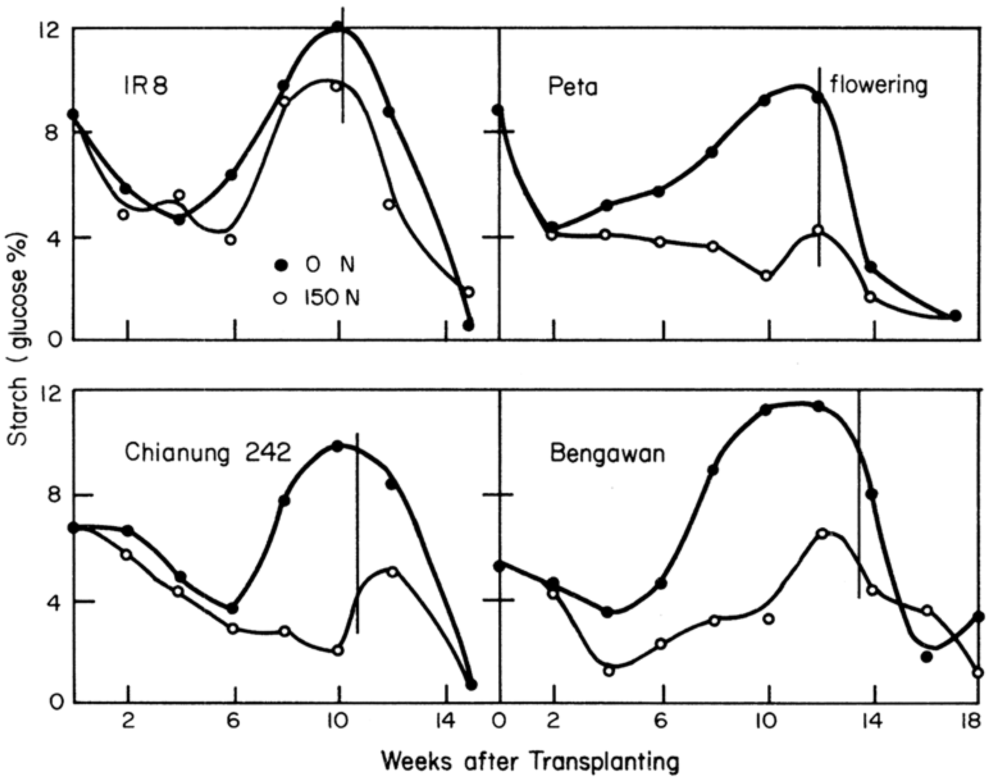


Fig. 2. Starch content of the leaf sheath plus culm of four varieties at successive growth stages, 1967 dry season.

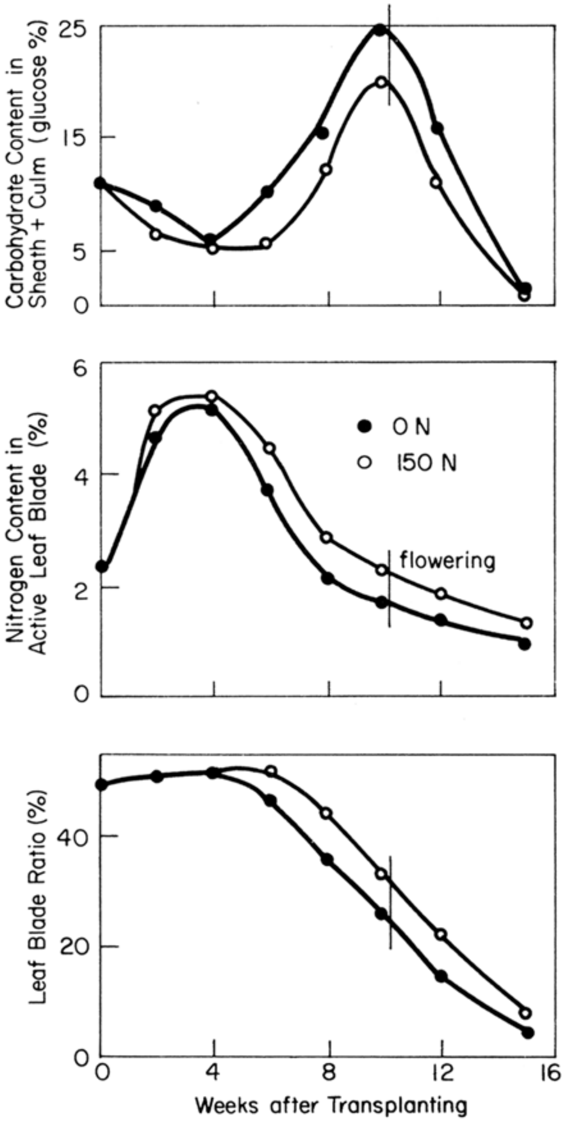


Fig. 3. Carbohydrate content of the leaf sheath plus culm, nitrogen content of the active leaf blade, and the active leaf blade ratio of IR8, 1967 dry season.

low tillering. As mentioned in the 1966 Annual Report, mean leaf openness can be used as a measure of leaf erectness. The mean leaf openness values measured at flowering clearly showed that IR8 has erect leaves, Peta and Chianung 242 have rather droopy leaves, and Bengawan has extremely droopy leaves.

In accordance with the mean leaf openness values, the population of IR8 maintained better light conditions at the same leaf area index (LAI) than any other variety. For instance, at 150 kg/ha N, IR8 and Chianung 242 differed greatly in LAI but not in light transmission ratio (LTR). The differences in light conditions of these populations were largely attributed to the different degrees of leaf erectness.

In a rice plant population, light tends to be the limiting factor in dry matter production when the LAI becomes large. Under such a condition, better light conditions within the population promote starch accumulation by affecting the photosynthetic activity of the population.

Since the starch content of the rice plant tends to be low under low light intensities, it can be expected to decrease under serious mutual shading. This suggests that as long as light conditions favorable for active photosynthesis are maintained within a population, the starch content of the plants may not necessarily decrease with increasing LAI and nitrogen uptake. It follows that an erect-leaved variety, such as IR8, can maintain better light conditions at high nitrogen levels than a variety with droopy leaves; as a result, the accumulation of starch is not markedly affected by increased LAI. At 0 kg/ha N, when the LAI was small and mutual shading was not a problem, all varieties used maintained about the same starch content. At 150 kg/ha N, when the LAI was large and mutual shading became serious, the starch content of the droopy-leaved varieties decreased.

These results indicate a close relationship between the starch content of the plant at a high nitrogen level and plant type. Therefore, a high starch content at a high nitrogen level may be used as a biochemical parameter for the high nitrogen responsiveness of rice varieties.

Apparent contribution rate of the carbohydrate accumulated before flowering to grain carbohydrate

The rice plant at flowering contains some sugar and starch, a larger portion of which is translocated to the grain during ripening. Therefore, grain carbohydrate can be conventionally divided into two parts: the carbohydrate (starch plus sugar) accumulated in the rice plant before flowering (henceforth referred to as "accumulated carbohydrate"), and that resulting from

Table 2. Some agronomic characters of four varieties, 1967 dry season.

Nitrogen level (kg/ha)	Variety	Growth duration (days)	Height at harvest (cm)	Panicle number/ sq m	Leaf blade mean*		
					Openness (degree)	Length (cm)	Width (cm)
0	IR8	123	84	200	9.7	32.5	1.15
	Peta	137	148	193	33.7	48.7	1.51
	Bengawan	144	166	223	61.3	60.9	1.24
	Chianung 242	122	124	168	30.8	45.4	1.21
150	IR8	122	98	340	10.8	46.5	1.45
	Peta	137	189	305	40.0	60.6	1.87
	Bengawan	146	209	280	88.8	67.7	1.41
	Chianung 242	125	159	258	33.9	55.1	1.43

*Average of all leaves at flowering.

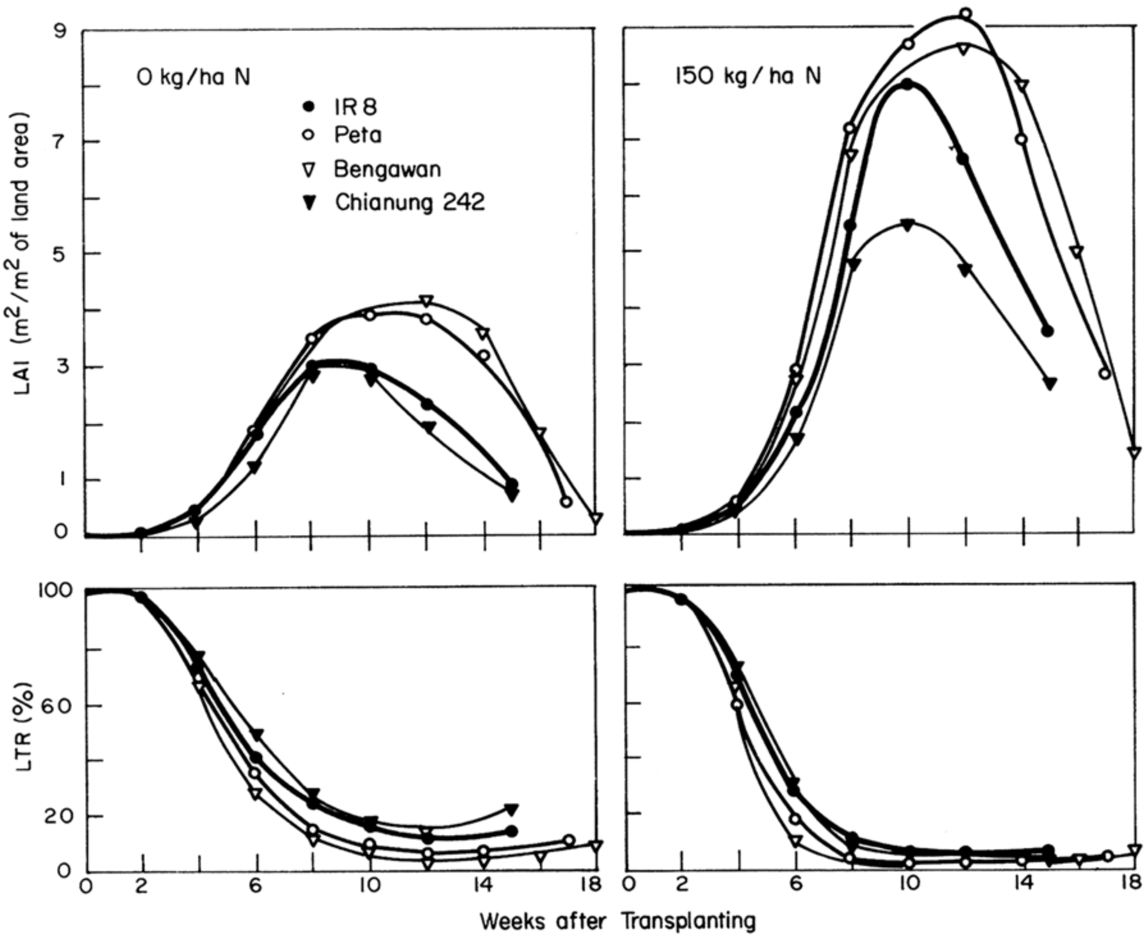


Fig. 4. Leaf area index (LAI) and light transmission ratio (LTR) of four varieties fertilized at 0 and at 150 kg/ha N at successive growth stages, 1967 dry season.

Table 3. Apparent contribution rate of sugar and starch accumulated before flowering to grain carbohydrate (1966 wet season and 1967 dry season).

Variety	Apparent Contribution Rate (%)	
Wet Season	0 kg/ha N	100 kg/ha N
IR8	13	11
Peta	25	12
CP231	0	2
Hung	66	44
Dry Season	0 kg/ha N	150 kg/ha N
IR8	33	22
Peta	34	16
Bengawan	38	29
Chianung 242	20	6

photosynthesis after flowering.

The apparent contribution rate of accumulated carbohydrate to grain carbohydrate was calculated according to the formula: Apparent contribution rate $= \frac{A-C}{B} \times 100$ where A represents the total carbohydrate content of the plant at flowering; B, the total carbohydrate content of the grain at harvest; and C, the total carbohydrate content of the leaf blade and the leaf sheath plus culm at harvest.

The apparent contribution rate was generally low (a) in the wet season as compared to the dry season, (b) at a high nitrogen level as compared to a low nitrogen level, and (c) with an early maturing variety as compared to a late maturing variety (Table 3). The data indicate that when nitrogen is applied to improved varieties such as IR8 or Chianung 242, more than 80 percent of the grain starch comes from photosynthesis after flowering. Considering that the improved varieties are short, and are early maturing, and also require more nitrogen, the dependence of grain starch on photosynthesis after flowering will assume greater importance.

Wet vs dry season

Figures 5 and 6 show the sugar and starch contents of IR8 and Peta in the wet and dry seasons.

Generally, both the sugar and starch contents of the two varieties were lower in the wet than in the dry season. This trend was particularly evident in the starch content. The lower carbohydrate content in the wet season probably resulted from the combination of relatively high temperatures and relatively low solar radiation.

All the results so far indicate that starch content is more affected by climate, plant type and nitrogen than total sugar content.

Growth Performance of Varieties of Different Tillering Ability

Varieties that are transplanted usually are relatively high tillering, and those that are direct-seeded usually are low tillering. Tall varieties are either high or low tillering, and short varieties, usually high tillering. Tallness often is associated with other undesirable plant characters.

There is little available information about low vs high tillering varieties under diverse cultural conditions when plant height is made short along with other improved plant characters.

Tillering ability, yield, and plasticity index of some selected lines and varieties

To select test varieties varying in tillering ability, 20 lines and varieties were grown at 20 x 20 cm and 100 x 100 cm spacings, and given 0 and 150 kg/ha N (henceforth, *variety* will be used to refer to both line and variety). Tiller number at 100 x 100 cm spacing was used as a measure of tillering ability.

Table 4 summarizes the data on panicle number and yield of six selected varieties and four popular varieties. IR8 can be considered high tillering but it is lower tillering than Taichung (Native) 1 and early-short Peta.

Plasticity index, defined as the ratio of grain weight per hill at 100 x 100 cm spacing to that at 20 x 20 cm spacing, was well correlated with panicle number at 100 x 100 cm spacing (Fig. 7). Generally, higher plasticity indices are associated with larger numbers of panicles. In other words, tillering ability is mainly responsible for varying plasticity indices.

Two of the 20 varieties had very heavy panicles, which contributed to their higher plasticity indices.

Response to spacing

Six selected varieties were grown at 10 x 10, 20 x 20, 30 x 30, 40 x 40 and 50 x 50 cm spacings and at two nitrogen levels, 0 and 100 kg/ha. Table 5 gives some information about the

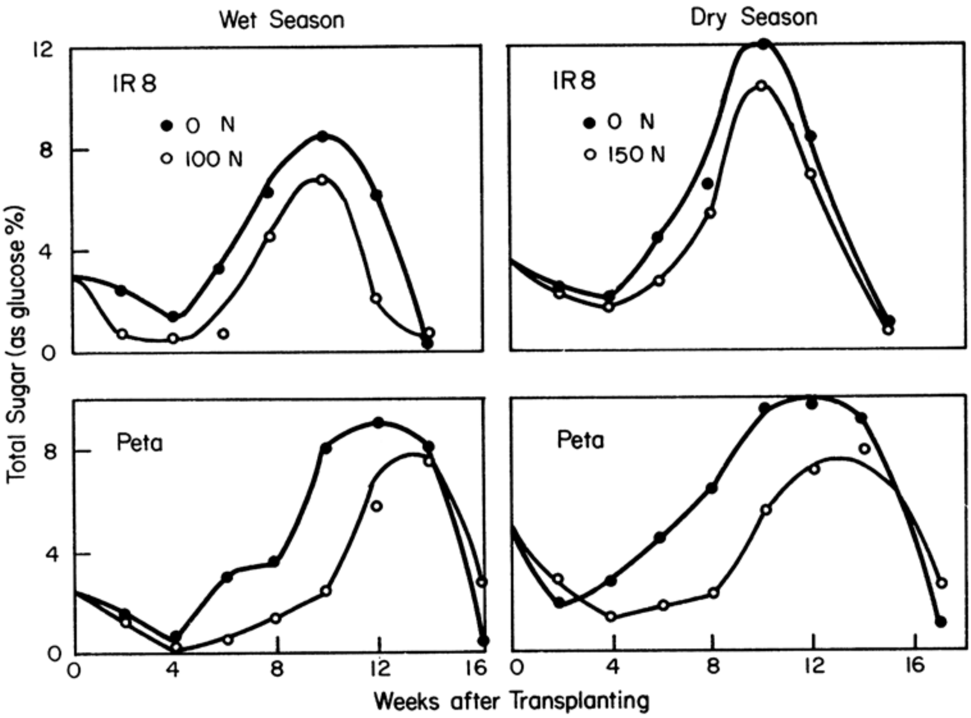


Fig. 5. Total sugar content of the leaf sheath plus culm of IR8 and Peta in the wet and in the dry season.

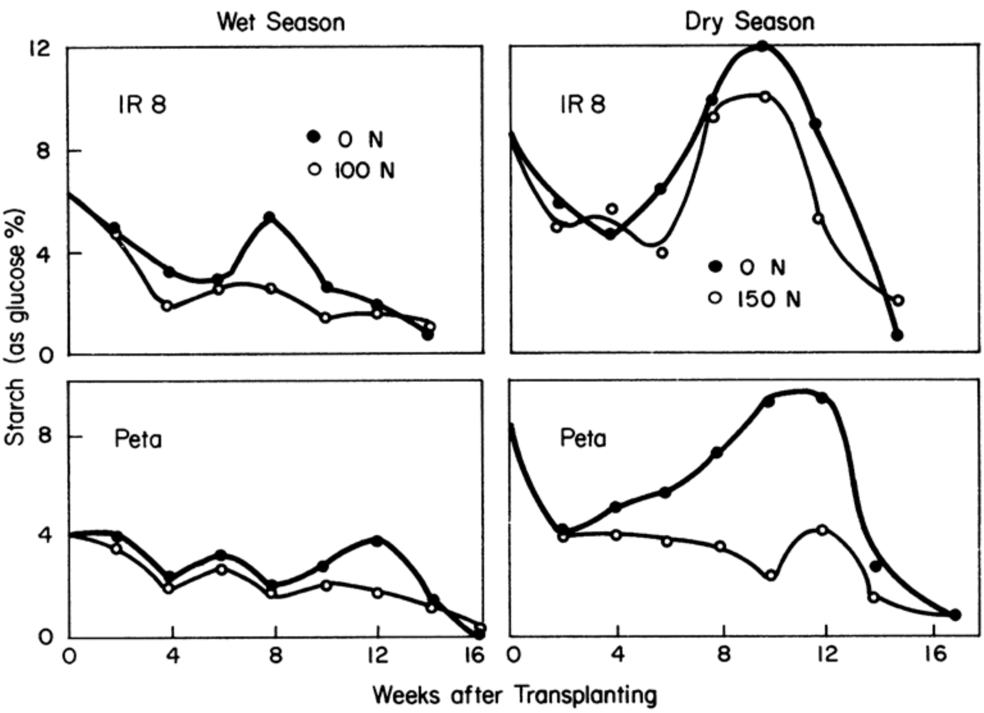


Fig. 6. Starch content of the leaf sheath plus culm of IR8 and Peta in the wet and in the dry season.

Table 4. Yield and tillering ability of some varieties and lines.

Variety	Yield, kg/ha				Panicle number per hill	
	20 x 20 cm		100 x 100 cm		20 x 20 cm	100 x 100 cm
	0 kg/ha N	150 kg/ha N	0 kg/ha N	150 kg/ha N	150 kg/ha N	150 kg/ha N
IR165-34-2-2	4416	5780	674	875	14.7	58
Kaohsiung 21	4348	5978	1189	1550	14.8	83
IR154-68-3-2-1-3	4383	6826	1347	1649	17.1	58
IR154-30-3-3-1	4316	5199	989	1162	15.8	64
IR154-45-1-3-3	4071	5842	1053	1237	10.5	48
IR154-18-2-1	4133	5466	1238	1583	17.4	94
Early-short Peta*	4396	6736	1591	1983	14.9	121
Late-short Peta†	3640	5148	1038	1600	12.0	106
Taichung (N) 1	4961	6918	2038	2562	18.5	126
IR8	4633	7225	1919	2237	15.0	94

* Known as IR262-A43-8-11-3-5.
† Known as IR262-A43-8-35-5-6.

Table 5. Growth characteristics of six varieties.

Variety used		Growth duration (days)	Tillering ability	Height (cm)
V_1	IRl65-34-2-2	119	Medium	96
V_2	IR154-45-1-3-3	98	Low	112
V_3	IR154-68-3-2-1-3	102	Medium	100
V_4	IR154-30-3-3-1	98	Medium	99
V_5	IR8	119	High	103
V_6	IR154-18-2-1	100	High	104

varieties, while Table 6 summarizes the data obtained on grain yield, number of panicles and average panicle weight. All the varieties used had erect, dark-green leaves, were 100 to 110 cm tall, and matured in 100 to 120 days from sowing.

All the varieties achieved their highest yields at 10 x 10 cm or 20 x 20 cm spacing. The yields at these spacings were practically the same although the number of panicles per square meter differed markedly among varieties. As shown in Fig. 8, the increase in grain yield was associated with the increase in number of panicles up to about 250 panicles/sq m when 100 kg/ha N was applied. Generally, an increase in the number of panicles per square meter was accompanied by a decrease in the average weight per panicle. This compensatory effect was particularly apparent above 250 panicles/sq m or between 10 x 10 and 20 x 20 cm spacings.

V_5 (IR8) and V_6 had about the same tillering ability but different tiller angles. The better adaptability of IR8 to wider spacings may be explained by its bigger tiller angle which enables it to cover land surface more effectively at wider spacings than V_6. In other words, IR8 can intercept more sunlight at wider spacings than V_6.

At 10 x 10 cm spacing, all the varieties had about the same number of panicles per square meter. However, the process by which each variety reached the same number of panicles differed according to tillering ability. As shown in Fig. 9, the percentage of effective tillers was lower in a high tillering variety than in a low tillering one. It seems that IR8 suffered from more serious mutual shading at 10 x 10 cm spacing than did V_2. As a result, a larger number of IR8 tillers died but the lower percentage of effective tillers practically did not affect the grain yield.

During the growing period, it was clear that rice leaves at closer spacing or those of a high-tillering variety were yellower than those at wider spacing or those of a low-tillering variety. To confirm if the yellower color was related to the nitrogen content of leaves, the nitrogen and chlorophyll contents were determined on samples taken about 7 weeks after transplanting. As shown in Table 7 and Fig. 10, the nitrogen content of leaves was inversely related to plant density, and there was a good correlation between nitrogen and chlorophyll contents.

Response to nitrogen levels

To study the nitrogen response of varieties of different tillering ability, the same six varieties were grown at 0, 30, 60, 90 and 120 kg/ha N at 20 x 20 cm spacing. All the varieties responded

Table. 6. Response to spacing of varieties differing in tillering ability.

(a) 0 kg/ha N

Variety	10 x 10 cm	20 x 20 cm	30 x 30 cm	40 x 40 cm	50 x 50 cm
		Number of panicles per sq m			
V_1	253	178	133	91	75
V_2	219	119	82	61	47
V_3	246	143	94	74	61
V_4	283	202	132	105	84
V_5	243	166	123	111	106
V_6	263	170	135	116	98
		Average panicle weight (g)			
V_1	1.75	2.64	2.76	2.90	2.49
V_2	1.67	3.73	4.31	4.31	4.24
V_3	2.29	3.52	3.98	4.18	4.00
V_4	1.87	2.23	2.48	2.19	2.49
V_5	2.08	3.05	3.13	3.27	2.74
V_6	2.01	2.85	2.86	2.63	2.77
		Grain yield (kg/ha)			
V_1	3455	3755	2727	2077	1644
V_2	3761	4055	3272	2644	1954
V_3	4050	4172	3450	2888	2333
V_4	4100	3988	3121	2622	1928
V_5	4667	4749	3694	3722	2989
V_6	4511	4515	3554	2838	2525

(b) 100 kg/ha N

Variety	10 x 10 cm	20 x 20 cm	30 x 30 cm	40 x 40 cm	50 x 50 cm
		Number of panicles per sq m			
V_1	356	242	172	146	95
V_2	350	194	140	96	70
V_3	320	243	160	124	103
V_4	330	260	202	154	106
V_5	340	250	198	167	141
V_6	346	292	204	154	143
		Average panicle weight (g)			
V_1	1.60	2.45	2.99	3.01	3.96
V_2	2.25	3.47	3.92	3.79	4.29
V_3	2.13	2.49	3.43	3.52	3.54
V_4	2.05	2.46	2.44	2.38	2.17
V_5	2.02	2.97	3.54	3.36	3.43
V_6	2.10	2.52	2.69	2.59	2.58
		Grain yield (kg/ha)			
V_1	5611	5194	4116	3060	2383
V_2	5744	5533	4494	3474	2803
V_3	5710	5716	4719	4455	3244
V_4	5565	5505	4427	3516	2500
V_5	6119	6444	5733	4816	4649
V_6	6116	6172	5172	4466	3412

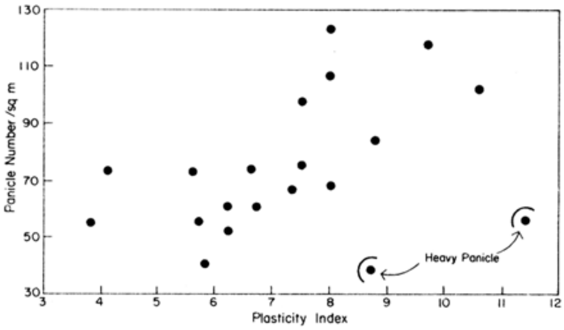


Fig. 7. Correlation between plasticity index and tillering ability.

similarly to nitrogen application (Table 8). They yielded 5 to 6 ton/ha with 120 kg/ha N. Since these varieties have good leaf characters, their yielding ability is governed by other factors such as panicle character or some physiological activities. With varieties of good plant type, it is a problem determining what other characters or physiological activities are associated with high nitrogen response or high yielding ability.

Variation of yield components as affected by spacing and nitrogen application

Table 9 shows the yield components of IR8 as affected by spacing and nitrogen application. With increasing density, the number of panicles per square meter increased but the number of spikelets per panicle decreased, and the percentage of filled grains and weight of 1,000 grains remained about the same. With increasing nitro-

Table 7. Nitrogen and chlorophyll contents of low and high tillering varieties at different spacings.

Spacing (cm)	V_2		V_6	
	N (%)	Chlorophyll*	N (%)	Chlorophyll*
10 x 10	2.65	0.70	2.44	0.61
20 x 20	3.11	0.79	2.83	0.74
30 x 30	3.59	0.82	3.54	0.76
40 x 40	3.96	0.94	3.97	0.80
50 x 50	3.67	0.93	4.23	0.80

*Chlorophyll content is expressed by the relative value of the optical density at 660 mu.

Table 8. Grain yield (kg/ha) of varieties differing in tillering ability at different nitrogen levels.

Variety	Nitrogen level (kg/ha)				
	0	30	60	90	120
V_1	3628	3967	4094	4583	5089
V_2	3906	4533	4844	5045	5478
V_3	4039	4622	4922	5433	5611
V_4	3850	4155	4722	5028	5037
V_5	5128	5317	5789	6022	6211
V_6	4539	5117	5650	5872	5739

Table 9. Yield components of IR8 as affected by spacing and nitrogen level, 1967 wet season.

Spacing (cm) and nitrogen level (kg/ha N)	No. panicles/ sq m	No. spikelets/ panicle	Filled grains (%)	1,000 grains (g)
		(100 kg/ha N)		
10 x 10 cm	340	78	82	28.7
20 x 20	250	115	85	28.0
30 x 30	198	140	86	27.8
40 x 40	167	134	84	27.8
50 x 50	141	135	84	28.1
		(20 x 20 cm spacing)		
0 kg/ha N	153	128	81	29.8
30	180	122	86	29.4
60	200	128	84	28.6
90	243	122	86	29.6
120	268	123	86	29.8

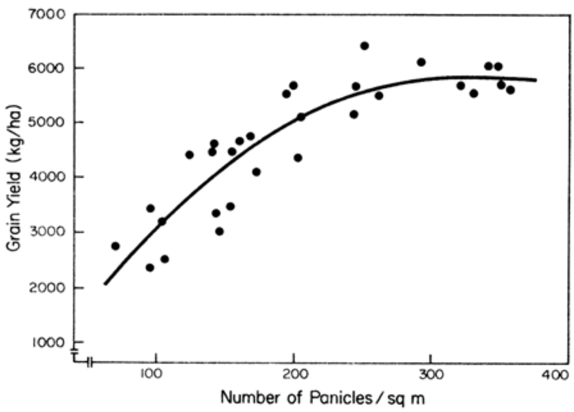


Fig. 8. Grain yield and panicle number (response to spacing: 100 kg/ha N), 1967 wet season.

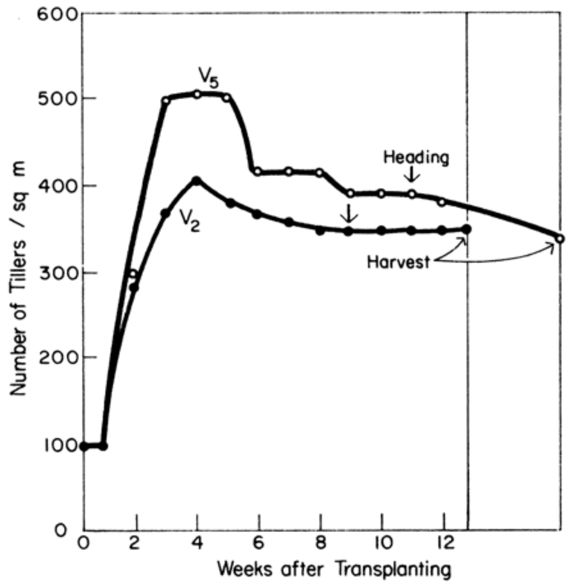


Fig. 9. Changes in tiller number of low and high tillering varieties at 10 x 10 cm spacing with 100 kg/ha N, 1967 wet season.

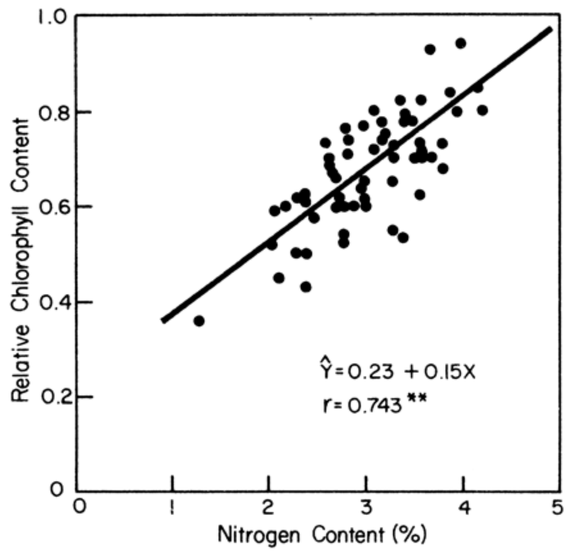


Fig. 10. Relationship between the chlorophyll and nitrogen contents of leaf blades.

Table 10. Variation coefficients (%) of yield components of six varieties between different spacings.*

Variety	No. of panicles/ sq m	No. of spikelets/ panicle	Percentage of filled grains	Weight of 1,000 grains (g)
V_1	47	22	4	5
V_2	61	20	3	4
V_3	45	18	9	6
V_4	40	7	4	4
V_5	34	21	4	4
V_6	38	7	6	5
Mean	44	16	5	5

* Data were taken from 100 kg/ha N plots.

gen level, the number of panicles per square meter increased but the other components remained about the same. This indicates that the increase in the grain yield of IR8 through nitrogen applications in the rainy season was governed largely by the increase in number of panicles per square meter.

Table 10 shows the variation coefficients of yield components of six varieties at different spacings. From this table, it is apparent that the number of panicles per square meter is the most variable yield component; the number of spikelets per panicle is affected by spacing to a lesser extent; and the variations in percentage of filled grains and weight of 1,000 grains are very small.

Studies on Photoperiod Response of the Rice Plant

Response of reported long-day and intermediate rice varieties to photoperiod

Although rice is generally considered a short-day plant, a delay in flowering by short-day treatment has been reported. Varieties with such a response would have potential use in physiological studies and breeding work, and would be most interesting ecologically. However, the

Table 11. The number of days from sowing to flowering of 13 varieties grown at different photoperiods.

Variety	(hr)					
	8	10	12	13	14	16
T-3 W356	88	82	90	98	127	137
B 76	76	69	72	79	86	91
Baok	136	126	122	125	147	163
GEB 24	73	63	90	*	†	†
CH-10	78	76	78	78	80	85
T.21	91	77	82	88	103	98
T.136	72	66	69	76	88	92
Heenati 8963	81	75	77	77	91	112
Heenati 8976	83	73	86	112	165	*
Heenati 8965	67	51	63	77	90	125
Karang Serang	127	115	111	111	114	121
Karang Serang Sel.	147	139	123	129	132	153
BPI-76 (sen.)	64	65	100	145	†	†

* Panicle formation but no emergence after 200 days of growth.
† No panicle initiation after 200 days of growth.

Table 12. Flowering response* of promising IR-lines to photoperiod.

Line	Photoperiod (hr)					BVP†	PSP‡
	10	12	13	14	16		
IR5-47-2	83	94	123	141	142	48	59
IR5-177-2-2-2	73	87	121	133	133	38	60
IR5-192-1-1	80	96	126	138	150	45	70
IR5-264-1-3-2	74	88	118	142	143	39	69
IR5-264-3-2-3	74	90	115	134	142	39	68
IR8 (40)	74	76	91	93	112	39	38
IR8 (68)	88	86	100	104	118	51	32
IR8-172-3-1-2	79	92	120	136	149	44	70
IR8-172-3-1-3	82	90	121	140	155	47	73
IR8-279-2-2-3	69	85	118	131	141	34	72
IR8-288-3-13(E)	79	82	88	95	114	44	35
IR8-288-3-16-1(E)	76	80	90	93	111	41	35
IR8-288-3-16-2(E)	75	80	92	94	112	40	37
IR8-288-3-17-1(L)	89	90	101	104	125	54	36
IR8-288-3-VL-8(L)	88	91	103	102	124	53	36
IR11-288-3-1-2	74	88	119	134	138	39	64
IR11-452-1-1	80	83	96	100	126	45	46
IR39-14	85	81	91	91	105	46	24
IR39-19	79	78	88	90	103	43	25
IR84-3-4-3	80	84	87	85	101	45	21
IR95-42-11-2-2	71	89	122	122	140	36	69
IR95-43-2-4	89	101	131	139	171	54	82
IR127-2-2-19	78	78	94	102	112	43	34
IR157-61-3-3	94	96	110	116	138	59	44
IR238-28-3-2	81	77	84	89	97	42	20
IR253-16-1-2	79	77	93	97	104	42	27

* Based on the number of days from sowing to flowering.
† Basic vegetative phase.
‡ Photoperiod-sensitive phase.

data reported on such varieties do not present a clear picture of their reaction, and are insufficient to warrant their being classified as intermediate, much less long-day, types. To seek further clarification, detailed tests were conducted on several varieties previously reported to be of long-day or intermediate type. BPI-76, a variety known to be photoperiod-sensitive, was included to serve as the control.

Table 11 shows the responses of the varieties grown under different photoperiods. All their responses were similar to those of short-day varieties. None of the varieties could be regarded as a long-day or intermediate plant.

Previous workers have concluded that these varieties were long-day plants, or that short-day treatment delayed flowering, probably because only two photoperiods were tested, one being the natural daylength. For example, if Baok is compared at 8 and 12 hours photoperiod, the 8-hour treatment would delay flowering by 14 days. The delay in flowering may become the basis of a conclusion that it is a long-day plant. However, the longer photoperiods of 10, 13, 14, and 16 hours used in the present tests show that Baok is a quantitative short-day plant. The delay in flowering with an 8-hour photoperiod, which is sub-optimum, is common with the short-day rice varieties. Other factors such as temperature may have greatly modified the response of these varieties in previous tests. Like BPI-76, GEB 24 and Heenati 8976 are qualitative, whereas the other varieties are quantitative, short-day plants.

More than a hundred varieties have been critically tested at the Institute and not one, so far, has shown a long-day response.

Response of IR-lines to photoperiod

Twenty-six IR-lines, the most promising ones developed at the Institute, were tested for their flowering response to photoperiod.

IR84-3-4-3 and IR238-28-3-2 were the two most insensitive IR-lines tested. IR39-14, IR39-19 and IR253-16-1-2 also showed insensitivity to photoperiod (Table 12).

Ten IR8 lines were included in the test, seven of which were practically insensitive to photoperiod, i.e., the difference in growth duration between the optimum and the longest photoperiod was around 30 days. If grown under photoperiods of between 10 and 14 hours, these lines should show little differences in growth duration, other environmental factors, such as temperature, not considered. The lines classified as early flowered earlier at all photoperiods than the late lines. IR8(40) flowered earlier than IR8(68), the line named officially as variety IR8. Three other IR8 lines showed high sensitivity to photoperiod.

All the IR5 lines tested were sensitive to photoperiod although they flowered at the different photoperiods used. This sensitivity to photoperiod may have little effect if the variety is grown in the tropics but would cause marked differences in growth duration if grown in subtropical areas.

The IR5 lines generally had shorter basic vegetative phase (bvp) but certainly longer than most photoperiod sensitive varieties. IR157-61-3-3 had the longest bvp, 59 days; IR95-43-2-4 and IR8-288-3-17-1 also had relatively high bvp, 54 days. The longest recorded bvp (71 days) in the previous tests was that of variety Sukanandi. Milfor-6(2) and Century Patna 231 had a bvp of around 60 days.

Studies on Internode Elongation

Gibberellin

Studies on the elongation of rice plant organs, particularly the internodes, were continued.

Preliminary experiments were conducted to select materials for detailed studies and at the same time to find the range of response of the rice plant to gibberellin (GA), generally known as a limiting factor in the elongation of plants.

From the 119 varieties and lines tested, (a) there was a correlation between the length of the second leaf sheath and the response to GA* of varieties belonging to the japonica, indica and dwarf groups (Fig. 11); (b) no such correlation was obtained from the javanica varieties; and (c) the shorter the plant, the shorter is the second leaf sheath and the higher is the response to GA.

*GA_3 was used throughout the experiment.

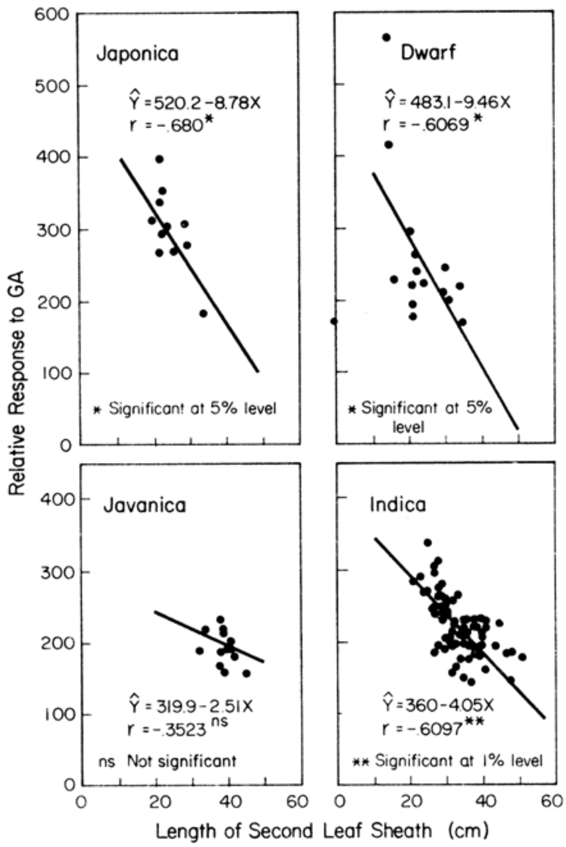


Fig. 11. Response of japonica, indica, javanica and dwarf lines to gibberellic acid.

Tall and short lines

From this experiment, four contrasting lines were selected for detailed studies.

These were Century Patna 231-normal (CPN), Century Patna 231-dwarf (CPD), tall Peta (TP) and short Peta (SP). The CP lines represent a type in which the difference in height between the dwarf and normal is negligible before panicle initiation and is apparent only at flowering (Fig. 12). CPD was obtained by irradiation. The Peta lines represent a type in which the difference in height is already apparent even before flowering. SP and TP were obtained by crossing Peta, a tall variety, and Taichung (Native) 1, a short variety, and then backcrossing the progenies to Peta three times.

Preliminary experiments showed that the CP lines did not differ in their response to GA at the seedling stage, and that this response was generally low. CPD is therefore one of the exceptions, GA having no effect on the growth of the second leaf sheath of this dwarf line. On the other hand, the Peta lines gave a much higher response to GA than the CP lines, with the short Peta being much more responsive than the tall Peta. Applying GA at the later growth stages gave the same comparative results.

The differences in response of the CP and Peta lines to GA at the seedling and later stages indicated that a difference in the mechanism of elongation is involved.

Biochemical studies of the different lines are underway. A comparison of GA-like substances in these lines showed no difference in content between the CP lines, but there was a big difference in the Peta lines (Figs. 13 and 14). The short Peta had almost no GA-like substance; this would explain to a great extent its short stature. Further studies, however, are needed to determine the mechanism involved in CP lines, especially CPD, which apparently is not limited in GA content.

Salt Tolerance of the Rice Plant

High salinity often limits rice growth in areas where the soil is affected by sea water or where precipitation is too low as compared to evaporation, resulting in the accumulation of salt near the soil surface. Considering that rice cultivation is being extended to saline areas, as in West Pakistan, it is expected that the salinity problem will assume greater importance. A series of experiments was conducted to study the effects of salt on the rice plant at different growth stages. Throughout the experiments, electric conductance (EC) was used to express the degree of salinity. EC can be used as a practical measure of salinity, despite any differences in physiological and biochemical activities between different species of ions.

When soil culture was employed, a simple technique was used to maintain salinity in the soil as uniform as possible. A certain concentration (0 ~ 0.6 %) of NaCl solution was added to a pot with a drainage tube at the bottom. The solution was circulated three times, twice a week, to obtain an equilibrium, and adjusted by giving either water or salt solutions to maintain a desired EC value whenever necessary.

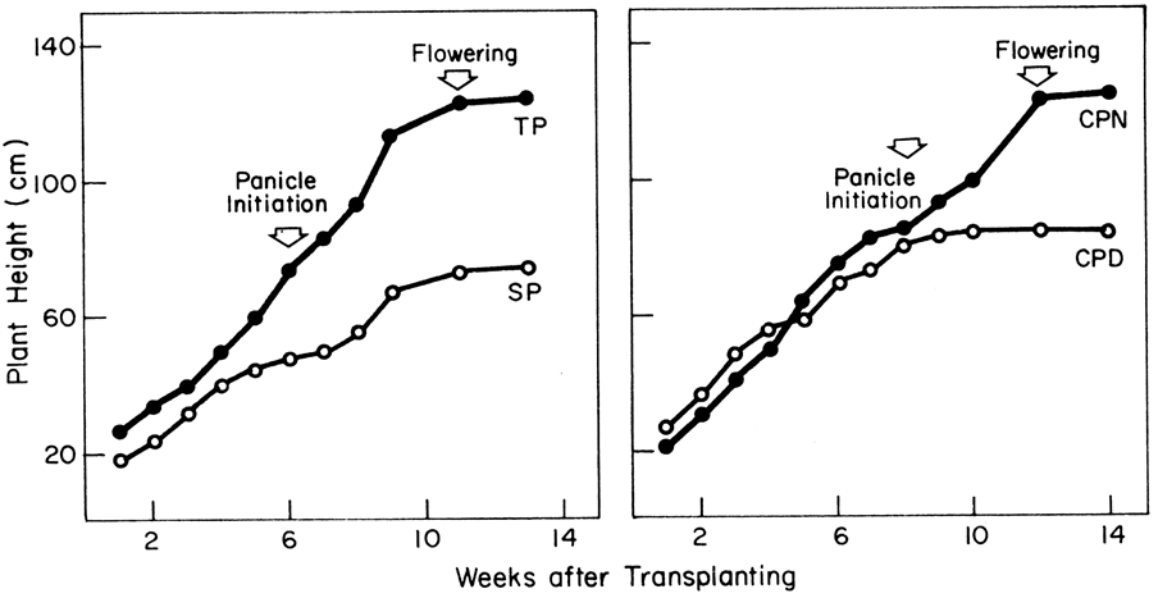


Fig. 12. Height of Peta and Century Patna lines at different growth stages.

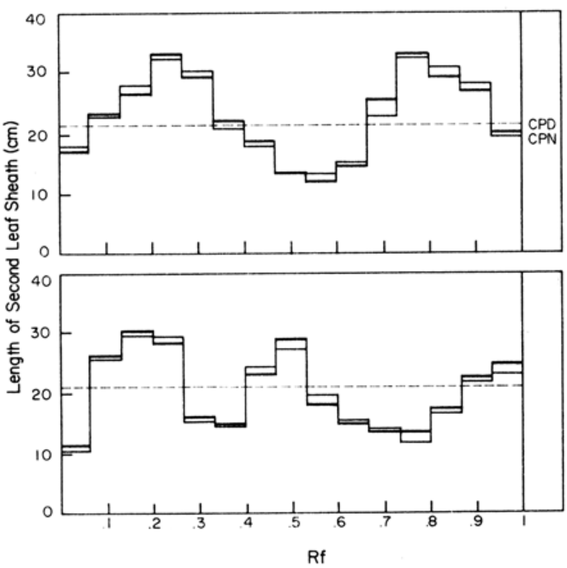


Fig. 13. Histogram of CP lines showing the GA-like substances and inhibitors in the leaf blades before panicle initiation. The broken line represents the response of the control.

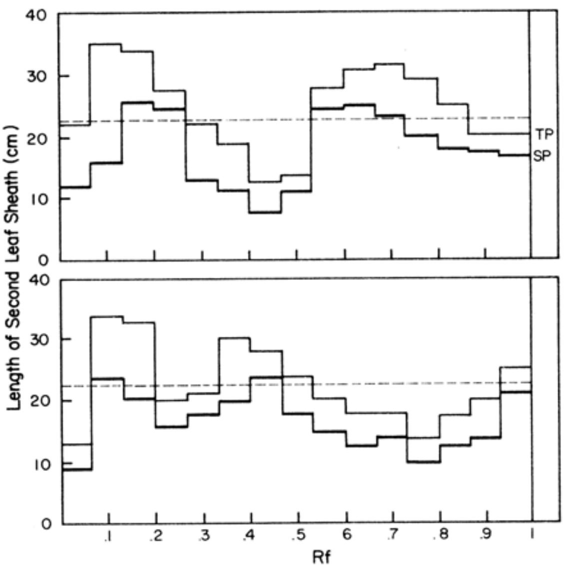


Fig. 14. Histogram of Peta lines showing the GA-like substances and inhibitors in the leaf blades before panicle initiation. The broken line represents the response of the control.

To compare the effects of salinity on rice growth at different stages, an EC value, at which the dry weight was reduced to half that of the control, was sought graphically.

Seed germination to seedling stage. To test the effects of salinity on seed germination and subsequently on plant growth, pre-germinated seeds were sown in the soil at the rate of 50 seeds per

Table 13. Effects of high salinity on the germination and seedling growth of variety IR8.

Experiment No.	EC of soil solution (u mhos cm $^{-1}$)	No. of germinated seeds	No. of surviving plants	Dry weight of shoots (g)
1	723	48	46	11.2
2	2512	43	42	10.1
3	4644	47	45	8.9
4	6633	47	36	6.3
5	8827	44	0.3	0.9
6	12,192	48	0	0

pot. As shown in Table 13, up to about 12,000μ mhos cm^{-1}, salinity did not affect seed germination. It did, however, affect subsequent plant growth. Below 4,600μ mhos cm^{-1}, seedling growth was normal, and at about 6,700μ mhos cm^{-1}, the dry weight was reduced to half that of the control (Fig. 15). The above data indicate that the rice plant tolerates salinity during seed germination but becomes susceptible to the ill effects of salinity at a subsequent growth stage.

Transplanting to seedling establishment. As transplanting is commonly practiced in rice-growing countries in Asia, the salt tolerance of the rice plant from transplanting to seedling establishment was studied. The rice plant was more susceptible to salt injury at this stage than from germination to the seedling stage. The dry weight was reduced to half that of the control at about 5,900μ mhos cm^{-1} (Table 14 and Fig. 15).

Vegetative, reproductive and ripening stages. A water culture experiment was conducted to study the salt tolerance of the rice plant during the vegetative, reproductive and ripening stages. There were four salt treatments (0.30% NaCl) in addition to the control: (a) from 1 week after transplanting to panicle initiation, (b) from panicle initiation to flowering, (c) from flowering to harvest, and (d) from 1 week after transplanting to harvest. The EC value of the culture solution without NaCl was 1,200μ mhos cm^{-1} and that with NaCl was 6,000μ mhos cm $^{-1}$.

Panicle weight was considerably affected by the salt treatment during the reproductive stage (Table 15). On the other hand, straw weight was only slightly affected. These results suggest that the rice plant is more susceptible to salt injury at the reproductive growth stage than at the vegetative and ripening stages.

Transplanting to harvest. A soil culture experiment was conducted to determine the salt tolerance of the rice plant during the entire growth stage, i.e. from transplanting to maturity. Plant growth was considerably affected by salt treatment at the early growth stages but the plant recovered to a certain extent later on. Table 16 summarizes the data obtained from this experiment. The panicle weight was reduced to half that of the control at about 7,000μ mhos cm^{-1} (Fig. 14).

Varietal difference. A water culture experiment was conducted to test varietal differences in salt tolerance. The varieties tested included IR8, Panganahao, Chianung 242, Pokkali, SR-26B, and Jhona 349. The last three named varieties are considered as salt tolerant. Panganahao is a local variety, popular in the calcareous soil area of Bohol Province in the Philippines.

The experiment consisted of six NaCl treatments—0, 0.2, 0.4, 0.6, 0.8 and 1.0 percent. At 0.8 and 1.0 percent NaCl, all the varieties died within a few days to 1 week after transplanting. IR8 survived until harvest at 0.6 percent NaCl but its panicle weight was almost nil. IR8, Pokkali and Jhona 349 were more resistant to high salt than SR-26B, Panganahao and Chianung 242 (Table 17).

Table 14. Effects of high salinity on the transplanting of variety IR8.

Experiment No.	EC of soil solution (u mhos cm $^{-1}$)	No. of surviving plants	Dry weight of shoots (g)
1	811	10	10.0
2	2679	10	8.9
3	4825	9.3	6.7
4	7209	5	1.6
5	9071	0	0
6	11,379	0	0

Table 15. Effects of high salinity on the vegetative and reproductive growth and ripening of variety IR8.

Experiment No.	Salt treatment	Height (cm)	No. of panicles	Dry weight (g)		
				Panicle	Straw	Root
1	None	125	85	150	242	30
2	Transplanting to panicle initiation	122	66	126	166	13
3	Panicle initiation to flowering	115	68	108	211	25
4	Flowering to harvest	126	67	142	227	30
5	Transplanting to harvest	115	63	50	163	13

Table 16. Effects of high salinity on the growth (all stages) and yield of the rice plant.

Experiment no.	EC of soil solution (u mhos cm^{-1})	Height (cm)	No. of panicles	Dry weight (g)	
				Panicle	Straw
1	1076	135	41	130	163
2	2029	134	41	129	133
3	5633	133	46	90	154
4	7824	109	30	18	76

Table 17. Varietal differences in salt tolerance.

Variety	NaCl(%)*	Height (cm)	No. of panicles	Dry weight (g)	
				Panicle †	Straw
IR8	0	101	51	146 (100)*	119
	0.2	94	50	87 (60)	115
	0.4	81	36	28 (19)	63
Pokkali	0	174	43	121 (100)	98
	0.2	162	37	87 (72)	84
	0.4	146	31	31 (26)	53
SR-26B	0	177	40	112 (100)	303
	0.2	163	22	29 (26)	282
	0.4	132	10	4 (4)	93
Panganahao	0	172	54	119 (100)	178
	0.2	157	41	20 (17)	177
	0.4	—	—	— —	—
Jhona 349	0	150	39	112 (100)	105
	0.2	139	40	85 (76)	87
	0.4	107	28	18 (16)	38
Chianung 242	0	141	40	132 (100)	160
	0.2	133	29	39 (30)	160
	0.4	—	—	— —	—

*EC: 1,200 u mhos^{-1} for 0%; 4,300 u mhos cm^{-1} for 0.2%; and 7,300 u mhos cm^{-1} for 0.4%.
†Figures in parentheses indicate relative yields, taking yield at 0% NaCl as 100.

Nature of high NaCl injury in rice growth

The above results indicate that the rice plant is most susceptible to high salinity at transplanting and at the reproductive stage. Since the rice plant tends to suffer from physiological shortage of water at these two stages, the results agree with the present understanding of the osmotic effects of high salt concentrations on water absorption. Table 18 shows an example of the effects of high salt concentrations on dry weight, grain yield components, and chemical composition of straw. During vegetative growth, tiller number was more affected by salt treatment than plant height. During the reproductive growth stage, the per-

Table 18. Effects of high salinity on the dry weight, yield components and chemical composition of variety IR8.

NaCl (%)	Dry Weight (g) Panicle	Dry Weight (g) Straw	Height (cm)	No. panicles/ pot	Average weight/ panicle (g)	No. spikelets/ panicle	Filled grains (%)	Straw (%) K	Straw (%) Na	Straw (%) Ca	Straw (%) Cl
0	146	119	101	51	2.85	119	93	2.97	0.72	0.57	2.06
0.2	87	115	94	50	1.75	105	72	1.44	2.75	0.34	4.49
0.4	28	63	81	36	0.78	73	44	1.25	3.00	0.47	6.17

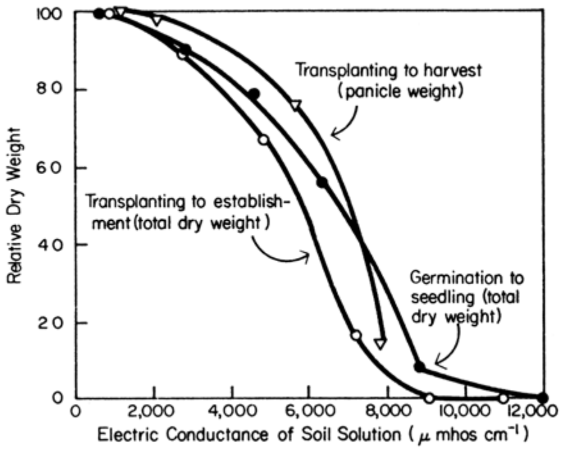


Fig. 15. Relationship between rice growth and electric conductance of soil solution.

centage of filled spikelets and the number of spikelets per panicle were markedly decreased by salt treatment, resulting in a considerable decrease in panicle weight. High salinity affected panicle weight more than it did straw weight. The potassium content of the straw decreased with increasing sodium content, suggesting an antagonism between potassium and sodium in their absorption by the rice plant.

Effects of Nitrogen, Phosphorus, and Potassium on Tillering of the Rice Plant

The critical level at which a nutrient is deficient or toxic often is a problem for diagnostic purposes. The nutrient content of a particular tissue or of the entire plant has been related to grain yield, photosynthetic activity per unit leaf area, and tillering performance with varying degrees of success. Since many factors affect grain yield, attempts to relate the nutrient content of a tissue to grain yield have met with little success. More reliable information may be obtained if an attempt is made to relate the nutrient content of a tissue to each of the growth components, e.g., tillering performance, leaf area increase, and photosynthetic activity per unit leaf area. The combined information may provide a reasonable basis for analyzing the growth of a rice population from the viewpoint of plant nutrition.

One of the characteristics of rice growth which can be a good measure of growth performance is tillering. It imposes a ceiling on number of panicles, which is a yield component.

As shown in Table 9, the effects of nitrogen application on grain yield can largely be attributed to the increase in number of panicles, which in turn is governed by the maximum number of tillers and the percentage of effective tillers. On the other hand, excessive vegetative growth, as often seen in direct-seeded rice, is usually associated with excessive tiller production. A study was therefore conducted to determine how environmental factors affect the tillering of the rice plant so that this characteristic can be adjusted to bring about a higher yield. The purpose of the study was to find a quantitative relationship between tillering and nitrogen, phosphorus, and potassium nutrition of the rice plant.

Kinetics of tillering

To formulate the kinetics of the tillering process, assume that the increase in tiller number per unit time is proportional to the total number of tillers present:

$$\frac{dN}{dt} = rN$$

where N stands for number of tillers, t for time and r for constant. This equation is exactly the same form as Blackman's compound interest law or kinetics of exponential phase of fungal growth. The solution for the equation is:

$$r = \frac{\log_e N - \log_e N_0}{t - t_0} = \frac{2.303\,(\log_{10} N - \log_{10} N_0)}{t - t_0}$$

The r may be called "relative tillering rate" (RTR) in analogy with relative growth rate. The validity of RTR can be easily assessed by plotting the tiller number vs time in a semi-log graph. Insofar as a linear relationship is maintained in the graph, it implies that none of the environmental or internal factors limits the tillering process under a given condition. To find out to what extent the above relationship holds, a water culture experiment was conducted. IR8 was grown in a 16-liter pot with 80 ppm nitrogen besides other nutrients under which no nutrient could be a limiting factor in rice growth for a certain period. As shown in Fig. 16, a logarithmic relationship holds up to 6 weeks after transplanting or up to 86 tillers per pot. This indicates that insofar as there is no limiting factor, the tillering process of the rice plant can more or less be explained by the preceding equation.

The above indicates that within a certain period, RTR can be used as a quantitative measure of environmental factors affecting the tillering process of the rice plant.

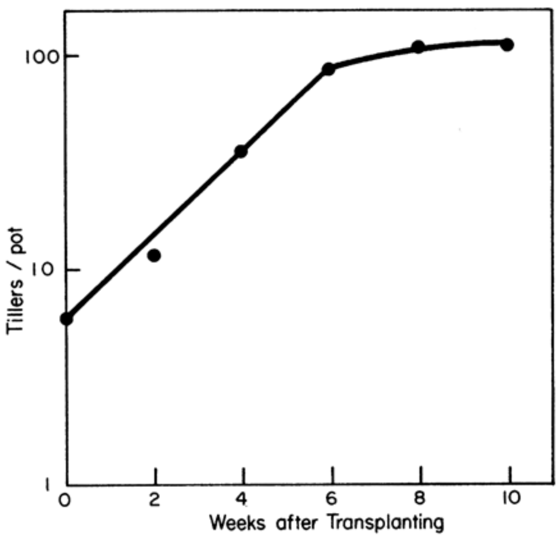


Fig. 16. Tillering of the rice plant grown in a 16-liter pot with 80 ppm of nitrogen.

Effects of nitrogen, phosphorus and potassium on relative tillering rate

To study the effects of nitrogen, phosphorus and potassium on relative tillering rate (RTR), a water culture experiment was conducted. The experiment consisted of four treatments: complete, low nitrogen, low phosphorus, and low potassium. Sampling was done every 2 weeks, and data were collected on dry weight, tiller number, height, leaf area and N, P, K content of active leaf blades. Low N, low P and low K caused typical deficiency symptoms to develop about 4 weeks after transplanting.

Table 19 summarizes the composition of the culture solutions used and the data collected.

As shown in Fig. 17, there is a linear relationship between RTR and nitrogen content in active leaf blades. At about 4 percent of nitrogen, tillering was very active; at about 2 percent of nitrogen, tillering stopped; and below 2 percent, the number of tillers decreased.

Since tillering and increase in weight are different phases of rice growth, relative growth rate (RGR) was also calculated to compare the effects of nitrogen on RTR and RGR.

As shown in Fig. 18, the maximum RGR was achieved at about 4 percent of nitrogen in active leaf blades but at about 2 percent of nitrogen when tillering stopped, the rice plant continued to increase in weight. A comparison between RTR and RGR indicates that when the rice plant becomes deficient in nitrogen, the tillering process is first affected while the rice plant still continues to grow in size and weight (See Table 19).

Figure 19 shows the relationship between RTR and phosphorus content in active leaf blades. Tillering was very active at about 0.2 percent of phosphorus, but stopped at about 0.03 percent.

It was reported in Japan that more than 0.20 percent of phosphorus was required for active tillering and at between 0.09 and 0.20 percent, tiller number did not increase, and at below 0.09 percent, tillers started to die. It seems that phosphorus requirement for tillering is lower in the tropics than in the temperate regions. In other words, the working efficiency of phosphorus in the rice plant seems to be higher in the tropics than in the temperate areas. This

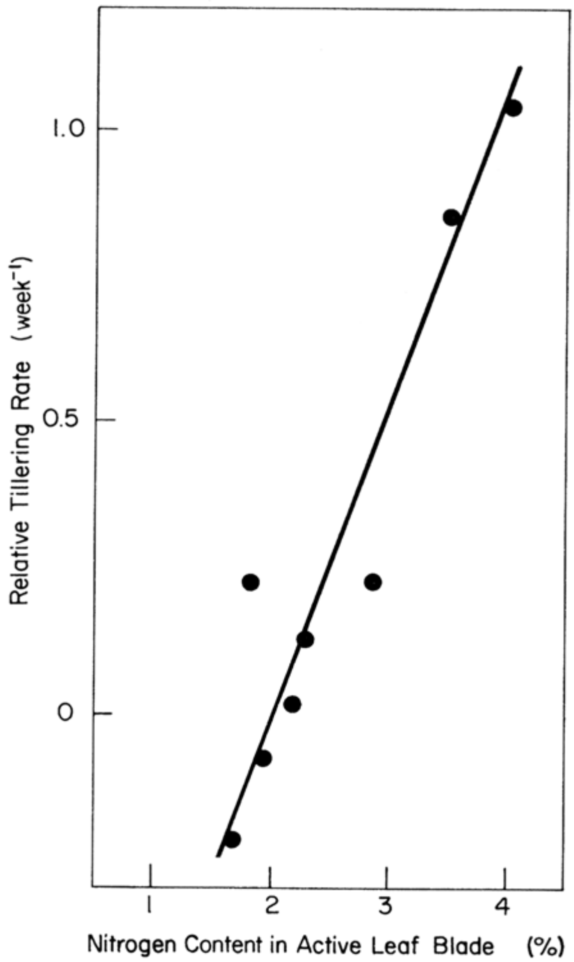


Fig. 17. The relationship between nitrogen content in the active leaf blade and relative tillering rate.

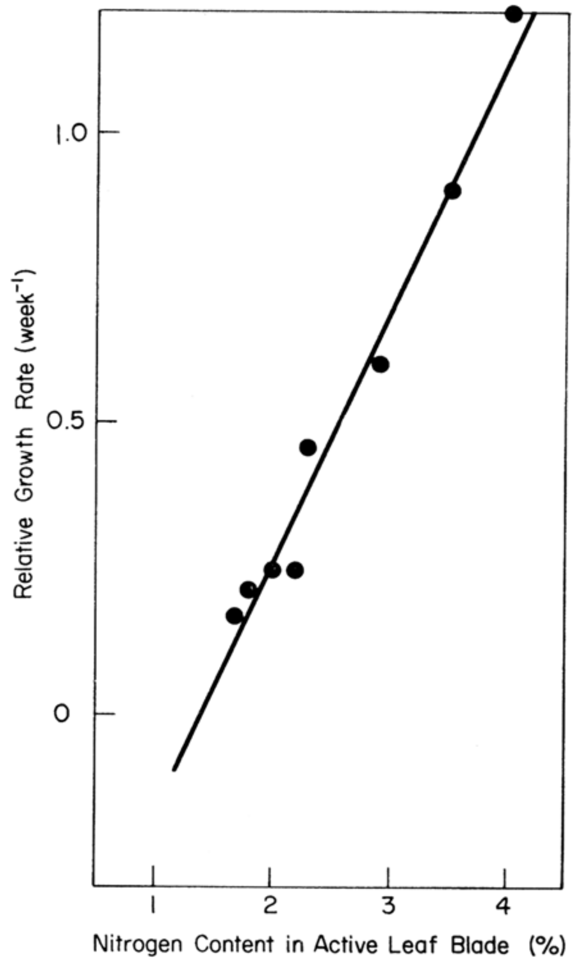


Fig. 18. The relationship between nitrogen content in the active leaf blade and relative growth rate.

aspect of plant nutrition requires further critical examination.

Figure 20 shows the relationship between RTR and potassium content in active leaf blades. At about 1.5 percent of potassium, tillering was very active, but at about 0.5 percent, it almost stopped.

As shown in Figs. 17 to 20, there are critical levels at which a nutrient causes maximum tillering or stops tillering. But between these two critical levels, there is a linear relationship between RTR and nutrient content. Table 20 summarizes the conclusions for diagnostic purposes.

Zinc Deficiency of the Rice Plant in Calcareous Soils

Zinc deficiency often is a problem in upland crops grown in calcareous soils. In the case of the rice plant, only one report (from India) has so far indicated that foliar spray of zinc sulfate improves the growth of the rice plant affected by a disorder known in India as the Khaira disease. Since information was lacking on the soil properties associated with the incidence of the disease and on the chemical composition of the affected plant, Institute plant physiologists made a trip in 1966 to Pant Nagar, Uttar Pradesh, India to collect soil and plant samples and gather more information about the disease.

Another trip in 1967 to Kala Shah Kaku, West Pakistan also revealed some unusual growth disturbances of the rice plant which might have resulted from zinc deficiency.

Field observations

In Pant Nagar, the Khaira disease has affected more than 16,000 hectares of rice field. This disease, suspected to be caused by zinc deficiency, usually occurs 1 or 2 years after the land has been reclaimed for rice production. The symptom of the disease is a brown discoloration of older leaves 2 to 3 weeks after transplanting. The affected plants are stunted, brown in color, and have scanty roots. When the plant is growing actively, the bases of the leaves become chlorotic. These symptoms are more apparent during bright sunny days. The plants recover to some extent about 6 weeks after transplanting.

In some fields at the Kala Shah Kaku Rice Research Station and the surrounding areas, about 3 weeks after transplanting, rice leaves develop brown streaks and blotches starting with the lower leaves. The affected plants usually recover sometime later but those severely affected die. The disorder is known as Hadda in this region. Heavy application of fertilizer aggravates the disorder but drainage alleviates it. The disorder, the cause of which is not known, usually occurs in the first year of reclamation.

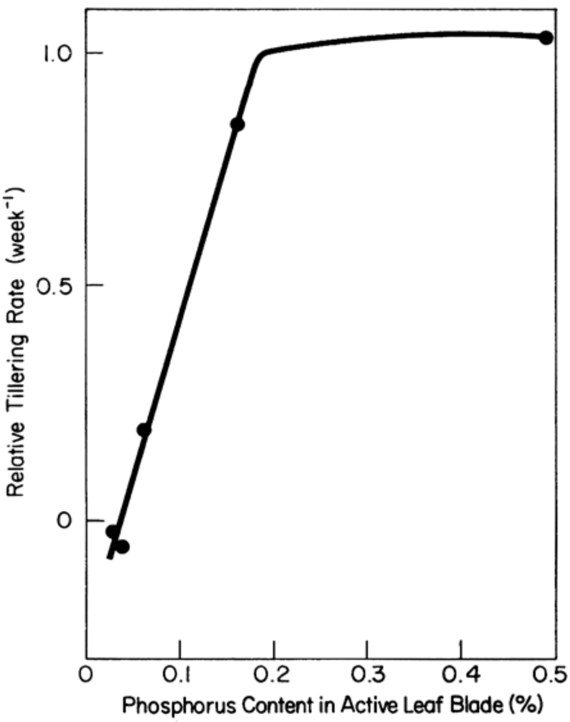


Fig. 19. The relationship between phosphorus content in the active leaf blade and relative tillering rate.

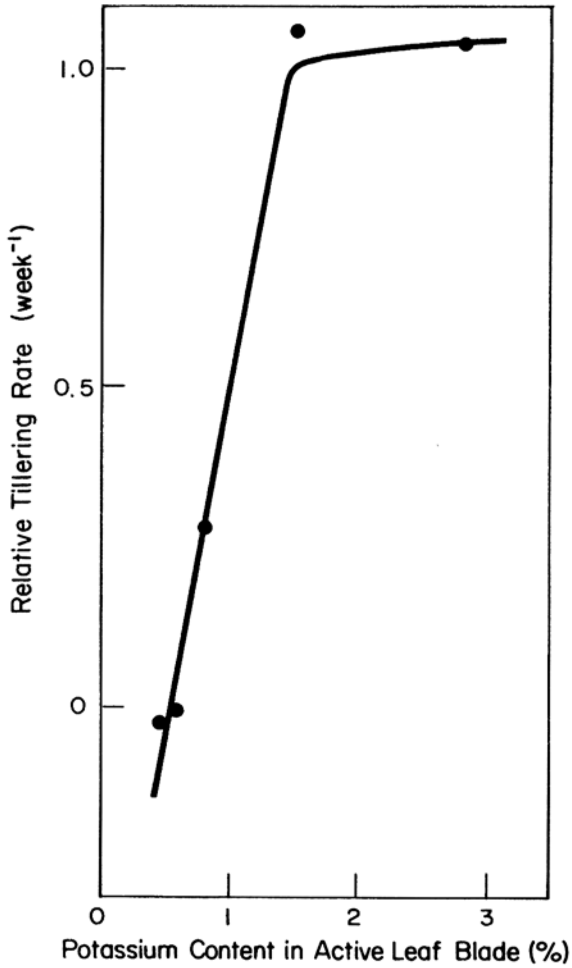


Fig. 20. The relationship between potassium content in the active leaf blade and relative tillering rate.

Analysis of soil and plant samples taken from the problem area

Table 21 shows the chemical properties of the soils taken from Pant Nagar and Kala Shah Kaku. Both soils are alkaline and the sum of cations extracted by IN-NH_4 OAc exceeds the CEC value; effervescence takes place when hydrochloric acid is added to the soils. These

Table 19. Growth and nutrient content* of the rice plant grown in culture solutions of different nutrient levels.

Culture solution	Growth and nutrient content	Weeks after transplanting				
		2	4	6	8	10
	Dry weight, g/pot	1.45	15.6	49.6	81.4	133
	Tiller no./pot	5.3	41.0	65.0	65.3	58.3
Complete	Height, cm	37	67	68	78	93
N = 40 ppm	Leaf area, cm²/pot	312	2280	4616	5734	6008
P = 5	N %	4.64	3.33	2.37	2.03	1.96
K = 40	P %	0.60	0.38	0.23	0.18	0.18
	K %	2.8	2.8	2.3	2.1	1.9
	Dry weight, g/pot	1.17	7.33	18.5	27.8	39.6
	Tiller no./pot	3.8	21.0	26.7	34.0	23.0
Low N	Height, cm	38	55	62	61	71
N = 10 ppm	Leaf area, cm²/pot	266	951	1405	1926	2206
P = 5	N %	4.32	2.66	1.90	1.66	1.64
K = 40	P %	0.63	0.53	0.45	0.43	0.33
	K %	2.9	2.5	1.9	1.8	1.9
	Dry weight, g/pot	1.13	6.41	15.4	27.7	36.6
	Tiller no./pot	3.8	21.0	32.7	31.0	29.3
Low P	Height, cm	33	53	56	60	68
N = 40 ppm	Leaf area, cm²/pot	207	834	1298	1377	1701
P = 0.5	N %	4.57	4.15	3.51	3.15	3.03
K = 40	P %	0.23	0.08	0.05	0.03	0.03
	K %	2.8	2.4	2.4	1.9	1.6
	Dry weight, g/pot	1.21	5.63	16.9	33.3	51.3
	Tiller no./pot	3.8	31.0	54.0	53.5	52.5
Low K	Height, cm	39	55	56	57	65
N = 40 ppm	Leaf area, cm²/pot	223	832	1230	2943	3980
P = 5	N %	4.83	4.18	3.19	3.38	3.47
K = 5	P %	0.68	0.50	0.25	0.25	0.25
	K %	2.0	1.0	0.6	0.5	0.5

* Nutrient content of active leaf blade.

Table 20. Levels at which nitrogen, phosphorus, and potassium critically affect the tillering process.

Nutrient	Tillering stops at	Maximum tillering rate achieved at
Nitrogen (N)	2%	4%
Phosphorus (P)	0.03	0.2
Potassium (K)	0.5	1.5

indicate that both soils are calcareous.

The plant sample from Pant Nagar had extremely low zinc content and rather low phosphorus, high calcium and sodium contents (Table 22). The sample from Kala Shah Kaku also showed very low zinc content and rather high iron, manganese and aluminum contents.

Both problem soils had (1) high soil pH and calcareous material and (2) low plant zinc content.

Greenhouse experiments

To find out if symptoms similar to those observed in the field could be reproduced in the rice plants grown on the same problem soils in the greenhouse, the variety Peta was grown on 500 g of Pant Nagar soil in two 600-ml polyethylene beakers. Along with adequate amounts of nitrogen, phosphorus, and potassium, zinc sulfate was added to one beaker at a concentration of 40 ppm, while the other beaker did not receive any additional zinc. About 3 weeks after transplanting, the plant without zinc developed interveinal chlorosis, brown streaks, marginal scorch of leaves, and stunted growth (Fig. 21). The effects on the dry weight and zinc content of the plants are shown in Table 23.

The addition of a small amount of zinc resulted in a remarkable increase in dry weight; this was associated with increased zinc content.

Table 21. Chemical properties of soil samples.

Source of soil sample	pH (H_2O)	Organic carbon (%)	CEC (me)	Exchangeable (me) Ca^{2+}	Mg^{2+}	K^+	Na^+	Available P (ppm)	Active Fe (%)
Pant Nagar, U.P., India	8.3	1.28	12.4	25.24	8.66	0.35	0.70	1.3	0.15
Kala Shah Kaku, West Pakistan	7.9	0.98	11.4	31.60	3.06	0.45	1.03	3.8	0.18

Table 22. Nutrient content of plant samples.

Source of plant sample	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	SiO_2 (%)	Na (%)	Mn (%)	Fe (ppm)	Al (ppm)	Zn (ppm)
Pant Nagar, U.P., India	2.26	0.06	3.32	1.07	0.65	12.8	2.97	138	735	340	7.7
Kala Shah Kaku, West Pakistan	2.44	0.25	3.30	0.14	0.27	13.4	0.70	558	954	468	9.8

A similar experiment was conducted on Kala Shah Kaku soil, with IR8 as the test variety. The treatment consisted of 0, 2, 4, 8, 16 and 32 ppm Zn. About 2 weeks after transplanting, the plant without added zinc started to develop interveinal chlorosis at the base of the lower

Table 23. Effects of zinc application on the dry weight and zinc content of the rice plant on Pant Nagar soil.

Treatment	Dry weight	Zn content
Without zinc	1.78 g	8 ppm
40 ppm zinc	5.71	151

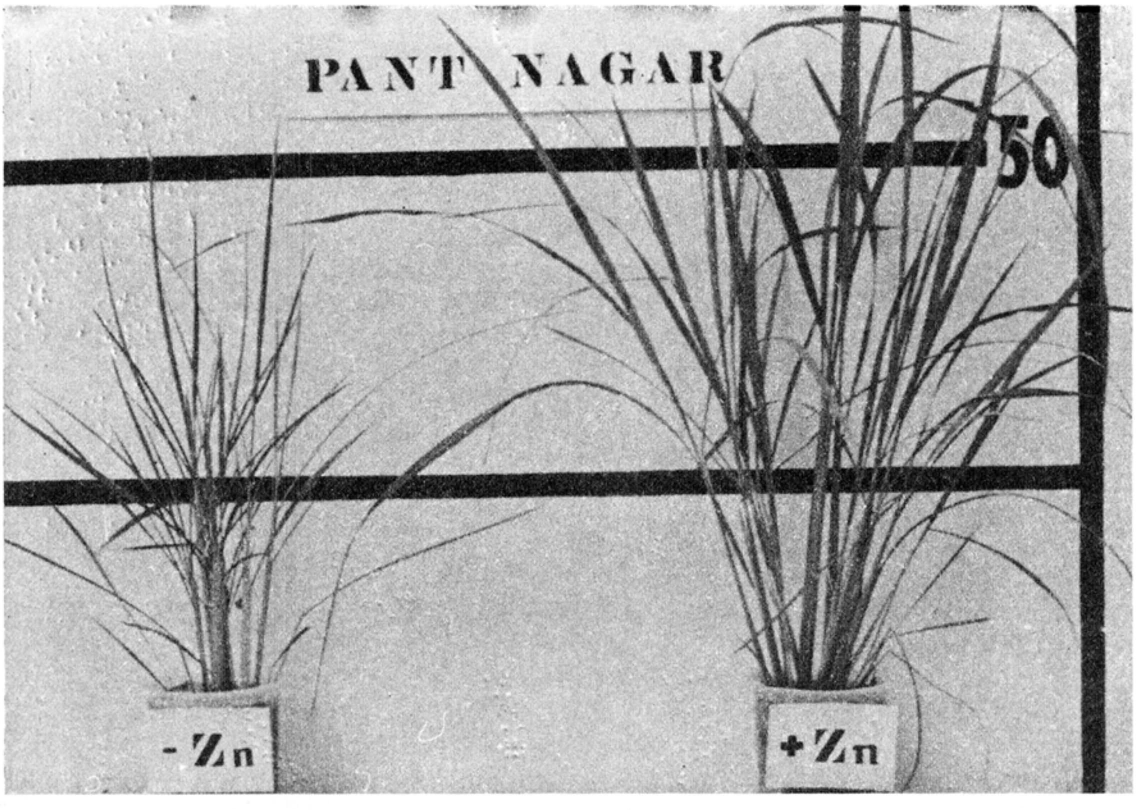


Fig. 21. Effect of zinc application on rice plants grown on Pant Nagar soil.

Table 24. Effects of zinc application on the dry weight and zinc content of the rice plant on Kala Shah Kaku soil.

Zn added	Dry weight	Zn content
0 ppm	1.02 g	9 ppm
2	2.40	14
4	1.92	18
8	2.87	23
16	2.65	23
32	2.88	34

Fig. 22. Effect of zinc application on rice plants grown on Kalah Shah Kaku soil.

leaves, followed by browning and stunting (Fig. 22). The addition of zinc resulted in increased dry weight and zinc content (Table 24).

These two experiments indicate that the disorder observed on the problem soils might have resulted from zinc deficiency. Since greenhouse and field conditions differ, the final conclusion should be from a field trial *in situ*.

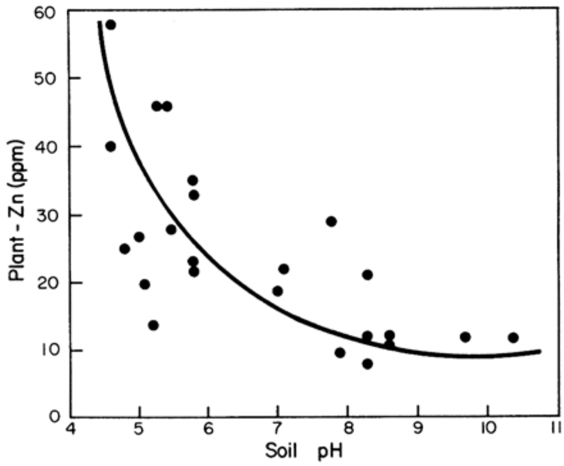


Fig. 23. The relationship between soil pH and plant zinc content.

Soil pH and plant zinc content

Since both Pant Nagar and Kala Shah Kaku soils are alkaline and zinc deficiency is often related to high pH in upland soils, an attempt was made to relate soil pH with plant zinc content on 24 samples collected from India and Pakistan. Figure 23 shows that the higher the soil pH, the lower the plant zinc content. This suggests that the availability of zinc, as affected by soil pH, may be one of the factors which affect zinc uptake of the rice plant. That drainage alleviates zinc deficiency suggests that zinc availability is related to reductive conditions in flooded soils. A study on zinc status of the soil and zinc uptake by the rice plant is now underway.

All the results suggest that zinc deficiency is likely to occur in the rice plant grown on alkaline pH or calcareous soils.

Cereal Chemistry

The integrated study of the relationship between the physicochemical properties of the rice endosperm and its processing, eating, and nutritive qualities was continued with emphasis on: (a) the influence of storage, parboiling, and variety on the physicochemical properties of the grain, (b) the relationship between starch gelatinization temperature and the other properties of the grain, (c) the screening of the IRRI world collection for high-protein rices, and (d) the physicochemical nature of rice protein. A study of rice hemicelluloses was initiated.

1967 ANNUAL REPORT, The International Rice Research Institute *Mailing Address:* Manila Hotel, Manila, Philippines

Factors Affecting Grain Quality

The texture of cooked rice is mainly correlated with the amylose and amylopectin contents (linear and branched molecules, respectively) of the starch. The gelatinization temperature of the starch and the protein content are physical barriers to the cooking of starch. Varietal and environmental factors are known to affect these grain properties.

Storage

Further results were obtained from the study, started in July 1966, of changes that occur during storage of IR8 rough rice, milled rice, and starch at ambient temperature. Rice samples were milled at monthly intervals and tested together with stored milled rice. The viability of the rough rice dropped during a storage period of one year (Fig. 1). In cooking tests, no change was observed in volume expansion and water absorption, but there was a progressive drop in dissolved solids during the cooking of the gruel. A slight drop in pH of the cooking gruel from 6.9 to 6.4 was noted for the stored milled samples only; this was probably due to the hydrolysis of surface fat into fatty acids. Presumably the cooking test employed was not very sensitive to improved water uptake and volume expansion of aged rice which have been reported. The water uptake of the grain on soaking for 1 day at ambient temperature also remained unchanged. In the amylograph, peak viscosity and final viscosity of 50 C showed increases within the first 4 months and then levelled off for both samples (Fig. 1).

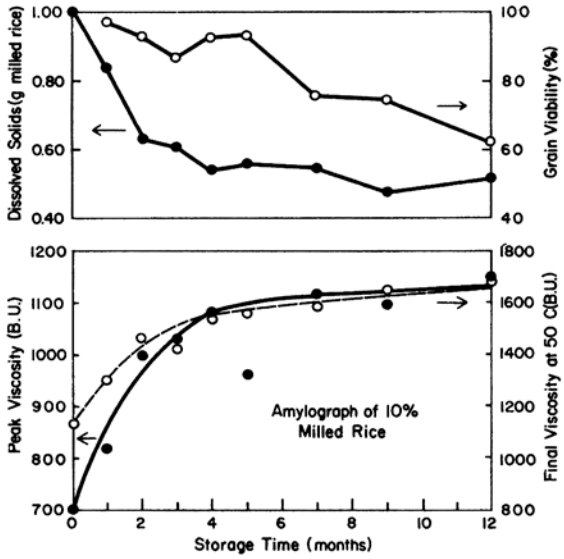


Fig.1 . Changes in physical properties and viability of IR8 rice during storage.

Practically the same changes occurred during storage of rice, whether in rough or milled form. These changes may have been mainly physical rather than biochemical [involving denaturation of amylases (starch hydrolyzing enzymes)] in nature. In the mature barley grain, β-amylases have previously been shown to be present in the endosperm in inactive form, presumably associated with the alkali-soluble protein, glutelin. In contrast, α-amylases are absent in the mature grain but are synthesized *de novo* during germination in the aleurone layers.

Amylose content was determined by its iodine binding capacity (IBC) in the milled samples and starch. On the average, pure rice amylose binds 19 percent by weight of iodine. The IBC of the samples did not change appreciably during storage. Their initial IBC level of 5.0 percent reached a maximum of 5.7 percent after 5 months, but dropped to 5.4 percent after 15 months. The IR8 starch with an IBC of 5.4 percent still had an IBC of 5.6 percent after 15 months of storage. There also was little change in the relative viscosity of the starch in dimethyl sulfoxide. Presumably the amylose: amylopectin ratio does not change appreciably during storage regardless of whether the rice is stored in the milled or unmilled form.

The absorbance at 280 mμ and the protein content by the Lowry method of the 0.5*M* sodium chloride—3*M* urea extract of the milled rices did not show a trend during storage. There was only a small difference between the ratio of the protein solubility fractions of brown rice of the freshly harvested sample and that of the 1-year-old sample. Presumably the protein fraction changed little during storage. These chemical studies indicated that the major grain constituents, starch and protein, changed little during storage.

In the developing IR8 grain, starch granules were found to be already birefringent and were

Table 1. Physicochemical properties of starch fractions developing IR8 rice grain.

Age of grain (days)	Recrystallized amylose		Amylopectin		
	IBC (%)	[η] (ml/g)	IBC (%)	[η] (ml/g)	$\overline{CL}$ (glucose units)
4*	11.8	205	4.04	208	29
21*	12.3	200	3.85	204	29
39*	13.2	192	3.07	201	27
39†	13.6	182	2.64	144	28
Standard error	0.26	3.9	0.07	4.6	0.4
LSD (0.05)	1.02	15	0.27	18	—

* Gelatinized by dimethyl sulfoxide pretreatment.
† Gelatinized by autoclaving for 2 hours at 125 C.

crystalline as evidenced by X-ray diffraction data even in the 4-day grain. Starch was pre-gelatinized by dimethyl sulfoxide with heating to 70 to 75 C, dispersed in boiling water, and the solution saturated with a mixture of 1-butanol and Pentasol 27 (1:1 by volume). Difficulty was encountered in the fractionation of IR8 starch due to co-precipitation of amylopectin with the amylose-butanol complex. This problem was reduced by decreasing the starch concentration in the first fractionation from 2 percent to not more than 1 percent. Results indicated no change in the intrinsic viscosity [η] of amylose and amylopectin during development (Table 1). [η] is a measure of molecular size. Consistently low IBC values were obtained for all amyloses, since values of 16 to 21 percent had been obtained for rice amyloses. The standard procedure of autoclaving for 2 hours at 125 C resulted in a drastic degradation of amylopectin as reflected by a reduction of its [η]. The mean chain lengths ($\overline{CL}$) of the amylopectins were identical.

Parboiling and grain properties

Parboiling has been traditionally employed in many parts of Asia. The process, which tends to accelerate the ageing of newly harvested rice, involves soaking rough rice in water to saturation, after which it is steamed and dried slowly. Little is known about the physicochemical changes that occur during this process. To accelerate soaking, which usually takes 3 to 4 days at ambient temperature, a higher steeping temperature (lower than the final gelatinization temperature of the rice starch) has been gaining usage.

IR8 rough rice (gelatinization temperature, 67 C) was soaked in 65 C water for 6.5 hours, steamed at 100 C for 8 to 14 minutes and air-dried. The opaque belly disappeared in all cases, but a white core was present in samples steamed for less than 12 minutes (Fig. 2). Presumably, it took the steam 12 minutes to completely penetrate the IR8 grain. Parboiling also was employed to eliminate the opacity of the whole grain of crumbly rice strain no. 7154 and of waxy rice. Parboiling caused a drastic reduction of the amylograph viscosity curves. It also resulted in a significant increase in grain hardness since parboiled rice had a lower degree of milling loss and a higher head rice yield, under identical milling parameters, and higher values (Kiya-type hardness tester) than raw rice.

Microscopic examination of the starch granules of parboiled IR8 rice under polarized light indicated that extensive gelatinization of the starch granules occurred during parboiling, especially during steaming. Very few birefringent granules and many swollen damaged granules were noted in the sample steamed for 12 minutes, whereas complete loss of starch birefringence was observed in the sample steamed for 14 minutes. Protein distribution remained the same and most of the granules

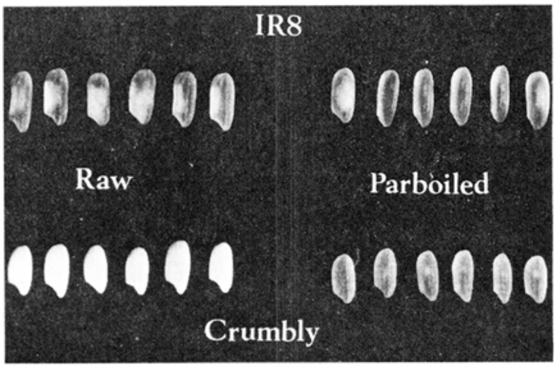


Fig. 2. Raw and parboiled milled samples of IR8 and crumbly rices differed in translucency. Parboiled grains with an opaque center were not steamed completely.

hardly changed in size and physical appearance during the steaming process. The improved translucency of the grain may be explained by the filling of the air spaces in the opaque portion of the raw grain with the swelling, gelatinized starch during steaming. The differences in properties of raw and parboiled rices may reflect differences between raw and retrograded (reassociated) gelatinized starch granules. Further work is in progress to determine the changes in other grain properties and the feasibility of evolving test methods for parboiled rice.

Variety screening

To further verify the extent of varietal differences in physicochemical properties of rice grown throughout the world, samples from Brazil, France, Hungary, Iran, Japan, South Korea, Peru, and Thailand were screened. The 10 samples from Brazil had milled rice amylose and protein levels of 19 and 24 percent and 9 to 13 percent, dry basis, respectively. They had low to intermediate gelatinization temperatures. The five French rice samples had 16 to 21 percent amylose, 7 to 12 percent protein, and low gelatinization temperatures, while the four Hungarian samples had 20 to 25 percent amylose, 7 to 9 percent protein, and low gelatinization temperatures. The 10 samples from Peru had 19 to 31 percent amylose, 5 to 11 percent protein and low to intermediate gelatinization temperatures. Eighteen Iranian samples had 15 to 28 percent amylose, 5 to 12 percent protein, and low to intermediate gelatinization temperatures. Because some of these varieties were similar in shape to 370 Basmati, they also were subjected to soaking-cooking tests. The results indicated that some of these samples also elongate to the same extent as 370 Basmati (Fig. 3). Certain short-grain varieties, such as the Spanish variety Bomba and the Burmese variety D25-4, elongated in the same manner during cooking.

The elongation during cooking of presoaked milled rice of 103 varieties was studied. The group consisted of 91 varieties and lines from the 1965-66 dry season yield trial and 12 other selected varieties. The ratio of length of cooked rice to that of raw rice was used as a measure of elongation. The samples had elongation ratios of 1.26 to 2.68, amylose values of 11.8 to 34.1 percent, and alkali spreading and clearing values of 2.0, 1.0 to 7.0, respectively. The elongation ratio correlated positively with the alkali spreading ($r = +0.445^{**}$) and clearing ($r = +0.387^{**}$) values of the grain, but not with amylose content ($r = -0.177$). The Burmese variety D25-4 showed the greatest ratio (2.68). This study demonstrated that extreme elongation during cooking of presoaked rice is not an exclusive property of long-grain rice.

Samples of six "soft" rice varieties from Niigata, Japan, were analyzed. The three varieties of better eating quality, by Japanese standards, tended to have lower amylose contents or gelatinization temperatures than those of poor eating quality. The samples had 12 to 18 percent amylose, 6 to 8 percent protein, and low gelatinization temperatures. The grains of two rice varieties grown at Kagawa, Japan, which were produced at two ambient temperatures, differed in gelatinization temperature, but not in starch viscosity.

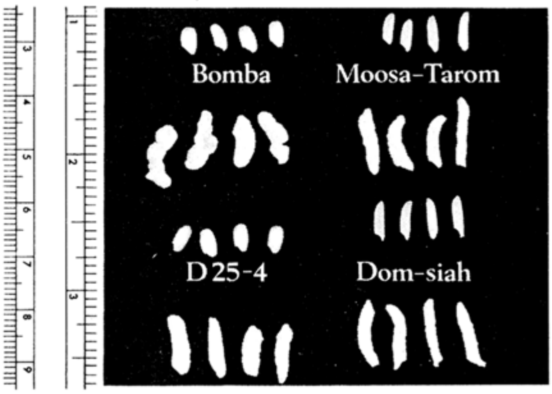


Fig. 3. Four selected varieties during cooking expanded lengthwise more than most varieties.

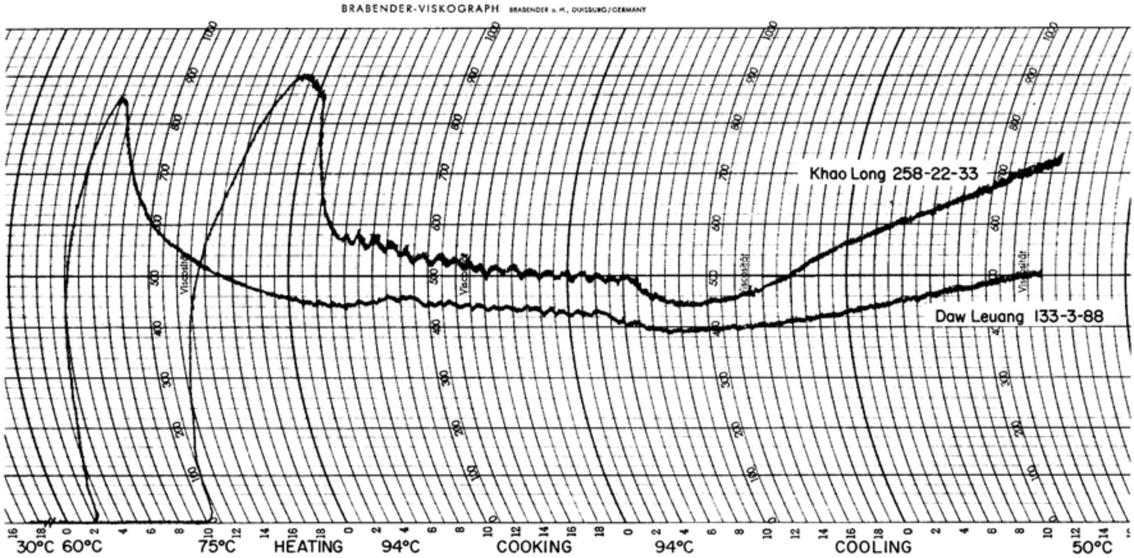


Fig. 4. Amylogram of two Thai opaque rices of good (Daw Leuang 133-3-88) and poor (Khao Long 258-22-33) eating quality. Khao Long is non-waxy.

The milled rice of five "native" Korean varieties had 7 to 8 percent protein, and low to intermediate gelatinization temperatures. Four of them had 18 to 21 percent amylose but the fifth sample had 32 percent amylose. In contrast, five new improved varieties which had been analyzed previously had 22 to 24 percent amylose. Some of the old, native varieties with lower amylose contents probably have better eating quality, by Korean standards, than the improved varieties. The sample with 32 percent amylose is considered of poor eating quality.

A study was made of one waxy and two non-waxy Thai rice varieties which were claimed to be of poor quality because they hardened faster after cooking than most other varieties. All three had intermediate gelatinization temperatures (over 69 C) as shown by alkali digestibility and amylogram tests (Fig. 4). In contrast, a good quality waxy sample such as Daw Leuang 133-3-88 had a low gelatinization temperature (59.5 C), which is characteristic of most Thai varieties. The steaming method employed for cooking may have caused the samples of higher gelatinization temperature to be undercooked under conditions in which the good quality varieties were already cooked. This procedure will cause the latter to have a harder texture due to incomplete cooking of the starch. Although a longer cooking time will solve the problem, it is impossible to identify such varieties beforehand from grain appearance alone. The alkali test is employed to detect those lines with intermediate gelatinization temperatures in the breeding program. The hard texture of Khao Long may be due to its nonwaxy starch (30% amylose) although it has an opaque endosperm which is characteristic of waxy rice.

Starch-iodine blue test

Use of the starch-iodine blue test of 100 C for rapid amylose screening of breeding lines was studied. Rice flours (40-mesh) of selected varieties with amylose contents (determined by colorimetric assay of Williams) up to 32 percent were leached with water at 100 C for 20 minutes at a ratio of 15 to 75 mg per 30 ml water. The results indicated a good linear relationship between leached-out amylose (indexed by the starch-iodine blue color), and amylose content of the flour only for samples with amylose content below 29 percent (Fig. 5). A possible explanation for the lower extraction rates for the high-amylose rices is the retrogradation of gelatinized amylose within the starch granule or from aqueous solution. Since essentially the same curve was obtained regardless of the rice: water ratio during extraction (Fig. 5), the reduction in amylose extraction must result from *in situ* retrogradation of amylose in the starch granule above the critical concentration. Essentially the same results were obtained with

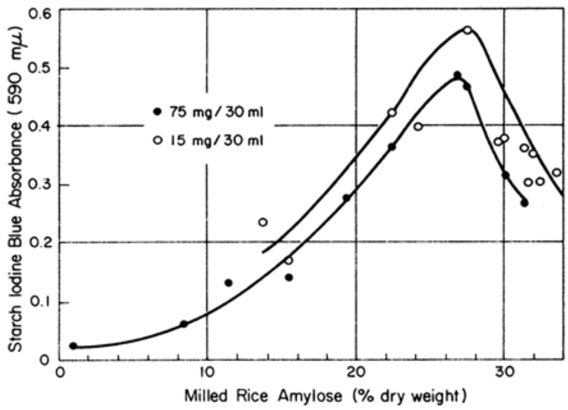


Fig. 5. Starch-iodine blue color at 100 C for two ratios of rice to water was a good measure of amylose content only for samples with amylose level below 29%.

extraction temperatures of 77, 80, 82, and 85 C. The other parameters of the starch-iodine blue test were shown to be unrelated to this phenomenon of reduced amylose extraction from high-amylose rices.

Relationship between Starch Gelatinization Temperature and Other Properties of Rice Grain and Starch

Gelatinization temperature is estimated in breeding lines and selections by the relative digestibility of milled rice in dilute alkali. Although varieties differ in these two properties, little is known about their actual importance and their relation to other grain properties. Previous results obtained at the Institute on different varieties grown under different environmental conditions showed little correlation between gelatinization temperature and other starch properties. To minimize environmental effects, the samples used in this study consisted of two crops of isogenic non-waxy lines and of waxy varieties differing in gelatinization temperature.

Isogenic non-waxy lines

The samples of two pairs of Peta/4 x Taichung (Native) 1 isogenic lines, one dwarf and the other tall, were provided by the Varietal Improvement Department. The samples differed essentially in alkali digestibility and gelatinization temperature but they had similar amylose contents (IBC, Table 3). The samples had similar amylograph curves except for the lower temperature of the initial increase in viscosity for the low-gelatinization-temperature samples. Little difference was noted in grain hardness.

Starch was isolated from the rice samples by protein extraction with sodium dodecyl benzene sulfonate solution and defatted with 95 percent ethanol. The samples had similar mean granule sizes (4.74 to 5.50 microns). The susceptibility of the starch granules to the action of dilute acid, α-amylase, and hot water was determined. Acid corrosion (lintnerization) of the granule was faster for the low-gelatinization-temperature samples, and the extent of hydrolysis with α-amylase was similarly related to this temperature for three out of four pairs of samples (Table 2). Water-absorption and solubility curves between 60 and 95 C showed differences among samples in the curve below 70 C only (Fig. 6), indicating that gelatinization temperature influences only the initial phase of the cooking of starch.

X-ray diffraction studies in cooperation with the Institute of Scientific and Industrial Research, Osaka University, Japan indicated that the lines

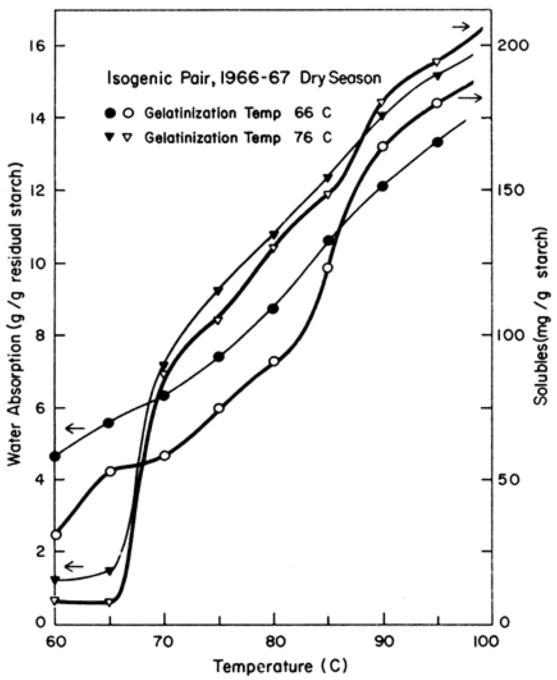


Fig. 6. Starch of isogenic non-waxy lines of different gelatinization temperatures differed only in the early phase of water absorption and solubility.

Table 2. Physicochemical properties of two pairs of isogenic nonwaxy rice grain and starch, differing in gelatinization temperature.

Sample number	1966-67 season	Alkali spreading, clearing values		Gelatinization temperature (C)	IBC (%)	Four-day lintnerization loss (%)	One-day α-amylolysis loss (%)
Regular-height pair							
73-13A	wet	7.0	6.0	54.5–60	4.70	52.7	45.0
73-12A	wet	5.0	3.0	62 –69	4.36	46.3	39.8
73-13B	dry	6.0	5.0	64 –68	4.95	43.2	31.2
73-12B	dry	4.6	3.0	71 –75	4.66	35.6	27.2
Short-height pair							
73-18A	wet	7.0	6.0	54 –60	4.68	58.0	55.0
73-20A	wet	4.9	3.0	65 –71	4.78	40.5	35.6
73-18B	dry	6.0	5.0	65.5–66	4.87	44.8	31.8
73-20B	dry	3.9	3.0	73.5–76	4.90	34.0	31.1
LSD (0.05)					0.12	2.9	1.5

Table 3. Physicochemical properties of starch fractions of two parts of isogenic nonwaxy rices differing in gelatinization temperature.

Sample number	Once-recrystallized amylose		Amylopectin		
	IBC (%)	$[\eta]$ (ml/g)	IBC (%)	$[\eta]$ (ml/g)	$\overline{CL}$ (glucose units)
73-13A	16.0	55	3.30	188	27.1
73-12A	16.6	118	2.28	150	27.7
73-18A	15.4	130	2.77	183	27.1
73-20A	16.8	91	2.15	160	26.5
LSD (0.05)	0.8	11	0.27	8	—

differed slightly in the degree of crystallinity, the sample with the higher gelatinization-temperature being more crystalline than its isogenic pair for both pairs and for both crops.

Starch fractions prepared by methods described earlier showed sample differences in $[\eta]$ of both amylose and amylopectin (Table 4). However, only the amylopectins showed a consistent relationship between $[\eta]$ and starch crystallinity. In both cases, samples with low amylopectin $[\eta]$ were more crystalline, regardless of amylose $[\eta]$.

Waxy varieties

Ten high-yielding waxy varieties developed at the University of the Philippines College of Agriculture (UPCA) have high gelatinization temperatures, whereas the only waxy Philippine Seedboard variety, Malagkit Sungsong, has a low gelatinization temperature. Crops from the 1966-67 plantings of these 10 varieties and two check varieties, Binondok and Malagkit Sungsong, were studied to better understand the relationship between gelatinization temperature difference and other properties of the rice grain.

Grain hardness was not correlated with gelatinization temperature of the waxy samples.

The varieties in the 1966-67 wet-season crop showed similar water uptake data on soaking at ambient temperature. The difference in water uptake, volume expansion, and dissolved solids in gruel was slight in the cooking test. On heating milled rice in water in a graduated cylinder at 85 C in the Refai test, the low-gelatinization-temperature samples increased in volume rapidly and stopped swelling after 80 minutes, whereas the high-type rices swelled slowly but continued to expand even up to 90 minutes (Fig. 7). Similarly, in the Ranghino test (wherein cooking time is determined at one-minute intervals on rice samples in a boiling water bath), the low-gelatinization-temperature rices were cooked within 14.5 minutes, while the high-gelatinization-temperature samples took 17.5 to 20.5 minutes to cook.

The low-gelatinization-temperature samples and three high-type waxy samples of both crops (the freshly harvested and the previous crop) were cooked in automatic electric cookers with 1.7 times the weight of water and were assessed by a taste panel at the UPCA Home Technology department. The results indicated little differences in the cohesiveness, tenderness, color, and gloss scores between the two gelatinization-temperature types and between the two crops of different ages (Table 4).

Although there were little differences in the physical properties of cooked rice of Philippine waxy varieties with low and high gelatinization temperatures, a Thai variety of intermediate gelatinization temperature, Khao Long 258-22-33, showed lower tenderness, cohesiveness, color, and gloss scores than the Philippine varieties and another Thai variety of low gelatinization temperature (Table 4). In their amylograms, the two Thai samples differed only in the temperature of initial viscosity increase and that of peak viscosity (Fig. 4). The contrasting properties between Khao Long and the waxy rices may be explained by the non-waxy starch of the former sample.

Amylograph viscosity curves verified the differences in gelatinization temperature among the waxy samples as evidenced by the difference in temperature at which viscosity initially increased. Both samples with low gelatinization temperatures, Malagkit Sungsong and Binondok, had suppressed amylograph viscosities in both crops. Their peak viscosities were not more than 200 Brabender units (B.U.), in contrast with over 600 B.U. for the high-gelatinization-temperature samples (Fig. 8). Previous results (Fig. 4) indicated that suppressed amylograph curves are not characteristic of samples with low gelatinization temperatures. These low amylograph viscosities may help explain why these samples swelled only as much as the other samples on cooking, in spite of their lower

Table 4. Eating quality scores* of cooked new and old samples of five Philippine waxy rices and of two Thai "opaque" rices.

Variety	Age	Tenderness	Cohesiveness	Color	Gloss
Binondok	old	6.5	6.0	5.2	6.4
	new	6.0	6.2	3.4	6.5
Malagkit Sungsong	old	7.0	6.8	4.4	7.5
	new	7.5	7.2	3.2	7.5
Morforbes 25	old	6.6	6.5	5.0	6.6
	new	6.0	7.0	5.5	7.0
Morforbes 122	old	6.5	7.8	2.6	8.0
	new	6.3	7.6	2.6	7.5
Sentje 117	old	5.8	6.8	5.6	7.5
	new	6.4	8.0	4.5	8.6
Khao Long 258-22-33†		3.6	3.2	1.2	2.8
Daw Leuang 133-3-88		6.5	7.8	3.2	7.5
LSD (0.05)		0.84	0.93	1.39	1.03

* Numerical scores from 1 to 9 were assigned, a score of "1" representing the lowest expression of this property in question and a score of "9" the highest expression.

† Nonwaxy starch.

Table 5. Physicochemical properties of waxy rice starch (1966 wet season).

Variety	Gelatinization temperature (C)	Four-day lintnerization loss (%)	One-day α-amylolysis loss (%)	$[\eta]$ (ml/g)
Binondok	61 –64	60.2	41.9	154
Malagkit Sungsong	62 –66	51.0	32.6	148
Morforbes 25	72.5–76	26.8	30.9	138
Morforbes 122	73 –76	27.5	28.2	129
Sentje 117	75 –78	15.6	30.6	134
LSD (0.05)		3.5	1.4	8

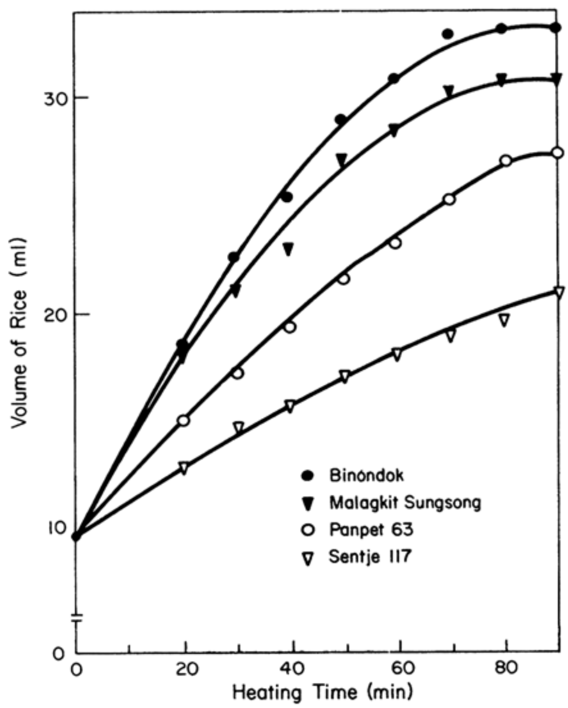


Fig. 7. Waxy rices with low gelatinization temperature swelled faster in the Refai test at 85 C than those with high temperature.

gelatinization temperatures.

Starches from the same five varieties were isolated from both crops. In the first crop, the difference in gelatinization temperature between the two types was at least 10 C (Table 5). Residual protein was low (0.1 to 0.8 %) and mean granule size did not vary considerably (3.56 to 3.99 microns) among samples. The acid-corrosion data showed a correlation between ease of gelatinization and accessibility to acid attack of the starch granule. The α-amylolysis data showed less difference between samples but the correlation with gelatinization temperature also tended to be negative. Similar results were obtained with the starches of the second crop. The values for α-amylolysis and lintnerization of waxy and non-waxy starches overlapped (Table 2).

Water absorption and solubility of the starches in hot water differed essentially at temperatures below 75 C (Fig. 9). This is understandable since gelatinization is just the initial phase of cooking. However, the values for Malagkit Sungsong were higher for both properties than the other starches. Waxy starch had higher water absorption and solubility values in hot water than non-waxy starch (Fig. 6).

The equilibrium moisture content of the starches at 96.5 percent relative humidity was not related to differences in gelatinization temperature.

Crystallinity studies of the starch granules showed that by X-ray diffraction the low-gelatinization-temperature samples were less crystalline than the other starches for the first crop. However, no difference was noted among the starches for the second or dry season crop. So far, the most crystalline sample studied was that of Malagkit Sungsong Puti, a waxy rice starch with a low gelatinization temperature and the lowest amylopectin $[\eta]$ (68 ml/g).

Amylopectins were prepared from waxy rice starch by pre-gelatinizing the starch with di-

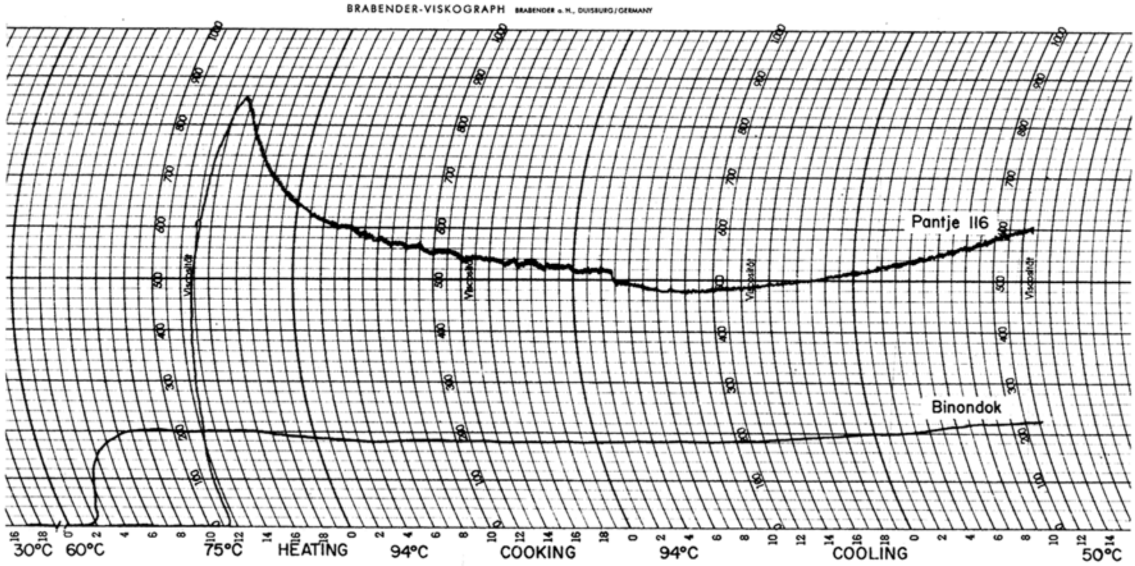


Fig. 8. Binondok and Pantje 116 waxy rices differed in amylograph viscosity curves and temperatures of initial viscosity increase and of peak viscosity.

methyl sulfoxide and dissolving the gelatinized starch in boiling water saturated with the mixture of 1-butanol and Pentasol 27. On cooling, the scum was removed and amylopectin was precipitated from the supernatant by the addition of 95 percent ethanol. The [η] data showed that the low-gelatinization-temperature samples had higher [η] than the others (Table 5). In addition, the samples with lower [η] were more crystalline. The relationship between crystallinity of starch granule and [η] of amylopectin fraction seemed consistent with previous results, whereas the relation between crystallinity and gelatinization temperature was not. This was apparent in the second crop, where the five waxy starches with similar crystallinity differed in gelatinization temperatures.

The Nava test has been claimed by its author to be a rapid measure of the molecular size of amylose and amylopectin of milled rice, based on the size of precipitated amylose and the amount of precipitated amylopectin, and the translucency of the supernatant liquor of the amylopectin suspension, respectively. Since the amylopectin [η] of the samples had been determined for some of the waxy samples, the Nava test was run on the waxy milled rices. Because these samples had no amylose, a greater volume of precipitated amylopectin than that reported for non-waxy rices was expected. The results showed little difference in the volume of amylopectin precipitate and in the translucency of the supernatant between the two types of samples. The amylopectin precipitate was not more than 1 ml whereas Nava reported as much as 5 ml for non-waxy rice. Obviously, the Nava test is not a sensitive measure of the molecular size of amylopectin.

The above results on non-waxy and waxy samples have shown little correlation between gelatinization temperature and other properties of the grain except cooking time. Since the difference in cooking time was not evident in the water absorption curve of the starch, it may reflect differences in the cooking barrier *in the milled grain* (from the surface to the core) of samples differing in gelatinization temperature.

Hemicelluloses

Aside from starch, the other polysaccharides in the rice grain are the cell-wall constituents—hemicellulose, cellulose, and pectin. Histochemical studies have shown that the middle lamella stained for protein rather than pectin, suggesting the presence of glyco-proteins. Although the cell walls of the rice endosperm are thin, varieties differ in the relative cell wall disruption pattern during cooking of milled rice. In the alkali digestibility test, not only the starch, but the whole endosperm seemed to reflect the digestibility to the reagent, since in the high-gelatinization-temperature samples, the whole endosperm remained in-

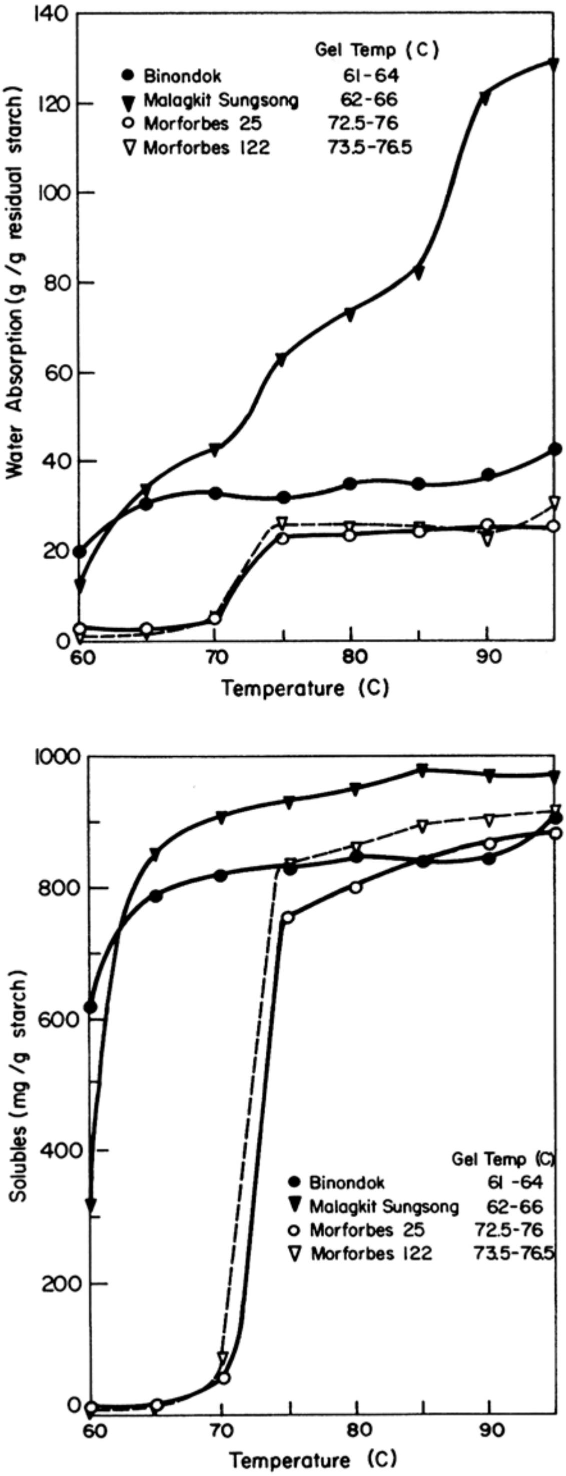


Fig. 9. Waxy starches differed mainly in the initial phase of their water absorption and solubility curves.

tact, although swollen. Studies on hemicelluloses of wheat showed that they exist mainly as glycoproteins, the carbohydrate fraction of which is rich in arabinose and xylose. Our previous screening work also showed that arabinose and xylose are present in the acid hydrolyzate of rice endosperm.

Isolation of hemicelluloses was done on milled IR8 rice. Water-soluble hemicellulose was isolated by aqueous extraction. The extract was heated to 90 C to destroy enzymic activities, treated with crystalline α-amylase to remove the contaminant starch, dialyzed, and freeze-dried. Paper chromatographic analysis of the acid hydrolyzate of this preparation showed that the main component sugar was glucose.

Insoluble hemicellulose was prepared from the residue of water extraction by cooking the washed rice and digesting the starch at 50 C with fungal α-amylase until the substance no longer stained blue with iodine. The residue was washed thoroughly with hot water, dialyzed, and freeze-dried. Paper chromatographic analysis of the hydrolyzate of this preparation showed that glucose was again the main sugar component.

Screening for High-Protein Rice

Since, among cereal proteins, rice protein has a high lysine value, the major nutritional limitation of rice protein is its low content in the grain. Because man will probably eat the same quantity of cooked rice regardless of its protein content, any increase in protein content would enhance the nutritional status of Asians, provided the quality of the protein is not lowered.

As the initial phase of a cooperative program of breeding for high protein rice, the IRRI world rice collection was screened for crude protein. Both planting material and crop from the Varietal Improvement multiplication of the collection were analyzed for crude protein in brown rice by a modified micro-Kjeldahl method. Samples were dehulled with a McGill sheller and approximately 200 mg of brown rice were disintegrated in a Wig-L-Bug amalgamator for 40 seconds. Flour samples (50 mg) were digested manually by the standard micro-Kjeldahl procedure in electrically heated units in which the rheostats were bypassed to improve

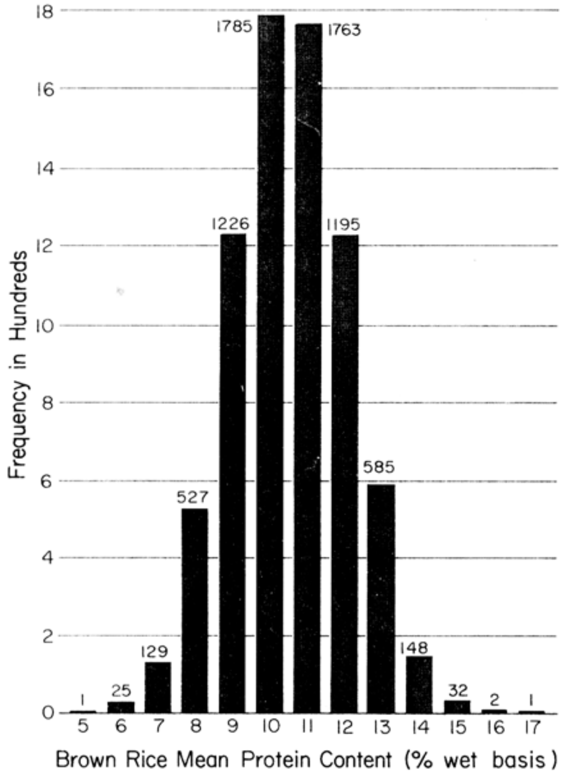


Fig. 10. Distribution of mean protein content of the planting material and crop of 7,419 varieties from the world collection (mean level of 10.5 ± 1.6%).

the heating efficiency. Digestions took 15 minutes. Preliminary experiments showed that the samples cleared up within the first 10 minutes of digestion but no further increase in ammonia recovery was observed up to 60 minutes digestion time. The digests were cooled, diluted to 25 ml with distilled water, and analyzed for ammonia in an Auto Analyzer (40 samples per hour) by the colorimetric assay at 610 mμ with phenol and hypochlorite in an alkaline medium. The standard curve was obtained from brown rice samples whose protein content (wet basis) has previously been determined by macro-Kjeldahl assay.

The mean protein content of the planting material and crop of 7,419 samples (3,431 for the wet season and 3,988 for the dry season) gave a modal distribution with a mean level of 10.5 ± 1.6 percent (Fig. 10).

A total of 101 varieties with at least 13.5 percent protein in each season together with those with a mean level of 14 percent were selected. These were analyzed for total amino acids with a Spinco Amino Acid Analyzer with an accelerated analysis system of 2 hours and 10 minutes and an Infotronics CRS 12AB automatic integrator and printer. The PA 28 resin was employed for the long column runs instead of the UR-30 resin.

Nitrogen recoveries in the amino acid assay ranged from 69 to 110 percent. The 101 samples showed a narrow range of values for all amino acids. The ranges of values for lysine and threonine are shown in Table 6. The tryptophan values, determined by the colorimetric method of Spies and Chambers, ranged from 0.52 to 0.89 percent of the protein. The low tryptophan values may have been partly due to the poorer tryptophan extraction from undefatted brown rice flour, since milled rice, which has a lower fat content gave values averaging 1 percent. The ratio of the sum of the eight essential amino acids (isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, and valine) to total amino acids ranged from 0.289 to 0.343. The results indicated that within the protein levels of 13.2 to 16.6 percent, the amino acid composition, except lysine level, was essentially independent of the protein level. The correlation between protein and lysine to protein was significant ($r = -0.249$**).

Forty-one of the high protein samples (all non-waxy) were from Hungary and 16 (all waxy) were from Thailand. Seventy-five of the samples were non-waxy and twenty-six were waxy. Eighteen were red-pericarped and two had tan-colored pericarps. The samples had brown rice length:width ratios of between 1.6 and 4.1 and a mean value of 2.4. The milled non-waxy samples had amylose values, determined colorimetrically, of 7.4 to 25.5 percent, wet basis. Using the alkali digestibility test, 84 varieties were found to have low gelatinization temperatures; 15, intermediate; and two, high. The two varieties with high gelatinization temperatures had low amylose contents of 7.4 and 7.7 percent. This agreed with previous findings that no high-amylose variety possesses a high gelatinization temperature.

The effect of high protein content on other properties of the grain of a few of these varieties is being studied. These properties include protein and amino acid distribution in the grain,

Table 6. Ranges in physicochemical properties of various *Oryza* samples.

Property	High protein rices		Wild species and hybrids		Cultivated rice
Protein (% wet basis)	13.2 –16.6	(*n*=101)	7.02 –14.0	(*n*=29)	4.8 –13.7
Lysine (g/16.8 g N)	2.94 – 4.06	(*n*=101)	3.12 – 4.48	(*n*=17)	3.32 – 4.31
Threonine (g/16.8 g N)	3.07 – 4.22	(*n*=101)	3.51 – 4.54	(*n*=17)	3.58 – 4.47
E:T ratio	0.289– 0.343	(*n*=101)	0.320– 0.344*	(*n*=17)	0.311– 0.337*
Amylose (% wet basis)	7.4 –25.5	(*n*= 75)	17.8 –23.9	(*n*=28)	9.0 –30.0
Gelatinization temperature (C)	low–high	(*n*=101)	60 –78	(*n*=29)	55 –78.5

* Tryptophan excluded.

Table 7. Protein level of brown rice from three plantings of five high-protein varieties.

Acc. no.	Variety name	1966 wet season		1966-67 dry season (concrete bed)
		Planting material	Crop (% wet basis)	
2169	Chok-jye-bi-chal	15.1	15.0	15.4
2251	Santo	16.7	14.2	13.8
2714	Rikuto Norin 20	14.5	13.5	14.3
3165	Omirt 39	14.7	13.6	12.8
3677	Crosa 2	15.1	14.0	13.7

cooking properties, grain hardness, and milling quality.

Because of the interaction between environment and protein content, a third planting of the 101 varieties during the 1967-68 dry season will be analyzed for protein content to determine which are consistently high-protein varieties. Breeders also will simultaneously determine the yield potential of such varieties. Since the protein content of rice has not been found to be correlated with any visual characteristics of the grain, screening for this property will have to be done chemically.

The protein content of five samples from three separate plantings gave further evidence that genetically high-protein varieties exist in nature (Table 7).

Some 400 additional entries to the world collection, which had recently (1967 wet season) been multiplied for the second time, will be screened for Kjeldahl nitrogen and may provide additional high-protein entries.

The 1966-67 dry season multiplication of induced mutants and check varieties of the International Atomic Energy Agency also were screened. They were found to have a protein range of 5.0 to 11.5 percent. The BPI-76-1 check variety had the highest protein content. The mutants had protein levels similar to those of the check varieties.

Brown rice from the Varietal Improvement yield trial (117 varieties and lines) for the 1966-67 dry season was screened for protein content. This constituent ranged from 5.0 to 12.3 percent among the samples, with IR268-48-2-1 (CI 9545/2 x Sigadis) having the highest value. The crops of future yield trials will be routinely screened for protein level.

Unreplicated lysine determinations were made on 3,188 samples based on the action of lysine decarboxylase on the hydrolyzate of 400 mg of brown rice in 2 ml of pH 6 buffer. The carbon dioxide produced was determined manometrically in a Warburg set-up at 37 C. Although the lysine standard gave reproducible results, variable results were often obtained with the samples. The decarboxylase enzyme has an optimum activity at pH 6. The low lysine values may be explained by the low pH of some of the hydrolyzates due to incomplete adjustment to pH 6 (and 2.0 ml) by adding 0.5*N* sodium hydroxide in the presence of a mixed indicator (methyl red-bromcresol green). However, high lysine values of over 5 percent are difficult to explain. With these 3,188 determinations using the Warburg apparatus, a mean lysine content of 3.68 ± 0.79 percent protein basis was obtained.

The feasibility of using the AutoAnalyzer system for determining lysine content was explored. However, less priority was given this phase of the program because the greater emphasis in this work was on high protein content rather than on high lysine content alone. The amount of carbon dioxide liberated in the AutoAnalyzer module was determined by the reduction in color intensity of phenolphthalein dissolved in carbonate-bicarbonate buffer. The standard macrocolor reagent was found sensitive for lysine concentration ranging from 10 to 40*mM*. A difference in 1*mM* (mean lysine concentration in the hydrolyzate of 400 mg rice in 10 ml) corresponded to a difference in transmittance of only 1.5 percent. Hence, the standard procedure (40 samples per hour) was not sensitive enough for the lysine level in these rice protein hydrolyzates. Improved sensitivity was obtained by analyzing only 20 samples per hour. Improving the sensitivity of the recorder by installing a range expansion kit may increase the differences in absorbance between samples using the standard carbonate-bicarbonate buffer. Anomalously high lysine values, which often were obtained in the Warburg apparatus, were not observed with the limited runs in the AutoAnalyzer. However, this method still will not be as sensitive and reproducible as the short column exchange chromatographic determination of lysine, and only after further improvements will it have possibilities as a screening technique. Use of the micro-color reagent (carbonate only) improved the sensitivity more than fifteen-fold, but the reproducibility of both baseline and peaks was reduced despite the placing of a sodium hydroxide trap (for carbon dioxide) to all air inlets.

Selected lysine analyses between 2.52 and 5.47 percent for 634 samples with a protein range of 6.66 to 18.2 percent correlated significantly ($r = -0.494^{**}$) with protein content. The correlation equation was $\hat{Y} = 5.24 - 0.17X$ and the mean lysine and protein contents were 3.63 and 9.49 percent, respectively. This indicates that only 25 percent of the variation in lysine content of brown rice was correlated with the variation in protein content.

Wild species and hybrids

The protein content of 29 brown rice samples, representing 11 wild species and two types of interspecific hybrids of the genus *Oryza*, ranged from 7 to 14 percent, wet basis. Amino acid analysis of 17 samples showed a range of values similar to that of cultivated rice (Table 6). Their amino acid contents were similar except for four acids. The correlation coefficient with protein content was negatively significant for lysine, and positive for phenylalanine and tyrosine. The coefficient for arginine was not significant.

The amylose contents and gelatinization temperatures of the 29 samples were also determined in milled rice. Except for the one waxy sample, the rices had a narrow range in amylose content of 18 to 24 percent, wet basis (Table 6). Although the gelatinization temperature values also showed a range similar to that of cultivated rice, a higher proportion (13 out of 29) had high gelatinization temperatures than had been observed for cultivated rice, including the high-protein varieties (12 out of 101). These studies indicated that the wild species of *Oryza* and some of their hybrids with *O. sativa* offer no advantage, in terms of physicochemical properties of the caryopsis, over existing cultivated rices in a breeding program since their properties fall within those observed for the latter.

Physicochemical Nature of Rice Protein

The isolation of native, unmodified protein from rice grain is difficult because of its insolubility in neutral solvents. Its main (80%) fraction is

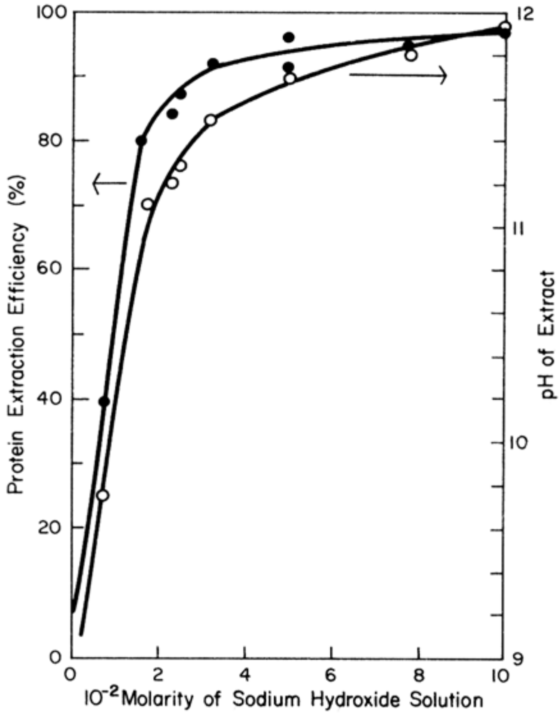


Fig. 11. The concentration of sodium hydroxide solvent affected the efficiency of extraction and pH of extracts of BPI-76 milled rice protein (2 ml/100 mg rice).

alkali-soluble protein, glutelin. The solvent 0.1*N* sodium hydroxide has a pH of over 10 at which it has been shown that degradation at least of the sulfur-containing amino acids occurs. To determine the optimum concentration of sodium hydroxide solution which will give an extract of pH below 10, 2.0 ml of various concentrations of this alkali were tried on 100 mg of 100-mesh milled rice flour of the variety BPI-76 with 13 percent protein. An extraction time of 6 hours was employed. Results indicated that protein extractions were very high at an alkali concentration close to 0.1*N*, but the pH of the extracts was above 10 (Fig. 11). The solvent 0.0075*N* alkali gave 39 percent extraction of the protein and an extract pH of 9.75. When the solvent: rice ratio (vol:wt) was reduced from 200:1 to 2:1, the 0.015*N* solution gave an extract with a pH of 9.7. This was used in subsequent isolation of native prolamin and glutelin from IR8 milled rice. Presumably, acidic substances which can partially neutralize the solvent are present in milled rice.

Extractants such as 0.4*M* calcium chloride and 0.008*M* calcium hydroxide at pH 10 are claimed to be specific for cottonseed protein and do not dissolve phosphorus-containing material. When tried on rice, the protein extractions were very poor and extraction efficiencies ranged from 8 to 17 percent.

Ultracentrifugation studies at 59,780 rpm of these dilute sodium hydroxide extracts of rice protein were also undertaken. Only two protein peaks of sedimentation constants ($S_{20,\text{ water}}$) of 2 and 4S (Svedbergs) were observed in the 0.1*N* extract but a third peak appeared in the 0.05*N* extract, with value of 6 to 7S. $S_{20,\text{ water}}$ is an index of molecular size. The results indicate less dissociation of rice protein with the more dilute alkali solutions. The addition of sodium chloride (0.1*M*) to reduce charge repulsion at this high pH did not appreciably alter the phenomenon observed above. The dilution of 0.1*N* sodium hydroxide extracts (4:1 solvent: rice) with the solvent resulted also in the disappearance of the 6S peak. The presence of the 6S peak was more distinct in BPI-76 with 13 percent protein than in IR8 with 8 percent at the same solvent:rice ratio. These results indicated a dissociation of rice protein into smaller sub-units at high alkali concentration or at low protein concentration. Further work is required to determine whether or not this phenomenon is reversible.

Salt-soluble rice proteins showed higher $S_{20,\text{ water}}$ values when dispersed in 0.2*M* sodium chloride than in 0.1*N* sodium hydroxide. This sodium chloride solvent was found to be very viscous.

Isolation of native protein as protein bodies from milled rice was also attempted using the discontinuous sucrose density gradient employed by Japanese workers. Three distinct zones of protein bodies were also obtained, dialyzed, and freeze-dried. Amino acid analysis of these crude preparations indicated little difference in amino acid pattern among the fractions.

Structural studies were performed on prolamin and glutelin. Sterilized prolamin and glutelin suspensions were hydrolyzed with Pronase (protein-hydrolyzing enzyme from *Streptomyces griseus*). Subsequent chromatography of the hydrolyzates (amino acid analyzer) showed that the aspartic and glutamic acids of these proteins were only partially in amide form since both the free acid and the amide forms (asparagine and glutamine) were detected in the chromatogram.

Preliminary studies were made to break disulfide bonds of prolamin and glutelin with the reagent 2-mercaptoethanol to determine whether the high molecular weight of these insoluble proteins is due to disulfide bond linkage of lower molecular weight proteins. Such a procedure will also make glutelin amenable to electrophoretic and other studies with the least degradation of its structure. Incomplete reduction was noted at pH 12 since a major fraction of the reduced proteins still was eluted at the void volume during gel filtration on Sephadex G-200. These experiments are being repeated at pH 8 on fresh undegraded preparations of glutelin and prolamin.

Amino acid analysis of the Sephadex gel filtration fraction from the developing and mature grain described previously showed that the middle fraction (molecular weight 50,000) had consistently lower lysine content than the two other fractions.

Varietal Improvement

IR5 was named and released by the Institute in 1967 as the second improved variety. Seeds of this variety have been distributed to 49 countries and territories.

IR8 continued to produce high yields under favorable management in tropical Asia, Africa and Latin America. Seeds of IR8 have been made available to 82 countries and territories. Meanwhile, pure seed programs of IR8 and IR5 were set up and breeder's seeds were distributed to several countries.

Efforts to develop improved selections which combine the IR8 plant type and other desired characteristics were continued. The traits being incorporated are early maturity, high levels of disease resistance, improved milling and cooking qualities, resistance to insects and unfavorable climatic factors. Over 35,000 pedigree rows were grown in 5 plantings. Cooperative testing of promising lines was conducted in several countries.

Genetic studies were continued to elucidate the inheritance of quantitative characters which are related to yielding ability, growth duration, lodging resistance, and grain dormancy. Cytologic investigations of sterility in indica x japonica hybrids were completed and new studies on sterile indica x indica hybrids were initiated.

Table 1. Promising crosses and backcrosses, made by the Varietal Improvement Department, combining improved plant type with other desirable plant and grain characteristics.

Cross no.	Parents	Generation	Maturity range (seeding to harvest)	Resistant to:	Plant and grain characteristics being incorporated into improved plant type
IR532 IR710 IR580	(Peta/3 x TN1) x TKM-6 (Peta/3 x TN1)/2 x TKM-6 IR8 x TKM-6	F_5, F_6 F_4 F_5	95 to over 145 days	Stem borer, blast, tungro, grassy stunt, bacterial leaf blight and leaf streak	Short, medium and long grain length; symmetrically shaped translucent grain; intermediate gelatinization temperatures
IR503 IR506 IR644 IR756	(Peta/3 x TN1) x (B589A4-18/2 x TN1) IR8 x (B589A4-18/2 x TN1) IR8/2 x (B589A4-18/2 x TN1) IR8/3 x (B589A4-18/2 x TN1)	F_5 F_5 F_4 F_4	100 to over 145 days	Blast, tungro, bacterial leaf blight and leaf streak, leaf shredding in typhoons	Smooth leaf and other plant parts; short, medium, and long grain length; symmetrically shaped, translucent grain; intermediate and high amylose content; low and intermediate gelatinization temperatures
IR626 IR751 IR875	IR8 x (Peta/5 x Belle Patna) IR8/2 x (Peta/5 x Belle Patna) IR8/3 x (Peta/5 x Belle Patna)	F_5 F_4 F_3	95 to145 days	Blast, tungro, grassy stunt, bacterial leaf blight and leaf streak, leaf shredding in typhoons	Smooth leaf and other plant parts; short, medium, and long grain length; symmetrically shaped translucent grain; intermediate and high amylose content; low and intermediate gelatinization temperatures
IR759 IR879 IR777 IR749 IR880 IR876	IR8 x (Peta/3 x Dawn) IR8/2 x (Peta/3 x Dawn) IR8/2 x Dawn IR8/2 x (81B-25 x Dawn) IR8/3 x (81B-Dawn) IR8/4 x (Dawn/3 x Sigadis)	F_4 F_4 F_4 F_4 F_3 F_2	120 to over 145 days	Blast, tungro, grassy stunt, bacterial leaf blight and leaf streak, leaf shredding in typhoons	Smooth leaf and other plant parts; low, intermediate and high tillering; medium and long grain length, symmetrically shaped translucent grain; intermediate and high amylose content; low and intermediate gelatinization temperatures
IR579	IR8 x Tadukan	F_5	100 to 140 days	Blast, tungro	Medium and long grain length; symmetrically shaped translucent grain
IR662	IR8 x [(H-105 x Dgwg) x (B589A4-18/2 x TN1)]	F_4	IR8 mat.	Blast, tungro, bacterial leaf blight and leaf streak	Symmetrically shaped translucent grain
IR822 IR932 IR825 IR877	IR8/2 x Pankhari 203 IR8/3 x Pankhari 203 (IR8 x Pankhari 203) x (Peta/6 x TN1) IR8/2 x (Dawn x Pankhari 203)	F_3 F_2 F_3 F_2	100 to over 145 days	Tungro, blast	Medium and long grain length; symmetrically shaped translucent grain
(IR1130 IR1154) IR1170 IR1063	 IR8/2 x Zenith IR8/3 x Zenith (Peta/3 x TN1)/2 x CI 9210	 F_3 F_2 F_2	105 to over 145 days	Bacterial leaf blight and leaf streak, tungro, blast. Resistance is dominant in F_1 plants	Medium and long grain length; intermediate and high amylose content; low and intermediate gelatinization temperatures
IR630	IR8 x IR5	F_3	120 to over 145 days	Tungro, grassy stunt, bacterial leaf blight	Short and intermediate plant height

IR930	IR8 x IR12-178	F_3	120 to 145 days	Grassy stunt, tungro	Short and intermediate plant height; short, medium and long grain length; symmetrically shaped translucent grain; intermediate and high amylose content
IR968	IR5 x IR12-178	F_2			
IR160	Nahng Mon S4 x TN1	F_8	130 to over 145 days	Grassy stunt, blast, and tungro in most crosses	Long grain length; symmetrically shaped translucent grain
IR788	IR8 x Nahng Mon S4	F_3			
IR789	IR8 x Muey Nahng 62M	F_3			
IR933	IR8/2 x Muey Nahng 62M	F_2			
IR844	(Peta/3 x TN1) x Puang Nahk 16	F_3			
IR787	IR8 x (CP 231 x SLO-17)	F_4	105 to 140 days	Tungro, bacterial leaf blight and leaf streak, leaf shredding in typhoons	Intermediate and short plant height; slow leaf senescence; smooth leaf and other plant parts; medium and long grain length; symmetrically shaped translucent grain; intermediate and high gelatinization temperatures
IR935	IR8/2 x (CP 231 x SLO-17)	F_3			
IR253	Gam Pai/2 x TN1	F_7	105 to over 145 days	Tungro, blast	Waxy endosperm
IR829	IR8 x (CP-SLO x Gam Pai)	F_3			
IR848	(Peta/3 x TN1) x CP-SLO x Gam Pai)	F_3			
IR837	(Peta/3 x TN1) x Niaw San PahTawng	F_3			

Varietal Testing and Development

World collection

The description and preservation of rice germ plasm were continued under a 4-year grant from the United States National Science Foundation. The collection of cultivated varieties of *Oryza sativa* now totals 10,831 accessions, of which 509 were received during the year. Field and laboratory morphologic-agronomic descriptions for about 8,500 accessions have been completed. Arrangements with International Business Machines (Philippines) Inc. were initiated to prepare for the transfer of recorded data to punch cards and magnetic tapes under a grant provided by the International Business Machines Corporation in New York.

About 5,727 accessions were regrown in two plantings during 1966-67 for seed renewal. The fresh seedlots were transferred to new containers to insure greater seed longevity.

During the year 1,764 seedlots of cultivated varieties from the collection were sent upon request to 121 agencies in 47 countries. Another 789 seed samples of wild taxa in the genus *Oryza* were supplied to 5 institutions in 4 countries.

Breeding program

IR8, and lines of a similar plant type, continued to show promise under a wide range of soil and climatic conditions. The favorable performance of these lines appears to be largely a result of a combination of desirable characteristics, which include (1) early vegetative vigor, (2) moderately high tillering capacity, (3) erect leaves of moderate length, and (4) short sturdy stems.

Because these traits influence yielding ability so favorably, the main breeding objectives as outlined in the 1966 Annual Report are being continued. They stress the incorporation of early maturity, disease resistance and improved milling and cooking qualities into the IR8 plant type. Other desirable traits which are being combined with the improved plant type are tolerance to cold weather, resistance to insect attack and to leaf damage during typhoons, and ability to tolerate deep water.

The more promising crosses and backcrosses made at the Institute are shown in Table 1. They represent only a small portion of the 1,300 crosses that have been made at the Institute since 1962. IR8, or lines of similar plant type, were used as one of the parents in most of the crosses listed. It will be noted that one or more backcrosses were made in many of the combinations and that the improved-plant-type-variety was used as the recurrent parent. In most of the crosses the IR8 plant type was recovered and several of the other desired traits were incorporated. A range of maturity, improved grain characteristics, and higher levels of resistance to one or more diseases were all involved in many of the crosses and backcrosses.

Maturity. Many areas throughout tropical Asia require earlier maturing varieties, particularly during the dry season when irrigation water is at a premium. Promising lines maturing in about 100 days after seeding in the seedbed were selected from crosses involving TKM-6, Belle Patna, Tadukan, Yukara, and other varieties. True-breeding lines combining early maturity and a good plant type are now available for testing in preliminary yield trials. Many of the early lines possess high levels of disease resistance, improved grain characteristics, possible tolerance to cold weather, and resistance to leaf injury during typhoons.

Disease resistance

Rice blast. Breeding for blast disease resistance is extremely complex because of the presence of numerous races of the causal fungus. For this reason, a number of resistant varieties of divergent origin were used as parental sources of resistance. They included Dawn, Gam Pai, H 105, Leuang Yai 34, Nahng Mon S-4, Sigadis, Tadukan, TKM-6, Zenith, and several Taiwan ponlai varieties.

Lines highly resistant to the blast disease were obtained from all crosses where a resistant variety was used as one of the parents. The degree of resistance of the selections was determined by growing the lines in a blast nursery, as described in previous Annual Reports. Numerous races of blast were present in the Institute blast nursery.

Resistant lines were also obtained from some of the crosses between susceptible and moderately susceptible to moderately resistant varieties.

Bacterial leaf blight and leaf streak. Varietal resistance to bacterial leaf blight and bacterial leaf streak are difficult to evaluate due to varying environmental conditions (temperature, humidity, winds severe enough to injure the leaves, etc.) and differences in virulence of strains of the causal organisms. Wide differences in varietal reaction to both diseases are consistently observed and resistance has been transferred through breeding.

Testing for resistance to bacterial leaf blight was carried out in close cooperation with Institute plant pathologists. Varieties showing resistance to bacterial leaf blight included Sigadis, B589A4-18, CP 231 x SLO-17, Dawn, 81B-25, TKM-6, Zenith, CI 9210, and several Taiwan japonica varieties. The flagleaf puncture method of inoculation was used to test the degree of resistance.

Field reaction has been relied upon in evaluating resistance to bacterial leaf streak. Each year, reasonably reliable information has been obtained. Many resistant lines were obtained from a wide range of varietal sources. Resistant parental varieties used included B581A6-545, CP 231 x SLO-17, Leuang Yai 34, Milfor-6(2), Nahng Mon S-4, Zenith, and several Taiwan ponlai varieties.

Tungro virus disease. Resistance to the tungro virus is an essential trait in tropical Asian varieties as this virus or closely related ones appear to be rather widespread. Under most field conditions, IR8 appears to have a satisfactory level of resistance.

Screenhouse inoculation tests conducted by Institute virologists indicate that Pankhari 203 is more resistant to the tungro virus than IR8, and a series of crosses and backcrosses were made to transfer this higher level of resistance of Pankhari 203 to IR8 and to other varieties. Up to this time, lines showing the resistant reaction of Pankhari 203, as determined by a screenhouse testing technique, have not been recovered from the Pankhari 203 crosses, but a large number of F_3 and F_4 lines will be tested in 1968.

The tungro resistance of Peta has been combined with resistance to blast, bacterial leaf blight and bacterial leaf streak in many improved plant type lines from a number of different crosses.

Grassy stunt virus disease. Varietal reaction to the grassy stunt virus was determined under field conditions. At the Institute heavy grassy stunt infection occurs when rice is sown from September to November. Highly susceptible varieties frequently show severe damage in spite of stringent leafhopper and planthopper control measures using insecticides. IR8 is susceptible to grassy stunt under these conditions, while IR5, Peta, Belle Patna, Dawn, CP 231 x SLO-17, TKM-6 and a number of the Thailand varieties appear to have considerable resistance. In at least some of the areas where IR5 has outperformed IR8, differences in levels of grassy stunt resistance may have been involved. IR12-178, a dwarf line developed from a cross between Mong Chim Vang A and I-geo-tze, may be resistant. The crosses of IR8 x IR5 and IR8 x IR12-178 probably combine resistance to both tungro and grassy stunt. Pedigree lines from both crosses will be tested in 1968.

Stem borer resistance

Studies on stem borer resistance were carried out in close cooperation with the Institute entomologists. TKM-6, a high grain quality variety from India, was selected by the entomologists as a stem borer resistant variety. The F_4 and later generation lines of a cross between a Peta/3 x Taichung (Native) 1 dwarf line and TKM-6 were screened by the entomologists for stem borer reaction. The results of these studies are presented in the Entomology section of this Report.

In addition to stem borer resistance, pedigree lines from the (Peta/3 x TN1) x TKM-6 cross showed good plant type of early, mid-season and late maturity. Some of them possessed resistance to the rice blast disease, the tungro and grassy stunt virus diseases and the bacterial leaf diseases. Lines showing excellent grain shape with clear translucent texture resulted from this cross. The cross, IR8 x TKM-6, has subsequently been handled in a manner similar to the (Peta/3 x TN1) x TKM-6 cross.

Resistance to leaf shredding during typhoons and slow vegetative senescence

The typhoons which occurred in October and November, 1967 severely damaged an August-sown pedigree nursery. Most of the tropical indica varieties showed severe shredding of leaf blades while the japonica varieties and U.S. varieties such as Belle Patna, Dawn, CP 231 x SLO-17, Zenith, and B547A3-47-15 were less severely damaged. Pedigree lines from crosses involving some of these varieties likewise showed less leaf injury. This characteristic, along with slower leaf senescence and cold tolerance, should be combined with the good plant type indica lines. The crosses IR8 x (Peta/5 x Belle Patna), IR8 x (Peta/3 x Dawn), IR8/2 x Zenith, IR8 x (CP 231 x SLO-17), and IR8/2 x (Yukara x TN1) all showed plants with moderate leaf shredding. By growing selections in areas where strong typhoons are apt to occur it should be possible to further evaluate breeding lines for this trait. Slow senescence may or may not be associated with resistance to leaf shredding.

Reaction to deep water

In 1965, Taichung (Native) 1 and a [Peta/2 x Taichung (Native) 1] dwarf line were both crossed with Leb Mue Nahng, a floating variety from Thailand. In the F_2 generation, only dwarf plants were selected for growing in pedigree rows during the 1966 wet season. The F_4 generation line selections were grown in a pedigree nursery sown in January 1967.

Remnant F_4 seedlings from this nursery were transplanted in a small pond. The seedlings were 36 days old when transplanted. After 10 days the water depth was increased from a few centimeters to about 20 cm, and over the next 11 days it was gradually increased to 50 cm. It was difficult to maintain a depth of over 45 cm but for the next 30 days a depth of from 45 to 60 cm was maintained.

The results were interesting in that many of the dwarf lines selected from the (Peta/2 x TN1) x Leb Mue Nahng and the Taichung (Native) 1 x Leb Mue Nahng crosses performed well in the deep water. They showed greater tolerance to deep water than certain intermediate height varieties. IR8 and Taichung (Native) 1 also showed a remarkable tolerance to deep water

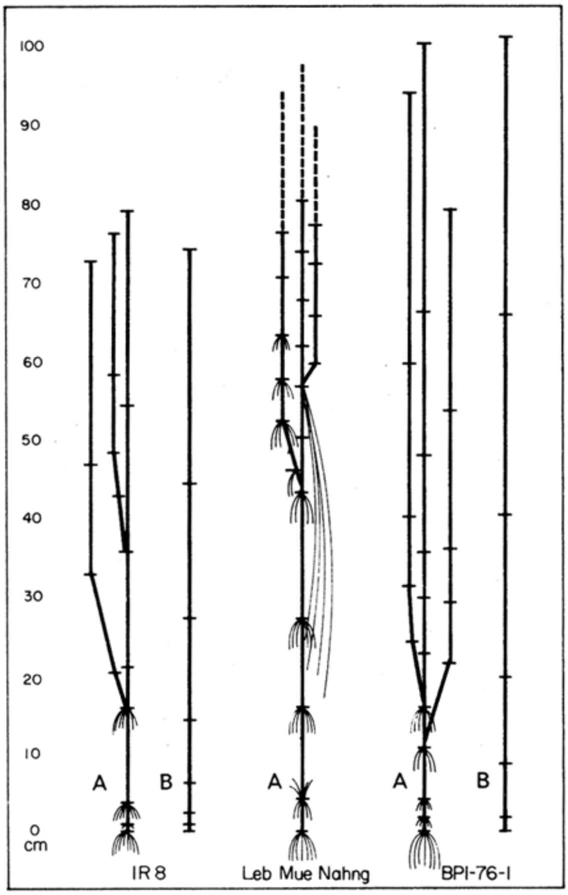


Fig. 1. Internode elongation on the main culm and tillering pattern of three varieties grown in deep water (A) and in shallow water (B).

but did not perform as well as many of the Leb Mue Nahng hybrid lines. Peta, a tall variety, made excellent growth under the deep water conditions while BPI-76, Leuang Yai 34, Nahng Mon S-4 and Sigadis appeared to be inferior to Taichung (Native) 1 and IR8. IR5, an intermediate height variety, showed rather poor growth, with less elongation of the lower internodes than was true for either IR8 or Taichung (Native) 1. The later maturity of IR5 may have been a factor. CP 231 x SLO-17 made the poorest growth; in fact most of the plants died.

An examination of the semi-dwarf plants grown in the deep water plot showed that they produced secondary tillers from the second or often from a higher node. For instance, IR8 produced a secondary tiller on the main culm at the third and fifth nodes above the soil surface, and Leb Mue Nahng, a floating variety, produced secondary tillers at the fourth and seventh nodes (Fig. 1). Adventitious roots appeared on these lower nodes as well as on other nodes either above or below them. In several lines, as many as five tillers were produced from above-ground nodes.

A comparison of semi-dwarf plants grown in deep water with corresponding lines grown in 5 cm of water showed two interesting trends: (1) the plants grown in deep water were not necessarily taller, and actually often were slightly shorter than those grown at the 5-cm water depth, and (2) the plants reacted to the rise in water level by producing longer and/or one or more internodes near the ground level (Fig. 1).

Progenies from the above lines were again grown in deep water during the wet season. Forty-five-day old seedlings were used for the main pedigree nursery. A selected number of 28 pedigree lines were transplanted using 29-day old seedlings. A group of 13 varieties were transplanted at 51 days after seeding. All three experiments were transplanted on August 24. Following transplanting a water depth of not over 5 cm was maintained for 15 days, and during the next 12 days, was gradually increased to 60 cm. The leaf tips of most plants were visible above the water most of the time. Starting about 51 days after transplanting as much as 85 cm of water was added but it was difficult to maintain a depth of over 60 cm. A depth of from 55 to 85 cm was then held until after most lines were fully headed, which was approximately 75 days after transplanting.

Many of the semi-dwarf lines from the Leb Mue Nahng crosses again showed remarkable tolerance to the deep water and tillered well when transplanted at 45 days. The lines transplanted at 28 days of age did not tiller well and made poor growth, some plants failing to survive.

The 13 varieties transplanted at 51 days after seeding survived the deep water remarkably well. IR5 did not show the poor response observed in the dry season test. Kaohsiung 21 and CP 231 x SLO-17 tillered poorly but many plants of these two varieties survived the deep water.

Milled grain characteristics

The milled grain characteristics which Institute breeders are selecting for are:

(1) Symmetrically shaped, short, medium and long grain. Broad or very slender grains are generally not preferred.

(2) Clear or translucent appearance of the grain with essentially no white or chalky areas in center (white center or white core) or along the lower side (white belly) of the grain.

(3) Intermediate and high amylose content, and

(4) Low, intermediate and high gelatinization temperatures.

IR8 produces a medium long, somewhat bold grain which has a rather large chalky area (white belly) along the lower side of the grain. The grains of IR8 show a rather high percentage of breakage when milled probably due to the boldness of the grain and to the white belly characteristic. However, total milled rice returns of IR8 are usually high. A grain type that is less bold and more symmetrically shaped than IR8 and of a clear or translucent appearance should result in less breakage without reducing total milled rice yields.

Improved grain shape and appearance may be relatively easy to select from hybrid progeny. In the F_3 generation of the backcross, IR8/2 x (Peta/5 x Belle Patna), many lines were selected showing grains of an improved shape that were relatively free from white belly. This is remarkable since both IR8 and Peta have a rather bold grain and show a high degree of white belly. Belle Patna was the probable donor parent for both traits and selection pressure for these characteristics was not started until the F_3 generation. Similar results have been obtained from other crosses and backcrosses.

Intermediate amylose content (23 to 26 percent) is preferred to high amylose content (30 percent) by most rice consumers in the Philippines. This preference may be rather widespread in rural areas throughout Asia. The intermediate amylose content of Belle Patna, Dawn, B589A4-18, and other varieties has been readily transferred to IR8 plant type lines. IR12-178, a dwarf height line from the cross of Mong Chim Vang A x I-geo-tze is of intermediate amylose content. It should be possible to combine intermediate amylose content, clear grain texture, good plant type, and resistance to tungro and grassy stunt in the crosses IR8 x IR12-178 and IR5 x IR12-178. Several other crosses involving improved grain quality are shown in Table 1.

F_2 and other bulk hybrid populations

Over 1,700 bulk hybrid populations were grown from seedings made in October and December 1966 and February, May, July and August 1967. Most of the populations were backcross combinations in the F_2 generation. Usually a population of 100 to 150 plants per backcross population, and 2,000 to 3,000 plants of single cross combinations, were grown. Tall or otherwise undesirable plants were removed from the populations at various times during the growing season.

Plant selections for growing in pedigree rows were made from promising populations. A large number of panicles were saved from a few of the populations for use in seeding a bulk plot for the next generation.

Pedigree nurseries

Pedigree nurseries were sown in October and December 1966 and in May, July, and August 1967. Over 35,000 rows, including check rows (every 20th row) were grown in the five nurseries. The pedigree lines varied from F_3 lines to advanced generation lines (F_6 to F_9). Selections from 289 different cross combinations were included in the 1967 nurseries.

Plant selections were made from about one-fifth of the rows. Generally, 3 plant selections per row were made, except in the case of certain F_3 rows where 6 or more plants were saved. After selections were made a representative portion of the grain from these rows was harvested as a bulk sample. The bulked grain samples are used for supplying seed to cooperators in other countries, and for disease and grain quality tests.

About 1,450 promising lines, which appeared to be breeding true, were harvested and are being advanced to preliminary yield trials.

Observational yield trials

Observational yield trials grown in single 4-row plots were seeded in October and December 1966 and May and July 1967. Of the 1,742 entries grown in the 4 tests 1,042 were new lines from pedigree nurseries grown for the first time in a yield trial.

Many promising entries were saved for further testing in preliminary yield trials and in the advanced yield trial.

Replicated yield trials

A dry season yield trial of 119 entries and a wet season trial of 120 entries were grown in duplicated 8-row plots 5 meters long. A 30 x 15 cm spacing using a single plant per hill was used in both experiments.

The same land area was used for the two experiments which were transplanted January 10 and July 25 using 20-day old seedlings. A total of 120 kg/ha nitrogen was applied to the dry season experiment and 90 kg/ha to the wet season experiment. Nitrogen topdressings were made 25 and 45 days after transplanting, using 30 kg/ha rates for the dry season and 20 kg/ha rates for the wet season experiment. The agronomic, disease, and quality data of some selected varieties and lines are presented in Table 2.

The average yield of the dry season experiment was 7,221 kg/ha with 30 entries yielding over 8,000 kg/ha. Twenty-five of the top entries were semi-dwarf lines with 22 of them originating from Peta x semi-dwarf crosses. Forty-eight of the entries yielded over 7,500 kg/ha and all but one were semi-dwarf lines. This is significant since only 59, or approximately one-half, of the entries were semi-dwarf lines. IR8 occurred three times in the trial and averaged 9,483 kg/ha.

Yields in the wet season experiment were reduced by wind damage including lodging caused by the October and November typhoons. All varieties lodged when hit by the extremely severe typhoon in November. The average yield of the test was 4,286 kg/ha with 28 entries averaging over 5,000 kg/ha. All but one of these higher yielding entries were semi-dwarf lines. IR8 was entered three times in the test and averaged 5,593 kg/ha.

The average annual yield per hectare from the two crops of all entries was 11,507 kg/ha. The yield of IR8 from the same two crops was 15,076 kg/ha. The highest total yield from 2 crops was 16,659 kg/ha, produced by IR39-14, a cross between Peta and Taichung (Native) 1.

IR8 selections in replicated yield trials

During the dry season 120 IR8 line selections were tested in a replicated yield trial. From this test 37 selections classified as tungro resistant were grown in a 4-replication test during the wet season. The trial was sown July 5 and transplanted on July 25. Single plants were spaced 30 x 15 cm apart in 8-row plots 5 meters long. A total of 110 kg/ha of nitrogen was applied. The basal application was 50 kg/ha of nitrogen, followed by top dressings of 20 kg/ha at 25, 45, and 65 days after transplanting.

The average yield of all lines was 5,645 kg/ha, with individual lines varying from 5,274 to 6,227 kg/ha. The typhoons which occurred in October and November caused severe lodging in essentially all plots. Only 6 plots in the entire experiment did not lodge and they were harvested prior to the more severe November typhoon. The original IR8, grown as a check variety, averaged 6,008 kg/ha but was harvested prior to the November typhoon.

Most of the lines were of uniform maturity and varied from slightly earlier to slightly later than the original selection.

International cooperative variety testing

The distribution of nursery-sized seedlots of Institute breeding lines to various cooperating agencies in the tropics was continued, and was expanded to include Colombia. In addition to early-generation (F_4 to F_7) lines, the breeding materials also included F_2 hybrid seeds and F_3 and F_4 seeds. Following initial observation and selection at the Institute, a number of lines were included in the national testing programs of India, Indonesia, Malaysia, Pakistan, Philippines and Thailand. Also the Institute received breeding lines recently developed in Argentina, Ceylon, Colombia, El Salvador, India, Indonesia, Korea, Liberia, Malaysia, Mexico, Spain, Taiwan and Thailand.

The cooperative tests have provided the Institute with a great deal of information about the varietal requirements of different countries and about the performance of breeding lines under a variety of climatic and biotic environments which are different from those of Los Baños.

Table 2. Agronomic, disease, and quality data on selected varieties and lines grown in replicated yield trials at two planting dates (December 1966 and June 1967), IRRI.

IRRI Acc. No.	Variety or selection	Grain yield (kg/ha)		Maturity days seeding-harvest)		Mean pl. ht. (cm)	Mean no. pan-icles/ plant	Mean lodging (%)		Disease				Seed dor-mancy (%)	Milled rice yields (%)		Gel. temp.	Amy-lose (%)
		Dec.	June	Dec.	June			Dec.	June	Tungro virus	Bact. lf bl.	Bact. streak	Blast		Head	Total		
105	Taichung (Native) 1	7428	5431	126	111	110	16	0	100	100	MS		VS	8	48.6	71.6	L	31.0
35	Peta	3871	1994	138	138	174	13	100	100	10.7	MS	S	MS	87	59.5	71.4	I	27.8
	C4-63	8241	4480	133	126	129	14	0	100	38.5	MR	MS	VS	55	64.3	71.2	H/HI	25.1
730	Milfor-6(2)	7065	4490	133	124	170	10	0	100	100	R	R	S	53	58.4	70.6	I	23.6
6993	CP 231 x SLO-17	6569	4056	121	117	108	14	0	0	100	R	R	VS	28	58.1	66.0	H	16.2
4095	Sigadis	4456	2214	138	128	177	12	100	100	27.6	R	S	MR	78	51.9	71.1	I	27.0
39	BPI-76	6778	1663	148	138	145	11	0	100	100	MS	MS	VS	87	56.6	63.8	H	22.5
9915	BPI-76-1 (Bicol)	6282	3718	127	126	145	11	8	100	75.9	MS	MS	S	49	64.4	69.3	HI	25.6
	IR4-93-2, H-105 x Dgwg	8197	4115	138	124	131	14	0	100	100	R	MS	R	4	58.1	70.6	L	31.7
10321	IR5, Peta x Tangkai Rotan	7928	3889	138	128	131	14	0	100	51.7	MR	MS	S	83	59.4	72.6	HI/I	33.7
	IR6-1-3-1, Siam 29 x Dgwg	7433	3820	127	111	114	16	0	10	100	MR	MS	MS	4	61.7	71.2	L	29.7
10320	IR8, Peta x Dgwg	9563	5976	133	117	107	13	0	87	68.8	MR	MS	VS	4	52.1	72.5	L	29.5
	IR39-14, Peta x TNI	9869	6790	133	117	97	17	0	0	100	MR			44	57.8	72.8	I	27.4
	IR60-12-4-1, BPI-76/2 x Ch. 8	6554	3061	133	124	141	10	0	100	92.3	R	R	MR	44	67.2	73.0	L	21.0
	IR76-154-1-2, BPI-76 x T. 176	5920	4049	130	124	127	15	0	100	3.7	R	R	VS	81	51.8	69.8	L	18.5
	IR84-82-3-4-3, Peta x PI 215936	7040	4300	124	111	121	13	0	90	0.0	R	R	S	11	51.2	73.7	H	16.2
	IR154-61-1-1, (CP-SLO) x TNI	7277	5303	124	108	93	15	0	0	100	MS	R	MS	0	63.0	71.2	H	14.7
	IR253-16-1-2, Gam Pai/2 x TN1	7307	3375	124	115	129	13	85	100	65.4	MS	S	VS	65	46.9	69.1	I	Waxy
	IR262-43-8-11, Peta/3 x TN1	7793	5826	121	111	92	15	0	75	45.5	MS	MS	MS	42	47.2	70.8	I/L	31.4
	IR400-28-4-5, Peta/4 x TN1	9587	5569	138	124	86	17	0	10	100	MR	MR	VS	61	50.7	73.7	L	30.6
	IR400-5-12-10-2, Peta/4 x TN1	8698	5508	124	111	91	18	0	60	55.6	MR	MR	MS	77	41.4	72.4	L	30.8

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.

For instance, the cooperative trials in Thailand gave information on varietal reactions to the "yellow-orange leaf virus". Regional tests elsewhere have provided information on the blast reaction and photoperiod response of certain lines. Such broad evaluation of breeding lines is made possible only through cooperative efforts.

During the year, about 12,400 seed packages of varying sizes were airshipped from the Institute's stock of improved varieties (IR8 and IR5) and breeding lines to 310 requesting agencies in 87 countries and territories. This quantity represents a more than 100-percent increase over the amount sent in 1966. The distribution of seeds covered countries and territories such as Afghanistan, Argentina, Austria (IAEA), Bolivia, Brunei, Burma, Cameroun, Caroline Islands (U.S.), Chile, Congo, Costa Rica, Ecuador, France, Gabon, Greece, Guam, Guinea (Portuguese), Haiti, Haute Volta, Honduras (Brit.), Hongkong, Israel, Italy, Ivory Coast, Kenya, Korea (S.), Liberia, Malagasy, Mali, Mariana Islands (U.S.), Mauritius, Mozambique, Niger, Papua and New Guinea, Portugal, Ryukyu Islands, Sierra Leone, Solomon Islands (Brit.), Somali, Sudan, Surinam, Swaziland, Switzerland, Tahiti, Tanzania, Tchad, Turkey, Union of South Africa, United Kingdom, Venezuela, Vietnam (S.), and the West Indies, in addition to those countries mentioned in the 1966 Annual Report.

Pure seed production program

The initial seed lot of IR8 was formed by bulking the seed produced from a single F_5 line selection harvested in February 1965. While the plant characteristics and grain features were uniform, a few early maturing variants appeared in the progeny of this original seed lot. All of the IR8 seeds distributed by the Institute in 1965 and 1966 originated from the multiplication of this initial bulk.

A seed purification program was started in 1966 from which a uniform maturing line was selected. Line No. 68 appeared to be of uniform maturity and was typical of the IR8 plant and grain type. It was tested in replicated yield trials during the 1967 wet and dry crop seasons and was found to yield essentially the same as the original IR8 line. No significant difference in reaction to diseases or in quality was noted and the line appeared to retain the other features of the original IR8 seed lot.

All purified seeds of IR8 supplied in 1967 to the national seed multiplication agencies of Ceylon, Colombia, India, Malaysia, Mexico, Pakistan, Philippines, and Vietnam were produced from this new seed source.

Yield trials of induced mutants and hybrid selections

The Institute continued to participate in the series of uniform yield trials sponsored by the FAO/IAEA. The yield trial of indica mutants and hybrids conducted in the 1966 wet season was reported last year (Annual Report, 1966). IR8 led the group of 7 mutants, 3 mutant x hybrid selections, 1 pureline variety, and 5 hybrid selections.

In the 1967 dry season trial, IR8 again topped the group and yielded significantly higher than the next ranking entry, Taichung (Native) 1. The ranking of other entries in the trial is shown in Fig. 2, which is based on Duncan's multiple range test. Six different yield groups are indicated by the test.

A similar trial of japonica mutants and hybrids was planted in the dry season and included six mutants, four parents and three hybrids. Tainan 3 and Kaohsiung 21 were the top yielding entries and comprised the first yield group. Three other yield groups were indicated by the multiple range test. Except for a parent and mutant from Japan and a parent from France, the remaining eight mutants and parents from Japan and Taiwan were placed in the second yield group (Fig. 3).

The indica entries were again planted at the end of February. Among the 16 entries, the photoperiod-sensitive Nahng Mon S-4 and its two mutants had not headed at the time the other entries were harvested. Eventually, these three entries were discarded. Based on the yield data obtained from the remaining entries, IR8 was again the leading entry at 6,700 kg/ha. It was followed by SH 30-21, KT 20-74, YH 1, Taichung (Native) 1 and IKB 4-2, all of which yielded around 6,000 kg/ha. The two mutants from India and two mutant x variety selections from the U.S. yielded from 2,800 to 3,900 kg/ha.

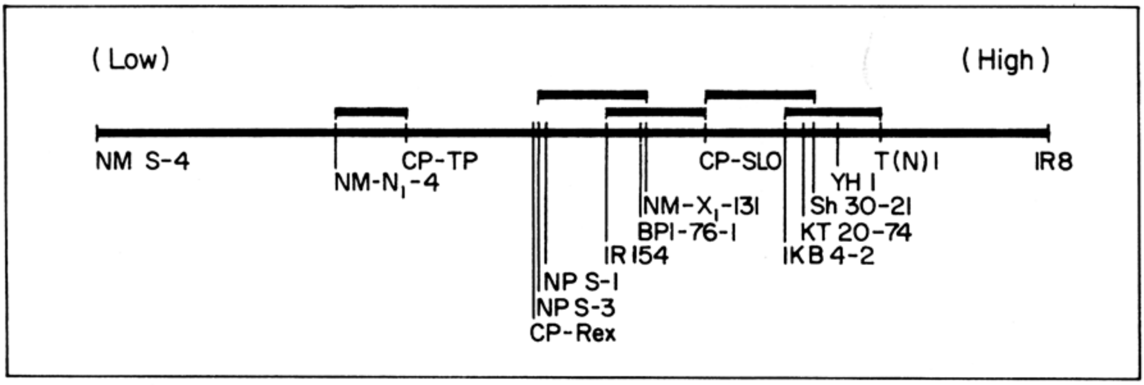


Fig. 2. Graphical array of grain yield of 16 entries in the IAEA uniform yield trial of indica types, 1967 dry season.

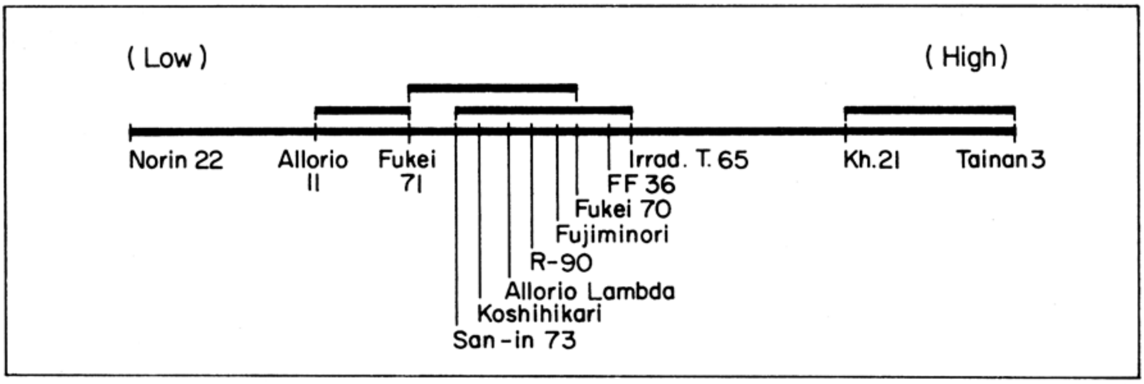


Fig. 3. Graphical array of grain yield of 13 entries in the IAEA uniform yield trial of japonica types, 1967 dry season.

Under the test conditions at Los Baños, none of the mutants or mutant x variety hybrids revealed any merit in yielding ability and/or in agronomic traits superior to those of their parents and/or hybrid selections evolved from conventional breeding programs.

International performance of IR8

Information on the yield performance of IR8 obtained from various countries and territories during the latter part of 1966 and in 1967 confirms the earlier reports (Annual Report, 1966) about the high yielding potential of IR8. Some of these yield data are summarized below to provide further information on the variety.

At the Kilanas Station in Brunei (Borneo Island), IR8 produced a yield of 5,680 kg/ha in a variety trial during the 1966-67 crop season. In a fertilizer experiment on Guadalcanal (British Solomon Islands), IR8 produced yields ranging from 4,100 to 7,300 kg/ha. In three regional trials planted around Ponape in the Caroline Islands (U.S.) in 1967, the variety gave an average yield of 5,500 kg/ha.

At several locations on the island of Java in Indonesia, yields obtained in the summer of 1966 ranged from 4,000 to 7,000 kg/ha. The Ministry of Agriculture has implemented a program for large-scale testing and seed multiplication of IR8, and in April named this variety Peta Baru 8. The yields obtained in 1967 ranged from 1,890 to 7,700 kg/ha.

In Ceylon, fields for seed testing and multiplication were set up in the spring under the supervision of the Central Agricultural Research Institute. IR8 has shown good promise on soils of adequate productivity in this country.

High yields were again reported from several locations in West Pakistan where climatic conditions in 1967 were favorable for high grain production. The yields ranged from 8,100 to 9,600 kg/ha.

In the advanced test (group I) of the regional trials conducted by the Philippine Seed Board (average of five stations), IR8 led a group of 12 entries with an average yield of 4,600 kg/ha. Peta produced a mean yield of 3,210 kg/ha in the same series of trials.

In the Pingtung area of southern Taiwan, IR8 yielded well in the first and second crops compared to the local indica varieties.

In South Vietnam where the variety is being tested at many locations, yields ranging from 2,800 to 10,230 kg/ha have been reported.

High yield figures were again received from cooperators in Mexico. The 1967 harvests ranged from 5,000 to 11,400 kg/ha in directly sown and in transplanted cultures.

In Panama, one upland planting gave 5,500 kg/ha of grain, which was more than twice the yield of other locally adapted varieties grown in the same field. Another trial produced 7,000 kg/ha.

At Sapu in Gambia, IR8 produced 6,300 kg/ha in the dry season. This figure compares favorably with the yields of Taiwan varieties grown in various parts of West Africa by Chinese agricultural missions.

On the basis of IR8 plantings using seeds initially supplied by the Institute, government authorities in Argentina, Burma, East Pakistan, Israel, Laos, Saudi Arabia and the United Arab Republic have imported IR8 seed from Philippine seed producers in sizeable quantities for large-scale plantings.

International performance and naming of IR5

Seeds of IR5 (strain IR5-47-2) were distributed to cooperators in the Philippines and in other countries during 1966.

The yield data from various sources show that IR5 has generally produced good yields in tropical Asian countries. In some locations, it outyielded IR8 partly because of its higher level of disease resistance. In other locations, however, it did not perform as well, primarily because of lower resistance to lodging and the consequent lower level of nitrogen responsiveness.

IR5 was selected from the fifth cross made at the Institute in 1962 between Peta, an improved variety from Indonesia, and Tangkai Rotan, a variety from Malaysia. Briefly, its history is as follows: From a bulk population of F_3 plants grown in the 1963-64 dry season, 303 plants were selected and grown in the 1964 wet season as single-plant rows. Three plants were selected from row 47 and planted as F_5 pedigree lines in the 1964-65 dry season. One of the progeny rows was harvested and designated as IR5-47-2.

IR5 is similar in many respects to IR8. It has excellent seedling vigor, erect leaves, and high tillering ability. However, IR5 is taller (130-140 cm) and matures later (130-145 days from seeding to harvest) than IR8. In most tropical areas, IR5 can be classified as weakly photoperiod-sensitive but non-seasonal. In the Philippines it can be planted any month of the year but growth duration varies as much as 20 days as revealed by date of planting experiments at Los Baños, Philippines. At the higher latitudes in the tropics and subtropics, the weakly photoperiod-sensitive behavior of IR5 may restrict its planting to certain crop seasons because of delayed maturity (see Annual Report, 1966, p. 27).

IR5 has medium-sized grains of moderate dormancy. Like its Peta parent, the milled rice of IR5 cooks dry and fluffy because of a high amylose content and an intermediate gelatinization temperature. Its cooking quality is rated acceptable for most of the Asian market, and its head rice recovery is higher than that of IR8.

Under field conditions, IR5 is more resistant to several diseases than IR8. Extensive observations in tropical Asia indicate that it is resistant to the tungro virus and moderately resistant to bacterial leaf blight. It appears to be more resistant to the grassy stunt virus than IR8. It is susceptible to some of the Philippine races of the blast fungus and moderately susceptible to bacterial streak.

Because of its relatively tall plant stature, IR5 is more prone to lodge at high fertility levels than IR8. As a result, the responsiveness of IR5 to added nitrogen is rated lower than that of IR8. For the same reason, the maximum yield potential of IR5 is considered to be lower than that of IR8. However, IR5 has outyielded IR8 in areas where the soil fertility is medium or low or the incidence of certain diseases is high.

In many respects, IR5 is a significant improvement over the conventional varieties now being grown in tropical Asia. On farms and on experimental plots where the soil fertility level is modest, IR5 has often produced good yields.

IR5 was tested at the Maligaya Rice Research and Training Center in Muñoz, Philippines in the 1966 dry season and was the leading entry among the 12 IRRI lines, with a yield of 6,000 kg/ha. IR5 was included in the regional trials of the Philippine Seed Board during the 1966 wet season. It led other entries (including IR8) at 3 locations (College of Agriculture of the University of the Philippines, the Maligaya Center, and the Bicol Rice and Corn Experiment Station).

In India, IR5-47-2 was grown at the All-India Coordinated Rice Improvement Project at Hyderabad, A.P. during the 1966 kharif season and its yield ranged from 3,800 to 5,000 kg/ha at two fertilizer levels. In the same experiment IR8 produced yields of from 5,400 to 6,000 kg/ha. At the Bukit Merah Padi Station in northern Malaysia, a variety trial was planted in October 1966. IR5 produced 4,200 kg/ha, similar to that of IR8 (4,700 kg/ha).

During the 1966 monsoon crop season at Savar Farm (Dacca), East Pakistan, IR5 and sister lines from the same cross were the highest yielding entries in a variety trial. IR5 produced 7,843 kg/ha.

In nine APC-IRRI cooperative variety trials in the 1966 dry season in the Philippines, IR5 produced from 3,400 to 8,700 kg/ha, averaging 5,310 kg/ha. IR8 averaged 5,060 kg/ha in the same series of trials which were well distributed over the country. In 20 similar plots in the 1966 wet season, the yields of IR5 ranged from 2,810 to 7,640 kg/ha, averaging 5,600 kg/ha. IR8 produced an average of 6,400 kg/ha in the same series of trials. In nine plots grown in the 1967 dry season, IR5 averaged 6,134 kg/ha which is below the average yield of 7,530 kg/ha for IR8.

During the 1967 dry season, IR5 produced yields ranging from 3,000 to 5,000 kg/ha on the Bangkhen Station in Thailand. In Kpong, Ghana, IR5 produced about 5,900 kg/ha in a one-half hectare March-planted trial. In Indonesia, where the variety has been named Peta Baru 5, the yields were around 5,000 kg/ha but occasionally reached 8,000 kg/ha in the dry season. The popularity of IR5 in several Asian countries prompted the Institute to recognize it as a variety and officially named it IR5 in mid-December of 1967. This is the second variety named by the Institute.

Genetic and Cytogenetic Studies

Diallel-cross analysis of quantitative characters in F_2 progenies

A previous study (Annual Report, 1966) of the F_1 hybrids of a 4-parent diallel-cross showed that additive effect was the predominant fraction of genetic variance in controlling parental differences concerning each of four quantitative traits: duration from seeding to heading, plant height, panicle number and panicle length. Dominance effect was also significant in controlling each of the four traits, with both dominant and recessive genes contributing to the genetic variance.

The data obtained from F_1 and F_2 progenies grown in the 1967 dry season are analyzed and summarized as follows.

Duration to heading. The 29-day difference in heading date between two extreme parents could be ascribed to four effective factors with additive effect ($Ef_1 \dots Ef_4$). The early parents carried dominant alleles and the late parents had recessive alleles. The *Ef* genes formed an epistatic series and showed unequal effects. The heritability estimates for the six crosses were extremely high, ranging from 87 to 95 percent.

Plant height. The minimum effective factor pairs varied from two to four pairs in this series of crosses. The overall 42-cm difference in height among parents may be ascribed to six independent genes with additive effect. The tall parents carried as many as four pairs of dominant alleles and the short parents had the recessive alleles. The six genes showed equal additive effect but differed in the strength of dominance effects. Heritability estimates were also high for plant height in the six crosses, ranging from 65 to 92 percent.

Panicle length. The genetic variance of this trait can be largely attributed to additive effect while dominance played a small part. The 12-cm

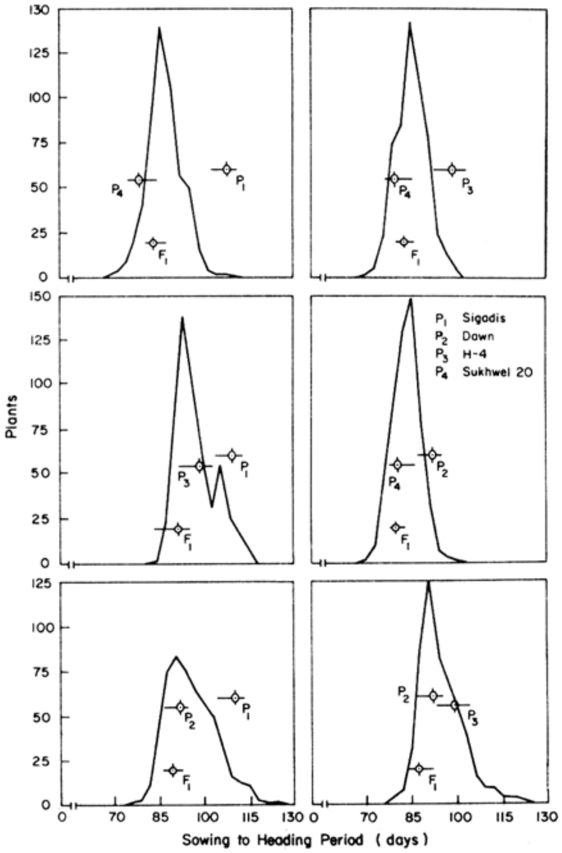


Fig. 4. Distribution and means of parents, F_1 and F_2 plants by the sowing to heading period in six crosses of the 4-parent diallel set. Solid horizontal lines show the range of parents and F_1 hybrids about the means (dotted circles). 1967 dry season, IRRI.

difference between extreme parents was controlled by five genes with long-panicled parents carrying as many as three pairs of dominant alleles. Again the five pairs of alleles showed differences in the strength of each pair. The heritability of panicle length was estimated to vary from 60 to 84 percent in the six crosses.

Panicle number. The range of 21 panicles between the two extreme parents can be accounted for by four independent genes of additive effect. Dominant alleles controlled high panicle number. The four parents differed in as many as four allelic pairs of unequal effect. The heritability estimates were relatively low, ranging from 39 to 72 percent. The heritability of panicle number is expected to be rather low as the trait is markedly affected by nutritional levels and environmental differences. The impact of nutrition and environment on tillers and/or panicle number has been amply indicated in experiments where different fertilizer levels or spacings were used.

Transgressive segregation was observed in each of the four quantitative traits in several F_2 populations. The data on the sowing to heading period (Fig. 4) agree with those on the basic vegetative phase obtained in previous years (Annual Report, 1965, 1966) that earliness is dominant to lateness and that the action of the polymeric genes was cumulative but unequal. The data on plant height (Fig. 5) are similar to those obtained from crosses involving the short-statured CP 231 x SLO-17 selection where a polygenic-additive system controlled the continuous variation in the F_2 populations (Annual Report, 1966). The transgressive segregation for long-panicled F_2 plants was also observed in the crosses involving CP 231 x SLO-17 and two U.S. selections (Annual Report, 1966).

Genetic association between six agronomic characters

Multivariate analysis and path analysis were

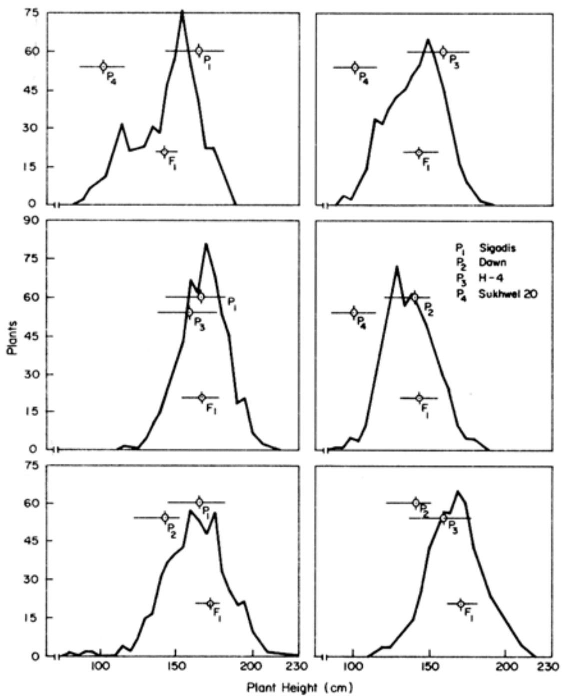


Fig. 5. Distribution and means of parents, F_1 and F_2 plants by plant height in six crosses of the 4-parent diallel set. Solid horizontal lines show the range of parents and F_1 hybrids about the means (dotted circles). 1967 dry season, IRRI.

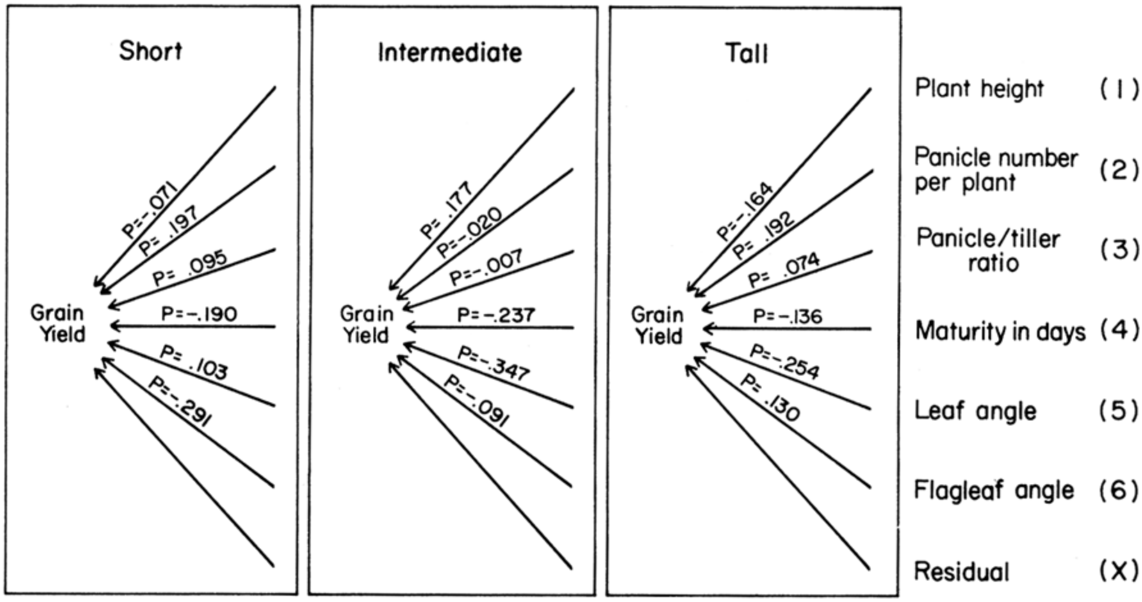


Fig. 6. Path diagram (partially given) showing the contribution of six agronomic traits to grain yield in three height groups of Peta x I-geo-tze F_7 lines.

made to evaluate the relationship between six plant characters and grain yield, and among the six characters in a representative sample of F_7 lines in the tall Peta x semi-dwarf I-geo-tze cross maintained as an unselected bulk from F_2 through F_5. The yield trials designed as simple lattices (7^2) were divided into three trials based on the height groups: tall, intermediate, and semi-dwarf. Each trial included the two parents and 47 lines. The six characters were: plant height, panicle number per plant, panicle to tiller ratio, days from seeding to maturity, angle of the leaf below the flagleaf, and angle of the flagleaf. The data on flagleaf angle were analyzed as coded numbers.

Highly significant differences were obtained among lines for grain yield and for all plant characters in all height groups, except for the ratio of panicles to tillers. Among the three height groups, the semi-dwarfs gave the highest mean yield (5,125 kg/ha), followed by the intermediate group (4,814 kg/ha), and the tall group (3,558 kg/ha).

Path analysis showed that among the semi-dwarf progenies, the erectness of the flagleaf made the largest contribution to grain yield, followed by high panicle number and early maturity (Fig. 6).

Among the intermediates, the erectness of the leaf below the flag contributed the most to high yield, but it was closely followed by earliness.

For the tall lines, erect leaves below the flagleaf and high panicle numbers contributed positively to yield, whereas tallness and late maturity gave negative contributions to yield. Drooping flagleaves did not appear to adversely affect grain yield in the tall lines.

Genotypic correlation coefficients showed a highly significant value between yield and height in a negative manner among the tall lines. High levels of yield were also positively correlated at the 1-percent level with high panicle number and erect leaves. Earliness and yield were correlated at the 5-percent level.

Among the intermediates, high yields were associated with shorter height, early maturity, and erect leaf angle in a highly significant manner. The correlation between yield and erect flagleaf angle was significant at the 5-percent level.

For the semi-dwarfs, only the erectness of leaves below the flag showed a positive genetic correlation with yield at the 5-percent level.

Inheritance and breeding behavior of grain dormancy

The breeding behavior of post-harvest dormancy in rice grains was traced in several crosses. Germination tests of hulled and dehulled grain samples of parent varieties, differing in dormancy readings but of the same post-maturation stage, indicate that the hulls (maternal tissues) play a primary role in conferring dormancy to freshly harvested grain samples. Dehulling of dormant varieties, such as Peta, raised the percentage of germination, in 5-day post-harvest samples, from a mean of less than 1 percent to

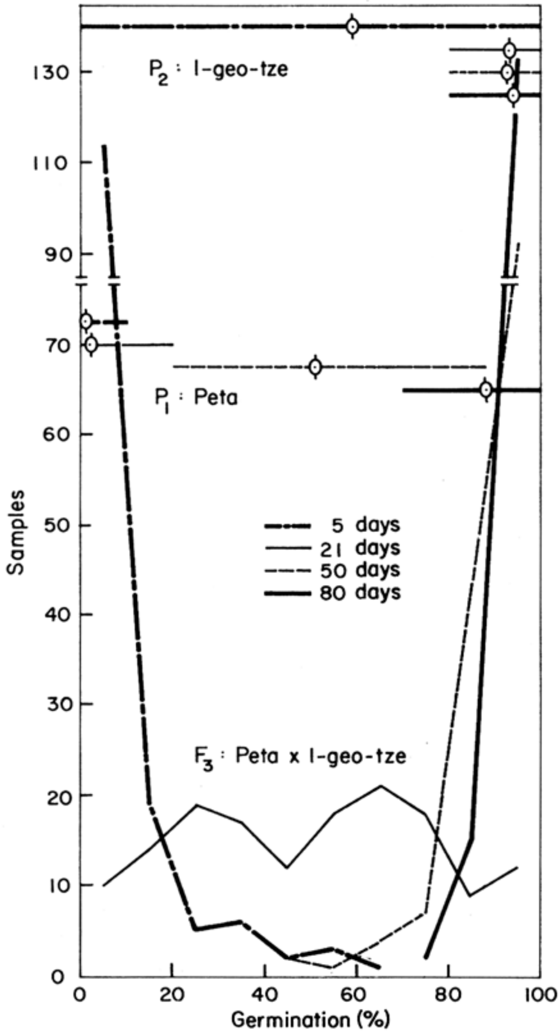


Fig. 7. Distributions and means of parents and F_3 seed samples ($=F_2$ plants) by germination percentage classes in the cross of Peta x I-geo-tze at 5, 21, 50 and 80 days after harvest. Horizontal lines show the range of parents about the means (dotted circles).

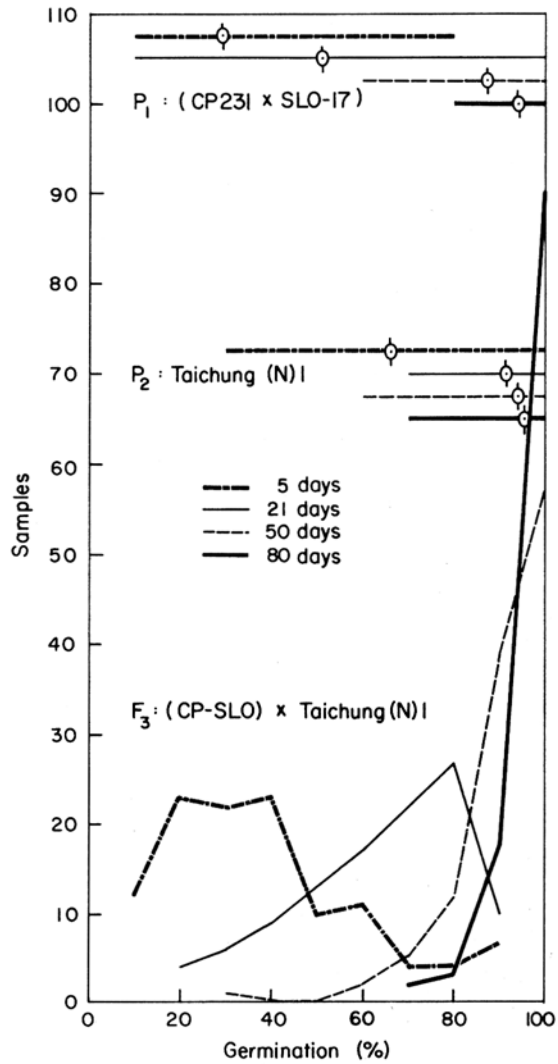


Fig. 8. Distributions and means of parents and F_3 seed samples ($=F_2$ plants) by germination percentage classes in the cross of (CP 231 x SLO-17) x Taichung (Native) 1 at 5,21, 50 and 80 days after harvest. Horizontal lines show the range of parents about the means (dotted circles).

about 65 percent. In weakly dormant varieties, 60 to 90 percent of the dehulled grains germinated. These were significantly higher than those of the hulled samples.

The readings on germinability of parents, F_3, and F_4 samples were determined from freshly harvested panicles. The grain samples were air-dried at room temperatures and germinated at four intervals: 5, 21, 50, and 80 days following harvest. Based on the dehulling tests, the F_3 and F_4 grain samples were taken to represent

F_2 and F_3 plants, respectively.

I-geo-tze is a non-dormant variety, while Peta produces dormant seed at harvest time. The distribution of dormancy in the F_3 generation of a cross between these two varieties is shown in Fig. 7. The distribution indicates a complex mode of inheritance suggestive of a multiplicative type of gene action. Five days after harvest, dormancy was dominant over low or non-dormancy. By 21 days the frequency of dormant samples became less, and by 50 days most of the F_3 samples behaved like the non-dormant parent, I-geo-tze.

In two weakly dormant x non-dormant crosses [CP 231 x SLO-17] x [Taichung (N) 1] and [(CP 231 x SLO-17) x (Dawn)], 5 days after harvest, the moderately dormant progenies constituted the majority of the F_3 samples, indicating the dominant nature of weak dormancy. Most of the F_3 grain samples gave germination readings similar to those of the common, weakly dormant parent in the crosses (CP 231 x SLO-17). However, in the 21-day tests, most of the samples behaved like the non-dormant parent, showing a rapid loss in dormancy with lapse in time (Fig. 8). In the 50- and 80-day tests, only a small number of samples showed indications of weak dormancy.

In a cross between two weakly dormant varieties, (CP 231 x SLO-17) x PI 215936, the mean germinability reading (27%) of the F_3 samples, taken 5 days after harvest, was similar to those of the parents, but the distribution was continuous and wide in range, with dormant and weakly dormant samples constituting the majority (Fig. 9). The distribution suggests a multiplicative type of gene action. In the 21-day test, the distribution became bimodal, with the two modes at the 50- and 80-percent classes of germinability. Only a few weakly dormant samples were found in the 50- and 80-day tests.

Heritability estimates of grain dormancy in 5-day and 21-day tests based on F_4/F_3 regression indicated a mean value of about 40 percent for the dormant x non-dormant cross. The mean heritability estimates were 18 percent for a cross between two weakly dormant varieties and 16 percent for a weakly dormant x non-dormant cross.

Correlation coefficients derived from the

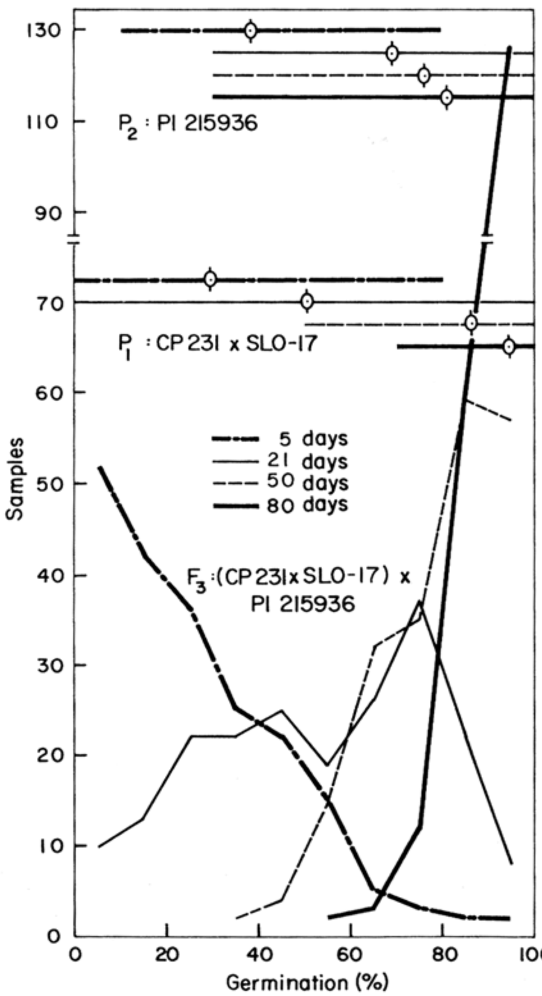


Fig. 9. Distributions and means of parents and F_3 seed samples (= F_2 plants) by germination percentage classes in the cross of PI 215936 x (CP 231 x SLO-17) at 5, 21, 50 and 80 days after harvest. Horizontal lines show the range of parents about the means (dotted circles).

number of days from seeding to harvest and the germination of F_3 grain samples in 5-day tests indicate that there was no association between the two traits in the dormant x non-dormant and weakly dormant x weakly dormant crosses. In a separate study in which different dormant parents of tropical origin were used, the F_2 grains from F_1 hybrids in 10 dormant x non-dormant crosses showed that in three crosses the mean germination counts of F_2 seeds in the 7-day tests were similar to those of the dormant parents, while in the other seven crosses the F_1 hybrids showed relatively higher germination readings than the dormant parents. The F_3 samples representing F_2 plants showed wide ranges of distribution in all crosses. The F_3 data also suggested a complex mode of inheritance. The breeding behavior of dormancy readings in the F_3 and F_4 samples varied among crosses involving different parents. However, the data indicated that it was feasible to select from F_2 populations a number of dormant plants that would breed true for this trait in the F_3. Heritability estimates based on F_4/F_3 grain samples averaged 40 percent in two dormant x non-dormant crosses. Selection in F_3 lines also showed that in dormant x non-dormant crosses where the dormant parent was photoperiod-sensitive, it is feasible to obtain dormant lines that are early maturing and non-sensitive.

The two series of experiments indicated three common features on grain dormancy: (1) a complex mode of inheritance, (2) the effect of variations in environmental factors on the expression of dormancy, (3) the relative ease in identifying moderately dormant genotypes which are early maturing and of short stature. The above postulates are supported by isolation from the breeding nurseries of a number of lines which have short-term, moderate levels of dormancy and which also have short stature, insensitivity to photoperiod, early maturity, and medium to long grains.

Atypical segregation of plant height in Basmati 370 x Taichung (Native) 1 cross

The Institute breeders had noted a deficiency of semi-dwarf F_2 plants in a few crosses involving Taichung (Native) 1 and tall, tropical varieties. Two crosses were reinvestigated in the dry season to check on the segregation of plant height. One of the crosses, Mas x Taichung (Native) 1, showed a satisfactory agreement with the 3 (tall): 1 (semi-dwarf) F_2 ratio in each of the reciprocal cross-combinations. However, the Basmati 370 x Taichung (Native) 1 F_2 populations in reciprocal crosses, each numbering over 1,000 plants, produced a unimodal distribution (Fig. 10), which differed significantly from the bimodal curves obtained from semi-dwarf x Peta crosses and others (Annual Report, 1964). The two reciprocal crosses were nearly identical in distribution.

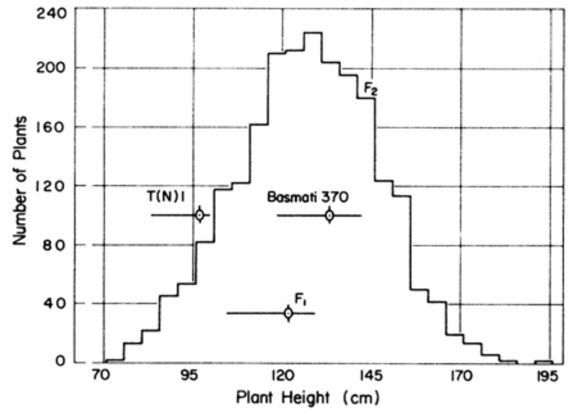


Fig. 10. Distribution and means of parents, F_1 hybrids and F_2 plants by plant height in the Basmati 370 x Taichung (Native) 1 cross. Solid horizontal lines show the range of parents and F_1 hybrids about the means (dotted circles). 1967 dry season, IRRI.

The Basmati 370 parent showed a normal degree of spikelet fertility at about 90 percent. The Taichung (Native) 1 parent had a lower level, averaging about 79 percent. The F_1 plants showed a variable range of fertility, averaging 55 percent in nine Taichung (Native) 1 x Basmati hybrids and averaging 28 percent in ten Basmati x Taichung (Native) 1 hybrids. However, the two reciprocal F_2 populations showed similar distribution in fertility readings. Both populations showed marked variations in spikelet fertility among F_2 plants. The mean fertility readings were 63 percent for Basmati x Taichung (Native) 1, and 70 percent for the reciprocal cross.

The correlation coefficients between height and spikelet fertility were .23 in the Taichung (Native) 1 x Basmati F_2 population and .44 in the reciprocal cross. Both estimates were significant at the 1-percent level.

A duplicate sample each of the F_2 populations was planted in the wet season. Again, the F_2 distributions were unimodal, showing a deficiency of F_2 plants which were similar to Taichung (Native) 1 in height (Fig. 11). Analysis of data on heading date and spikelet fertility is being conducted to provide auxiliary information on this aberrant segregation for height.

Inheritance of photoperiod-sensitivity

Hybrid populations grown in previous years (Annual Report, 1965, 1966) indicated that (a) in photoperiod-sensitive x insensitive crosses, one

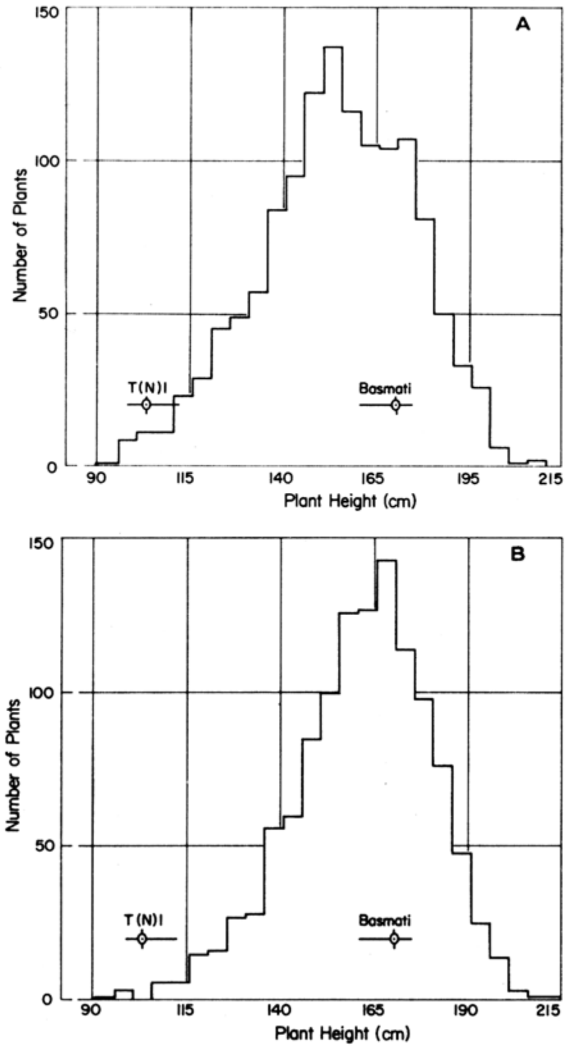


Fig. 11. Distribution and means of parents and F_2 plants by plant height in (A) Basmati 370 x Taichung (Native) 1 and (B) its reciprocal cross. Solid horizontal lines show the range of parents about the means (dotted circles). 1967 wet season, IRRI.

or two (duplicate) dominant *Se* genes controlled the photoperiod-sensitive response, and (b) in photoperiod-sensitive x sensitive crosses, the sensitive varieties differed in the optimum photoperiod (where minimum duration to flowering occurs) and in the critical photoperiod (beyond which no flowering occurs). Earlier studies on the F_2 plants of the Raminad Strain 3 x BPI-76 cross produced 3 (short): 1 (long) ratios for both the optimum and the critical photoperiods. There appeared to be a genetic association between short optimum and short critical photoperiods.

Three F_2 populations were planted on June 26 under field conditions to determine the heading behavior in crosses among three sensitive parents: Raminad Strain 3, Siam 29 and BPI-76. The three populations showed different distribution curves but indicated three common features: (a) most of the F_2 plants were intermediate in heading date between the slightly early parent, BPI-76, and the late one (Siam 29 or R. S. 3), although a number of segregates were either earlier or later than the early or late parent by a few days, (b) all of the F_2 plants could be classified as photoperiod-sensitive under natural daylength, and (c) any of the parents having a shorter optimum photoperiod flowered later in the experiment. While detailed analysis of the heading data is underway, it appears that the major Se_1 gene in the three parents belongs to a complex locus or a multiple allelic series. Siam 29 carried the duplicate set of Se_1 and Se_2 genes.

The F_2 populations of three sensitive x insensitive crosses were planted in the field during March under long daylength. A bimodal distribution was observed in the BPI-76 x Milfor-6(2)

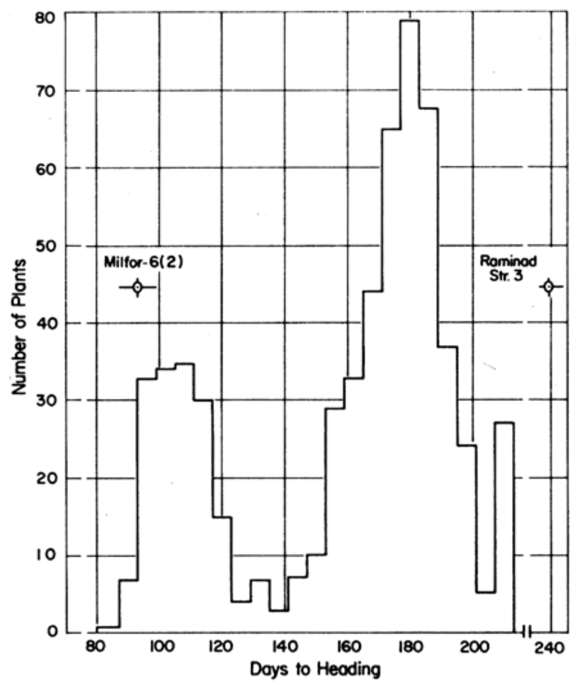


Fig. 12. Distribution and means of parents and F_2 plants of the photoperiod-sensitive x insensitive cross, Raminad Strain 3 x Milfor-6(2), by the sowing to heading period (days). Solid horizontal lines show the range of parents about the means (dotted circles). Seeded on March 27, 1967.

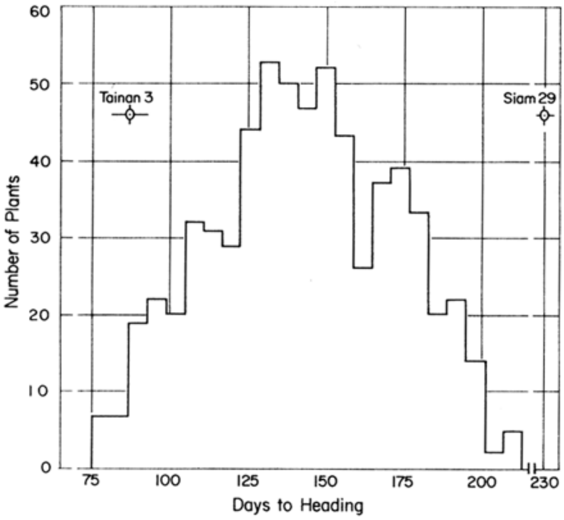


Fig. 13. Distribution and means of parents and F_2 plants of the photoperiod-sensitive x insensitive cross, Siam 29 x Tainan 3, by the sowing to heading period (days). Solid horizontal lines show the range of parents about the means (dotted circles). Seeded on March 27, 1967.

and Raminad Strain 3 x Milfor-6(2) crosses, which supported the F_2 findings obtained earlier under controlled photoperiods that a pair of *Se* alleles each in BPI-76 and R. S. 3 governed the sensitive response. However, the expression of the *Se* alleles again appeared to be incompletely dominant under natural daylength in both crosses (Fig. 12). In the Siam 29 x Tainan 3 cross, an essentially continuous distribution was obtained. The F_2 distribution was not identical with the 15 (sensitive) : 1 (insensitive) ratio which would be expected from the postulated genotype of Siam 29, Se_1 Se_1 Se_2 Se_2 (Fig. 13).

The above fiindings illustrate the less discrete segregation behavior of sensitive x insensitive hybrids grown under a changing daylength in field experiments as compared to those obtained under controlled photoperiods (Annual Report, 1965, 1966). The observations also indicate the extent of interaction between genes controlling photoperiod-sensitive response and a changing photoperiod.

Cytological Study of F_3 and F_4 Sterility in Indica x Japonica Hybrids

Previous studies (Annual Report, 1964, 1965) on the F_1 and F_2 hybrids of varying spikelet sterility showed a wide range of meiotic abnormalities which exceeded similar ones found in fertile parents both in type and frequency. However, no clear-cut correlation was found between the extent of spikelet sterility and the frequency of any of the meiotic abnormalities.

Two highly sterile crosses of Siam 29 x Kaohsiung 68 and T 1242 x PI 215936, which also showed the most diverse array of meiotic irregularities, were followed into the F_3 and F_4 generations. The spikelet fertility of the F_3 plants ranged from 18.1 to 90.7 percent; the F_4, 0.4 to 98.4 percent.

Four of the fourteen F_3 plants originating from a Siam 29 x Kaohsiung 68 F_2 plant, which showed the highest frequency (51.2%) of inversion loops, also exhibited such configurations but at a lower range of 2.5 to 4.0 percent. Anaphase I bridges with fragments were observed in only one plant at a frequency of 3.8 percent. The seed fertility of this plant was 35.3 percent.

From one F_2 plant of the T 1242 x PI 215936 cross, showing the highest frequency (5.3%) of translocation configuration at pachynema, three of the fourteen F_3 plants exhibited a chain-of-four configuration (2%) at metaphase I. The fertility of these plants was around 70 percent. From another F_2 family, which showed a high frequency of laggards but no configuration indicative of translocation, two cells exhibiting the cross configuration at pachynema were observed in one F_3 plant. Spikelet fertility of this plant was 39.9 percent.

Aside from translocation configurations and inversion loops, other meiotic abnormalities that were observed in the F_2 plants as well as their F_3's were: "loose pairing" (2 to 26%), unequal bivalents (3.7 to 7.5%) and duplication-deficiency loops (2 to 4%) at pachynema; cells with 2 to 6 univalents (2 to 12%), one quadrivalent (2 to 4%), and 11 or 13 bivalents (2 to 4%) at diakinesis. One cell each at diakinesis and metaphase I had 24 univalents.

Observations on the F_4 plants showed similar results as the F_3's. Translocations in the form of chains-of-four and a trivalent plus a univalent were observed at a frequency of 2 to 4 percent. Cells with extra chromosomes (2-12%), four to six univalents (2-6%), and bridges with and without fragments (2-8%) were also observed, in addition to the usual two univalents and quadrivalents observed in the earlier generations.

Several other abnormalities not observed in the F_2 and F_3 populations were detected in the F_4's. These were elongated bivalents (4%), characteristic of chromosomes with reduced chiasma frequency, and multiple bridges with fragments (4%) in 3 of the 52 plants observed. The bridges seem to be largely due to stickiness of the chromosomes rather than to inversions.

As in the F_1 and F_2 observations, there appears to be no direct association between the frequency of chromosomal aberrations and of spikelet sterility. The above observations, therefore, agree with the earlier postulate that the chromosomal aberrations at meiosis could only partly explain the spikelet sterility found in hybrid progenies of indica x japonica crosses. The cytological observations in F_1, F_2, F_3 and F_4 plants suggest that a mechanism of genic imbalance also operates in the hybrids.

Sterility in hybrids of indica x indica crosses

While spikelet sterility in the progenies of indica x japonica hybrids has been much emphasized by rice breeders and cytogeneticists, the sterility in the progenies of some indica x indica crosses has not been fully investigated. Hybrids of varying degrees of sterility have been observed in the F_1 hybrids of 37 crosses grown during the wet crosses in the Institute's breeding nurseries. In many cases, the sterile hybrids involve a tropical indica variety and a semi-dwarf from Taiwan or IR8.

A number of crosses were made among the newer semi-dwarf varieties, the tall indica varieties of tropical origin, and the bulu varieties from Indonesia, in order to determine the cytogenetic basis of sterility in such crosses and to compare the cytogenetic findings with those observed in indica x japonica hybrids (Annual Report, 1964, 1965, 1966). The spikelet sterility found in the F_1 hybrids of 37 crosses grown during the wet season ranged from 20 to 90 percent, with the modal class at about 40 percent. The most sterile cross was IR8 x Pankhari 203, with a sterility count of 92 percent.

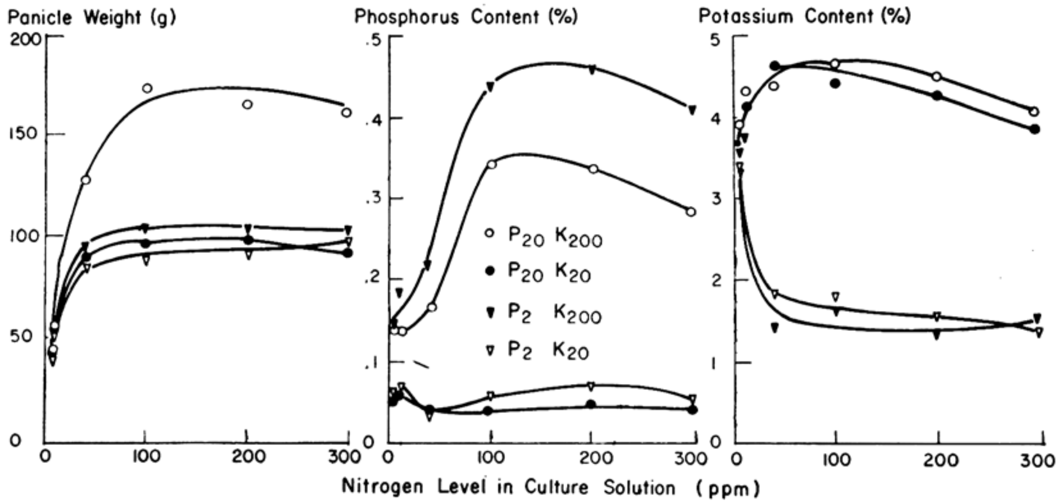


Fig. 29. Panicle weight and percentage of phosphorus and potassium at different levels of nitrogen with different levels of phosphorus and potassium.

cal level the rice plant suffers from iron toxicity. Not much information is available about the actual magnitude of this critical level, however, and the existing data are frequently contradictory. Data also are lacking concerning the critical level of iron within the plant and of the various factors which affect the development of iron deficiency symptoms. Several experiments relating to this problem were undertaken in 1964.

During the panicle initiation stage, leaf blades of the variety Peta were detached and placed in test tubes containing solutions of varying concentrations of ferrous iron (as $FeSO_4$) at pH 3.2. The lower cut ends of the blades were dipped in these solutions for periods of 24 hours. With 0 and 2 ppm Fe, the detached leaves remained normal, while at 50 ppm tiny brown spots appeared and the leaves became discolored. Similar tiny brown spots developed on leaves in the 100 and 500 ppm solutions, but these were joined together to form larger dark brown spots, and the leaves developed an overall light brown color. With ferric iron (as $Fe_2(SO_4)_3$) treatments, the same symptoms developed.

To test the effect of iron in the nutrient solution on the percentage of iron in various tissues, intact plants were placed for 4 days in solutions with various concentrations of iron. The pH of the solution was kept at 3.7, nitrogen was supplied as NH_4^+ and iron as Fe^{++}. Nitrogen gas was passed through the solutions to exclude oxygen.

Plants grown at 2, 10, and 50 ppm Fe were normal, while those at 100 ppm were weak and displayed on older leaves the tiny brown spots which are characteristic as excess of iron. At 500 ppm there were brown spots all over the leaves. The roots of plants in solutions of 50 ppm of Fe or higher were reddish brown.

The iron content (Table 15) was highest in the roots, followed by the culm and the older leaves. The lowest

Table 15. Iron content of various organs of the rice plant as affected by the iron level in culture solution.

Fe level in culture solution (ppm)	Fe content (ppm)			
	Young leaves	Old leaves	Culm	Roots
2	85	105	162	840
10	133	154	672	1260
50	178	175	1372	5780
100	196	336	2224	9800
500	476	1152	3584	22920

Plant Pathology

In 1967 (*1*) *rice varieties and hybrid lines were tested in a continuing search for resistance to blast, bacterial leaf blight, and tungro virus;* (*2*) *a proposal was made to standardize the international race numbers of* Pyricularia oryzae*;* (*3*) *the variability of pathogenicity of* P. oryzae *from single lesions and from monoconidal subcultures was demonstrated;* (*4*) *the change of pathogenic races in the blast nursery was studied;* (*5*) *additional new hosts of* Xanthomonas oryzae *were revealed;* (*6*)*a technique for testing varietal resistance to bacterial leaf streak was developed;* (*7*) *the effect of diseases on rice yield was determined;* (*8*) *the mechanism of resistance to diseases was investigated;* (*9*) *the interaction between plant, vector and virus was examined; and* (*10*) *the rice tungro disease was identified in Indonesia. These developments have yielded knowledge essential for achieving rice disease control through varietal resistance.*

Rice Blast

International Uniform Blast Nurseries

Two sets of varieties were tested in uniform blast nurseries. One was the original set of 258 varieties which for convenience has been called the "IBN (International Blast Nursery) set". The other was the "BRWCV (Blast Resistant World Collection Varieties) set" consisting of 321 varieties selected from the world collection of 8,231 varieties which are being tested repeatedly at the Institute blast nursery for their reaction to blast.

A total of 53 and 50 "IBN sets" were sent to 18 countries for tests in 1966 and 1967, respectively. On the other hand, 14 and 48 "BRWCV sets" were sent to 7 and 19 countries for tests in 1966 and 1967, respectively. For the "IBN set", a total of 34 and 25 sets of data were received from 13 countries (Colombia, Guinea, Guyana, India, Indonesia, Iran, Korea, Malaysia, Nepal, East Pakistan, Philippines, Taiwan and Thailand) and 8 countries (Ceylon, Guyana, Korea, Malaysia, Panama, Philippines, Taiwan, and Thailand) in 1966 and 1967, respectively. For the "BRWCV set", 14 sets of data were received from Korea, East Pakistan, Philippines, Taiwan, and Thailand in 1966, and 18 sets of data from Ceylon, Korea, Malaysia, Philippines and Thailand in 1967.

The data on the "IBN set" indicated that Te-tep, Tadukan and PI 231129 did not show susceptible reaction in 1966, and Te-tep, C 46-15, Trang Cut. L. 11, and R 67 did not show susceptible reaction in all tests in 1967. However, based on susceptibility index that equals to $(1N_R + 3N_M + 5N_S)/(N_R + N_M + N_S)$, where N_R, N_M, and N_S are numbers of resistant, intermediate, and susceptible reactions of a variety in all test stations, the most resistant varieties for 1966 and 1967 are listed in Table 1.

Based on the combined results of 1966 and 1967, the susceptibility index of 19 varieties of the "BRWCV set" did not exceed 1.200. These varieties are listed in Table 2. Several varieties included in this set appear to be potential sources of resistance to blast.

Table 1. The most resistant 25 varieties of the "IBN set" in the 1966 and 1967 International Uniform Blast Nurseries.

Variety	Susceptibility index			Total no. susceptible cases/no. of tests
	1966	1967	1966-1967	
Te-tep	1.182	1.000	1.091	0/58
Tadukan	1.323	1.480	1.402	2/56
C 46-15	1.706	1.160	1.433	3/59
Nang chet cuc	1.583	1.417	1.500	2/48
CI 7787	1.545	1.480	1.513	2/58
Trang Cut. L. 11	2.083	1.160	1.622	4/49
D 25-4	1.706	1.560	1.633	6/59
Pah Leuad 111	1.323	1.957	1.640	5/54
Pah Leuad 29-8-11	1.667	1.640	1.654	4/58
PI 231129	1.417	2.000	1.709	2/36
K.P.F. 6	1.824	1.640	1.732	3/59
H-4	1.848	1.640	1.744	8/58
Kataktara DA 2	1.765	1.750	1.758	3/58
M-302	1.882	1.640	1.761	5/59
Lo Shu Ngar	1.667	1.880	1.774	5/58
Lembu Basah	1.750	1.800	1.775	3/49
H-5	2.000	1.583	1.792	6/56
R 67	1.880	1.720	1.800	2/50
E-425	1.560	2.040	1.800	3/50
Padang Trengganu 22	1.467	2.200	1.834	5/55
Zenith	1.824	1.917	1.871	8/58
Mo-R-500 x Nato	1.647	2.095	1.871	9/55
PI 231128	1.720	2.040	1.880	6/50
Dawn	2.059	1.720	1.890	8/59
E1	2.000	1.800	1.900	5/59

Standardization of international race numbers
Eight rice varieties—Raminad Str. 3, Zenith, NP 125, Usen, Dular, Kanto 51, Sha-tiao-tsao (S), and Caloro—have been selected as an international set for differentiating the races of *Pyricularia** *oryzae*.† The letter "I" was used for international races, followed by the group-letter, A, B, C, D, E, F, G, or H, according to the susceptibility of the key varieties. The arabic numeral following the group-letter indicated the race number. Based on 32 different pathogenic patterns of the tested isolates, 3, 6, 5, 11, 2, 2, 2, and 1 were designated as races for IA, IB, IC, ID, IE, IF, IG, and IH, respectively.

The selected international set of rice varieties has been accepted and used since 1965 for differentiating the races of *P. oryzae* not only by the Institute but also by workers in other countries. A total of 49 different pathogenic patterns had been found from the tests of Philippine isolates and 24 of them belong to the IA group. In India, workers on blast races found 11 races in the IA group alone. Since only IA-1, IA-2, and IA-3 were designated by Atkins et al. in the IA group, the additional race numbers have been given by different groups of race workers. Thus one race may have different race numbers in different countries. The numbering of races will become more confusing when more groups of workers assign different race numbers to the same race. Consequently, there is urgent need to standardize international race numbers.

Based on eight international differential varieties, at most, only 256 races can be differentiated. The races can be standardized by pre-designating their numbers. The international race numbers therefore are IA-1 to IA-128, IB-1 to IB-64, IC-1 to IC-32, ID-1 to ID-16, IE-1 to IE-8, IF-1 to IF-4, IG-1 to IG-2, IH-1, and II-1, and the respective reactions of differential varieties are shown in Table 3.

Since the reaction of a variety to a race may be neither susceptible nor resistant but intermediate, small letters, a, b, c, d, e, f, g, and h, after the race numbers are suggested for use in distinguishing races with intermediate reaction if necessary. Each letter refers to the intermediate instead of resistant reaction of a particular variety. For example, IA-120d and IA-120ch are similar to IA-120 but differ in the intermediate reactions on Usen and NP 125 and Caloro, respectively.

Pyricularia **races at the Institute blast nursery**
A study initiated in August 1966 to investigate the seasonal shift of races and their populations in the Institute blast nursery was continued. Blast disease specimens were collected monthly and single-spore isolates were made. The monosporial cultures were inoculated to both the international and the Philippine differential varieties.

Preliminary results showed that several races occurred each month, and that these races differed between months. In almost all instances, at least one race did not occur in the previous month. Some races occurred in many months within the period of the study, while others occurred only once or periodically.

The total number of races during the year was 24 for the international and 42 for the Philip-

Table 2. The 19 most resistant varieties of the "BRWCV set" in the 1966 and 1967 Uniform Blast Nurseries.

Variety	IRRI Acc. no.	Susceptibility index combined 1966 and 1967	No. of susceptible cases/no. of tests
Ram Tulasi	181	1.065	0/31
DNJ-131	8435	1.071	0/28
DZ-193	8517	1.071	0/28
CI 2011-1	3311	1.125	0/32
CI 27-3	3464	1.129	0/31
Ca 902/b/2/1	6349	1.129	1/31
DNJ-129	8436	1.143	0/28
DNJ-142	8426	1.143	1/28
JC 46	9106	1.148	0/27
DV-12	8811	1.154	0/26
Ctg. 680	8683	1.154	1/26
Thavalakkanan Ptb 9	6274	1.194	0/31
Pi 5	6732	1.194	0/31
268b/Pr/8/1/1	7623	1.194	0/31
Dissi Hatif (DH2)	7802	1.194	0/31
Ca 902/b/3/3	6347	1.194	1/31
Ca 902/b/2/2	6382	1.194	1/31
N. 32	3717	1.200	0/30
Carreon	5993	1.200	0/30

*The spelling of *Pyricularia* instead of *Piricularia* was adopted in accordance with the international code for botanical nomenclature.

†Atkins, et. al. An international set of rice varieties for differentiating races of *Piricularia oryzae*. *Phytopathology* 57:297-310, 1967.

Table 3. Proposed international race numbers for *Pyricularia oryzae* races.

Race group and no.	Reaction of differential variety							
	Raminad Str. 3	Zenith	NP 125	Usen	Dular	Kanto 51	Sha-tiao-tsao (S)	Caloro
IA-1	S	S	S	S	S	S	S	S
IA-2	S	S	S	S	S	S	S	R
IA-3	S	S	S	S	S	S	R	S
IA-4	S	S	S	S	S	S	R	R
IA-5	S	S	S	S	S	R	S	S
IA-6	S	S	S	S	S	R	S	R
IA-7	S	S	S	S	S	R	R	S
IA-8	S	S	S	S	S	R	R	R
IA-9	S	S	S	S	R	S	S	S
IA-10	S	S	S	S	R	S	S	R
IA-11	S	S	S	S	R	S	R	S
IA-12	S	S	S	S	R	S	R	R
IA-13	S	S	S	S	R	R	S	S
IA-14	S	S	S	S	R	R	S	R
IA-15	S	S	S	S	R	R	R	S
IA-16	S	S	S	S	R	R	R	R
IA-17	S	S	S	R	S	S	S	S
IA-18	S	S	S	R	S	S	S	R
IA-19	S	S	S	R	S	S	R	S
IA-20	S	S	S	R	S	S	R	R
IA-21	S	S	S	R	S	R	S	S
IA-22	S	S	S	R	S	R	S	R
IA-23	S	S	S	R	S	R	R	S
IA-24	S	S	S	R	S	R	R	R
IA-25	S	S	S	R	R	S	S	S
IA-26	S	S	S	R	R	S	S	R
IA-27	S	S	S	R	R	S	R	S
IA-28	S	S	S	R	R	S	R	R
IA-29	S	S	S	R	R	R	S	S
IA-30	S	S	S	R	R	R	S	R
IA-31	S	S	S	R	R	R	R	S
IA-32	S	S	S	R	R	R	R	R
IA-33	S	S	R	S	S	S	S	S
IA-34	S	S	R	S	S	S	S	R
IA-35	S	S	R	S	S	S	R	S
IA-36	S	S	R	S	S	S	R	R
IA-37	S	S	R	S	S	R	S	S
IA-38	S	S	R	S	S	R	S	R
IA-39	S	S	R	S	S	R	R	S
IA-40	S	S	R	S	S	R	R	R
IA-41	S	S	R	S	R	S	S	S
IA-42	S	S	R	S	R	S	S	R
IA-43	S	S	R	S	R	S	R	S
IA-44	S	S	R	S	R	S	R	R
IA-45	S	S	R	S	R	R	S	S
IA-46	S	S	R	S	R	R	S	R
IA-47	S	S	R	S	R	R	R	S
IA-48	S	S	R	S	R	R	R	R
IA-49	S	S	R	R	S	S	S	S
IA-50	S	S	R	R	S	S	S	R
IA-51	S	S	R	R	S	S	R	S
IA-52	S	S	R	R	S	S	R	R
IA-53	S	S	R	R	S	R	S	S
IA-54	S	S	R	R	S	R	S	R
IA-55	S	S	R	R	S	R	R	S
IA-56	S	S	R	R	S	R	R	R
IA-57	S	S	R	R	R	S	S	S
IA-58	S	S	R	R	R	S	S	R
IA-59	S	S	R	R	R	S	R	S
IA-60	S	S	R	R	R	S	R	R
IA-61	S	S	R	R	R	R	S	S
IA-62	S	S	R	R	R	R	S	R
IA-63	S	S	R	R	R	R	R	S
IA-64	S	S	R	R	R	R	R	R
IA-65	S	R	S	S	S	S	S	S
IA-66	S	R	S	S	S	S	S	R
IA-67	S	R	S	S	S	S	R	S
IA-68	S	R	S	S	S	S	R	R
IA-69	S	R	S	S	S	R	S	S
IA-70	S	R	S	S	S	R	S	R
IA-71	S	R	S	S	S	R	R	S
IA-72	S	R	S	S	S	R	R	R
IA-73	S	R	S	S	R	S	S	S
IA-74	S	R	S	S	R	S	S	R
IA-75	S	R	S	S	R	S	R	S
IA-76	S	R	S	S	R	S	R	R
IA-77	S	R	S	S	R	R	S	S
IA-78	S	R	S	S	R	R	S	R
IA-79	S	R	S	S	R	R	R	S
IA-80	S	R	S	S	R	R	R	R
IA-81	S	R	S	R	S	S	S	S
IA-82	S	R	S	R	S	S	S	R
IA-83	S	R	S	R	S	S	R	S
IA-84	S	R	S	R	S	S	R	R
IA-85	S	R	S	R	S	R	S	S
IA-86	S	R	S	R	S	R	S	R
IA-87	S	R	S	R	S	R	R	S
IA-88	S	R	S	R	S	R	R	R
IA-89	S	R	S	R	R	S	S	S
IA-90	S	R	S	R	R	S	S	R
IA-91	S	R	S	R	R	S	R	S
IA-92	S	R	S	R	R	S	R	R
IA-93	S	R	S	R	R	R	S	S
IA-94	S	R	S	R	R	R	S	R
IA-95	S	R	S	R	R	R	R	S
IA-96	S	R	S	R	R	R	R	R
IA-97	S	R	R	S	S	S	S	S
IA-98	S	R	R	S	S	S	S	R
IA-99	S	R	R	S	S	S	R	S
IA-100	S	R	R	S	S	S	R	R
IA-101	S	R	R	S	S	R	S	S
IA-102	S	R	R	S	S	R	S	R
IA-103	S	R	R	S	S	R	R	S
IA-104	S	R	R	S	S	R	R	R
IA-105	S	R	R	S	R	S	S	S
IA-106	S	R	R	S	R	S	S	R
IA-107	S	R	R	S	R	S	R	S
IA-108	S	R	R	S	R	S	R	R

Table 3. continuation.

Race group and no.	Raminad Str. 3	Zenith	NP 125	Usen	Dular	Kanto 51	Sha-tiao-tsao (S)	Caloro
	Reaction of differential variety							
IA-109	S	R	R	S	R	R	S	S
IA-110	S	R	R	S	R	R	S	R
IA-111	S	R	R	S	R	R	R	S
IA-112	S	R	R	S	R	R	R	R
IA-113	S	R	R	R	S	S	S	S
IA-114	S	R	R	R	S	S	S	R
IA-115	S	R	R	R	S	S	R	S
IA-116	S	R	R	R	S	S	R	R
IA-117	S	R	R	R	S	R	S	S
IA-118	S	R	R	R	S	R	S	R
IA-119	S	R	R	R	S	R	R	S
IA-120	S	R	R	R	S	R	R	R
IA-121	S	R	R	R	R	S	S	S
IA-122	S	R	R	R	R	S	S	R
IA-123	S	R	R	R	R	S	R	S
IA-124	S	R	R	R	R	S	R	R
IA-125	S	R	R	R	R	R	S	S
IA-126	S	R	R	R	R	R	S	R
IA-127	S	R	R	R	R	R	R	S
IA-128	S	R	R	R	R	R	R	R
IB-1	R	S	S	S	S	S	S	S
IB-2	R	S	S	S	S	S	S	R
IB-3	R	S	S	S	S	S	R	S
IB-4	R	S	S	S	S	S	R	R
IB-5	R	S	S	S	S	R	S	S
IB-6	R	S	S	S	S	R	S	R
IB-7	R	S	S	S	S	R	R	S
IB-8	R	S	S	S	S	R	R	R
IB-9	R	S	S	S	R	S	S	S
IB-10	R	S	S	S	R	S	S	R
IB-11	R	S	S	S	R	S	R	S
IB-12	R	S	S	S	R	S	R	R
IB-13	R	S	S	S	R	R	S	S
IB-14	R	S	S	S	R	R	S	R
IB-15	R	S	S	S	R	R	R	S
IB-16	R	S	S	S	R	R	R	R
IB-17	R	S	S	R	S	S	S	S
IB-18	R	S	S	R	S	S	S	R
IB-19	R	S	S	R	S	S	R	S
IB-20	R	S	S	R	S	S	R	R
IB-21	R	S	S	R	S	R	S	S
IB-22	R	S	S	R	S	R	S	R
IB-23	R	S	S	R	S	R	R	S
IB-24	R	S	S	R	S	R	R	R
IB-25	R	S	S	R	R	S	S	S
IB-26	R	S	S	R	R	S	S	R
IB-27	R	S	S	R	R	S	R	S
IB-28	R	S	S	R	R	S	R	R
IB-29	R	S	S	R	R	R	S	S
IB-30	R	S	S	R	R	R	S	R
IB-31	R	S	S	R	R	R	R	S
IB-32	R	S	S	R	R	R	R	R
IB-33	R	S	R	S	S	S	S	S

Race group and no.	Raminad Str. 3	Zenith	NP 125	Usen	Dular	Kanto 51	Sha-tiao-tsao (S)	Caloro
	Reaction of differential variety							
IB-34	R	S	R	S	S	S	S	R
IB-35	R	S	R	S	S	S	R	S
IB-36	R	S	R	S	S	S	R	R
IB-37	R	S	R	S	S	R	S	S
IB-38	R	S	R	S	S	R	S	R
IB-39	R	S	R	S	S	R	R	S
IB-40	R	S	R	S	S	R	R	R
IB-41	R	S	R	S	R	S	S	S
IB-42	R	S	R	S	R	S	S	R
IB-43	R	S	R	S	R	S	R	S
IB-44	R	S	R	S	R	S	R	R
IB-45	R	S	R	S	R	R	S	S
IB-46	R	S	R	S	R	R	S	R
IB-47	R	S	R	S	R	R	R	S
IB-48	R	S	R	S	R	R	R	R
IB-49	R	S	R	R	S	S	S	S
IB-50	R	S	R	R	S	S	S	R
IB-51	R	S	R	R	S	S	R	S
IB-52	R	S	R	R	S	S	R	R
IB-53	R	S	R	R	S	R	S	S
IB-54	R	S	R	R	S	R	S	R
IB-55	R	S	R	R	S	R	R	S
IB-56	R	S	R	R	S	R	R	R
IB-57	R	S	R	R	R	S	S	S
IB-58	R	S	R	R	R	S	S	R
IB-59	R	S	R	R	R	S	R	S
IB-60	R	S	R	R	R	S	R	R
IB-61	R	S	R	R	R	R	S	S
IB-62	R	S	R	R	R	R	S	R
IB-63	R	S	R	R	R	R	R	S
IB-64	R	S	R	R	R	R	R	R
IC-1	R	R	S	S	S	S	S	S
IC-2	R	R	S	S	S	S	S	R
IC-3	R	R	S	S	S	S	R	S
IC-4	R	R	S	S	S	S	R	R
IC-5	R	R	S	S	S	R	S	S
IC-6	R	R	S	S	S	R	S	R
IC-7	R	R	S	S	S	R	R	S
IC-8	R	R	S	S	S	R	R	R
IC-9	R	R	S	S	R	S	S	S
IC-10	R	R	S	S	R	S	S	R
IC-11	R	R	S	S	R	S	R	S
IC-12	R	R	S	S	R	S	R	R
IC-13	R	R	S	S	R	R	S	S
IC-14	R	R	S	S	R	R	S	R
IC-15	R	R	S	S	R	R	R	S
IC-16	R	R	S	S	R	R	R	R
IC-17	R	R	S	R	S	S	S	S
IC-18	R	R	S	R	S	S	S	R
IC-19	R	R	S	R	S	S	R	S
IC-20	R	R	S	R	S	S	R	R
IC-21	R	R	S	R	S	R	S	S
IC-22	R	R	S	R	S	R	S	R

Table 3. continuation.

Race group and no.	Reaction of differential variety							
	Raminad Str. 3	Zenith	NP 125	Usen	Dular	Kanto 51	Sha-tiao-tsao (S	Caloro
IC-23	R	R	S	R	S	R	R	S
IC-24	R	R	S	R	S	R	R	R
IC-25	R	R	S	R	R	S	S	S
IC-26	R	R	S	R	R	S	S	R
IC-27	R	R	S	R	R	S	R	S
IC-28	R	R	S	R	R	S	R	R
IC-29	R	R	S	R	R	R	S	S
IC-30	R	R	S	R	R	R	S	R
IC-31	R	R	S	R	R	R	R	S
IC-32	R	R	S	R	R	R	R	R
ID-1	R	R	R	S	S	S	S	S
ID-2	R	R	R	S	S	S	S	R
ID-3	R	R	R	S	S	S	R	S
ID-4	R	R	R	S	S	S	R	R
ID-5	R	R	R	S	S	R	S	S
ID-6	R	R	R	S	S	R	S	R
ID-7	R	R	R	S	S	R	R	S
ID-8	R	R	R	S	S	R	R	R
ID-9	R	R	R	S	R	S	S	S
ID-10	R	R	R	S	R	S	S	R
ID-11	R	R	R	S	R	S	R	S
ID-12	R	R	R	S	R	S	R	R
ID-13	R	R	R	S	R	R	S	S
ID-14	R	R	R	S	R	R	S	R
ID-15	R	R	R	S	R	R	R	S
ID-16	R	R	R	S	R	R	R	R
IE-1	R	R	R	R	S	S	S	S
IE-2	R	R	R	R	S	S	S	R
IE-3	R	R	R	R	S	S	R	S
IE-4	R	R	R	R	S	S	R	R
IE-5	R	R	R	R	S	R	S	S
IE-6	R	R	R	R	S	R	S	R
IE-7	R	R	R	R	S	R	R	S
IE-8	R	R	R	R	S	R	R	R
IF-1	R	R	R	R	R	S	S	S
IF-2	R	R	R	R	R	S	S	R
IF-3	R	R	R	R	R	S	R	S
IF-4	R	R	R	R	R	S	R	R
IG-1	R	R	R	R	R	R	S	S
IG-2	R	R	R	R	R	R	S	R
IH-1	R	R	R	R	R	R	R	S
II-1	R	R	R	R	R	R	R	R

pine differential varieties. Most of the isolates belonged to IA-109 and P8.

New pathogenic races of *P. oryzae* in the Philippines

Studies on the identification of races were continued. Of the 247 isolates previously tested, 47 and 28 races were identified by the Philippine and the international differential varieties, respectively. In 1967, 521 isolates, mostly collected from the Institute blast nursery, were tested. They were classified into 66 races based on Philippine differentials. Of these, 41 are new. According to the suggested international set of differentials, these races belong to 37 international race groups, of which 16 were found previously. Consequently, based on the Philippine differentials, 88 races have been identified (Table 4). Based on the international differentials a total of 49 races has been determined (Table 5). Twenty-four, 6, 5, 8, 2, 2, and 1 races belong to IA, IB, IC, ID, IE, IG and IH groups, respectively. However, another race which induced resistant reactions in all international differential varieties was added.

Most of the isolates tested belonged to race P8, followed by P16 and P12. On international varieties, most of the isolates are classified under IA-109 with IA-110 and IA-45 ranking second and third, respectively.

Physiologic races of *P. oryzae* originating from single lesions

A typical leaf lesion of blast disease produces 4,000 to 5,000 conidia each night for 2 weeks under laboratory conditions. Studies were made to determine whether or not these conidia differ in pathogenicity. Four lesions of a susceptible variety, Tjeremas, from the blast nursery were collected about a month apart. They were surface-sterilized and washed thoroughly with sterile distilled water. Each lesion was kept in a moist petri dish. Fifty-six, 44, 50 and 39 single conidia from each lesion were isolated after a new crop of conidia was produced in the petri dishes. The monosporial cultures were inoculated separately on both the Philippine and international differential varieties. The results (Table 6) showed that 14 races were differentiated from the 56 monoconidial cultures of lesion no. 1, 8 from the 44 monoconidial cultures of lesion no. 2, 10 from the 50 monoconidial cultures of lesion no. 3, and only 2 from the 39 monoconidial cultures of lesion no. 4. Based on the international differential varieties, the numbers of races were 10, 8, 8, and 1 for lesion nos. 1, 2, 3, and 4, respectively (Table 6). The results show

Table 4. Physiologic races of *Pyricularia oryzae* based upon Philippine differential varieties.

Race no.	Kataktara DA 2	CI 5309	Chokoto	CO 25	Wagwag	Paikantao	Peta	Raminad Str. 3	Taichung T.C.W.C.	Lacrosse	Sha-tiao-tsao (S)	Khao-tah-haeng 17	Total no. of isolates	
													1962-1966	1967
P1	R	S	R	R	R	R	R	R	R	R	S	S	2	0
P2	R	M	S	R	R	M	R	R	S	S	S	S	1	0
P3	R	R	S	S	R	S	R	R	S	S	S	S	1	0
P4	R	R	R	S	R	R	S	R	S	S	R	S	2	0
P5	R	R	R	S	R	S	R	S	S	S	S	S	2	0
P6	R	R	R	S	R	S	S	S	S	S	S	S	1	2
P7	R	R	R	S	R	S	S	R	S	S	S	S	4	0
P8	R	R	R	R	S	R	S	S	S	S	S	S	13	173
P9	R	R	R	R	S	R	R	S	S	S	S	S	28	5
P10	R	R	R	R	S	S	R	R	S	S	S	S	4	0
P11	R	R	R	R	S	S	R	S	S	S	S	S	19	1
P12	R	R	R	M	S	S	S	S	S	S	S	S	3	45
P13	R	R	R	R	R	S	R	R	S	S	S	S	8	0
P14	R	R	R	R	R	S	R	S	S	S	S	S	7	0
P15	R	R	R	R	R	R	S	R	R	R	S	S	9	5
P16	R	R	R	R	R	R	S	S	R	R	S	S	3	65
P17	R	R	R	R	R	R	S	S	S	S	S	S	7	8
P18	R	R	R	R	R	R	S	R	R	S	S	S	8	5
P19	R	R	R	R	R	R	S	R	S	S	S	S	6	14
P20	R	R	R	R	R	R	R	S	R	R	S	S	10	4
P21	R	R	R	R	R	R	R	S	S	S	S	S	16	1
P22	R	R	R	R	R	R	R	S	R	S	S	S	7	1
P23	R	R	R	R	R	R	R	R	S	S	S	S	16	1
P24	R	R	R	R	R	R	R	R	R	S	R	S	2	1
P25	R	R	R	R	R	R	R	R	R	R	S	S	24	0
P26	R	R	R	R	R	R	R	R	R	R	R	S	5	5
P27	R	S	S	S	R	S	S	R	S	S	S	S	2	0
P28	R	R	R	S	R	R	S	S	S	S	S	S	2	2
P29	R	R	R	R	S	R	R	S	R	R	S	S	7	1
P30	R	R	R	R	R	R	S	S	R	S	S	S	7	29
P31	R	R	R	R	R	R	R	R	R	S	S	S	2	0
P32	R	R	R	R	S	R	R	S	R	S	S	S	3	1
P33	R	S	S	R	S	R	R	S	S	S	S	S	1	0
P34	M	S	S	S	R	S	S	R	S	S	S	S	1	0
P35	R	R	R	R	R	R	S	R	S	R	S	S	1	0
P36	R	R	R	R	S	R	S	R	S	S	S	S	1	7
P37	S	S	S	R	S	S	R	M	S	S	S	S	1	2
P38	R	R	R	R	R	R	S	R	R	R	R	S	1	3
P39	R	R	R	R	S	R	R	R	R	R	R	S	1	0
P40	R	R	R	R	R	S	R	R	R	S	S	S	1	0
P41	R	R	R	S	R	R	R	R	R	R	S	S	2	0
P42	R	R	R	R	R	S	R	R	R	R	S	S	1	0
P43	R	R	R	R	S	R	R	R	R	R	S	S	1	0
P44	R	R	R	R	S	R	R	R	R	S	S	S	1	0
P45	R	R	R	R	R	S	S	R	R	R	S	S	1	0
P46	R	R	R	R	R	R	R	S	S	R	S	S	1	1
P47	R	R	R	R	R	R	S	S	S	S	R	S	1	3
P48	R	R	R	R	R	R	R	R	S	R	S	S		1
P49	R	R	R	R	S	S	R	S	S	R	S	S		1
P50	R	R	R	S	S	S	S	S	S	S	S	S		1
P51	R	R	R	R	R	R	S	R	S	R	R	S		1
P52	R	R	R	S	S	R	S	S	S	S	S	S		6
P53	R	R	R	R	R	S	S	R	S	S	S	S		2
P54	R	R	R	S	R	R	S	S	S	R	S	S		1
P55	R	R	R	S	R	R	S	S	R	S	S	S		5
P56	R	R	R	S	R	R	S	S	R	R	S	S		6

Table 4. continuation.

Race no.	Kataktara DA 2	CI 5309	Chokoto	CO 25	Wagwag	Paikantao	Peta	Raminad Str. 3	Taichung T.C.W.C.	Lacrosse	Sha-tiao-tsao (S)	Khao-tah-haeng 17	Total no. of isolates	
													1962-1966	1967
P57	R	R	R	R	R	R	S	S	R	R	R	S		21
P58	R	R	R	R	R	R	R	S	R	R	R	S		4
P59	R	R	R	R	S	S	R	S	S	R	R	S		1
P60	R	R	R	S	R	R	S	R	R	R	R	S		1
P61	R	R	R	R	R	R	R	S	R	S	R	S		1
P62	R	R	R	R	S	R	S	S	R	S	S	S		8
P63	R	R	S	S	R	R	S	R	R	R	R	S		1
P64	R	R	R	R	S	R	S	R	S	R	S	S		2
P65	R	R	S	R	R	R	S	R	S	S	S	S		1
P66	R	R	R	S	S	R	S	R	S	S	S	S		2
P67	R	R	S	S	S	R	S	S	S	S	S	S		2
P68	R	R	S	R	S	R	S	S	S	S	S	S		1
P69	R	R	R	S	R	R	S	S	R	S	R	S		1
P70	R	R	R	R	S	R	S	S	R	R	S	S		7
P71	R	R	R	R	S	S	S	R	S	S	S	S		1
P72	R	R	R	S	S	R	S	S	R	S	S	S		2
P73	R	R	R	R	R	R	S	S	R	S	R	S		2
P74	R	R	R	R	S	R	S	R	S	R	R	S		1
P75	R	R	R	R	S	R	S	S	R	R	R	S		3
P76	R	R	R	R	S	R	S	S	S	S	R	S		1
P77	R	R	R	S	R	R	S	S	R	R	R	S		1
P78	R	R	R	S	S	R	S	S	R	R	S	S		1
P79	R	R	R	R	R	R	S	S	S	R	R	S		1
P80	R	R	R	R	S	R	S	R	R	S	R	S		1
P81	R	R	R	R	S	R	S	S	S	R	S	S		1
P82	R	R	R	R	S	R	S	S	R	S	R	S		1
P83	R	S	S	S	R	R	S	S	R	R	S	S		2
P84	S	S	S	R	R	R	R	R	S	S	S	S		15
P85	S	S	S	R	S	R	R	S	S	S	S	S		23
P86	S	S	S	R	R	R	R	S	S	R	S	S		1
P87	S	S	S	S	S	R	S	S	S	S	S	S		1
P88	R	R	R	R	S	R	S	R	S	S	R	S		1
Total no. of races													47	66
Total no. of isolates													247	521

the variability of the fungus and suggest that the conventional method of race identification, i.e., using tissue culture and single conidium to represent an isolate present only a partial picture of the pathogenicity of the fungus isolates. This phenomenon may be explained by heterocaryosis of the fungus although some workers reported that most of the fungus cells contained only one nucleus. A new approach for studying the pathogenicity seems necessary.

Variable pathogenicity of monoconidial subcultures of *P. oryzae*

Earlier studies (Annual Report, 1966) indicated that subcultures from monoconidial cultures change in pathogenicity on differential varieties. New races were classified among the monoconidial subcultures. In 1967 studies were made to confirm the results obtained previously. Four monoconidial cultures from lesion studies, L-1-43 and L-1-49 of lesion no. 1 and L-2-36 and L-2-42 of lesion no. 2, were further studied. Twenty-five monoconidial subcultures from each of the four cultures were inoculated on both Philippine and international differential varieties. As shown in Table 7, the subcultures were differentiated into several races except L-2-36, the 25 subcultures of which did not differ in pathogenicity. It appears that the pathogenicity of monoconidial subcultures may not be identi-

Table 5. Races of *Pyricularia oryzae* in the Philippines in international numbers.

International race no.	No. of isolates		International race no.	No. of isolates	
	1962-66	1967		1962-66	1967
IA-1	0	1	IB-45	12	6
IA-5	1	0	IB-45	5	0
IA-9	1	0	IB-48	1	1
IA-28	0	1	IC-1a	1	14
IA-41	0	1	IC-5	1	0
IA-45	35	28	IC-9b	1	0
IA-46	7	28	IC-13	1	0
IA-47	0	1	IC-32	0	1
IA-65	0	25	ID-	0	2
IA-77	2	0	ID-5	0	2
IA-98	0	2	ID-9	3	0
IA-101	1	1	ID-10	1	0
IA-102	1	0	ID-13	36	21
IA-105	1	1	ID-14	27	7
IA-106	0	1	ID-15	4	1
IA-108	0	1	ID-16	5	6
IA-109	73	230	IE-5	0	1
IA-110	14	81	IE-7	0	1
IA-111	3	8	IG-1	1	2
IA-112	0	29	IG-2	5	1
IA-117	0	2	IH-1	1	0
IA-125	0	3	II-1	0	3
IA-126	0	5			
IA-128	0	1	Total (49 races)		
IB-1	3	0	No. of races	28	37
IB-4	0	1	No. of isolates	247	521
IB-26	0	1			

cal and varies among original cultures.

Reducing sugar:total nitrogen ratio of rice in relation to blast resistance

A study of the correlation between certain morphological or physiological features of plants and disease resistance, although useful, does not necessarily determine the nature of resistance. Earlier studies (Annual Report, 1966) have shown that rice leaves with a high ratio of reducing sugars to total nitrogen (RS:N) were resistant to most of the isolates of *P. oryzae*, while leaves with a low RS:N ratio were susceptible. High nitrogen level in the soil and low temperature are known to increase the susceptibility to blast. Rice leaves grown under these different conditions were analyzed to find how the RS:N ratio changes. The RS:N ratio was higher at lower nitrogen levels and higher temperatures (Table 8). This seems to be in line with the susceptibility or resistance of rice leaves under these conditions.

Bacterial Blight

Varietal resistance

About 7,000 varieties were preliminarily screened for bacterial leaf blight resistance in 1965 and 1966. A total of 300 selected resistant varieties were further tested against other virulent strains of the organism both at the seedling and flowering stages. Some 102 varieties were highly resistant to the most virulent strains of the bacterium so far found in the Philippines. The following varieties were found resistant to four virulent isolates and may be used as sources of resistance.

Variety	IRRI Acc. no.	Isolate			
		B2	B6	B15	KD
1. Zenith	131	R	R	R	M
2. TKM 6	237	R	R	R	R
3. Wase Aikoku 3	525	R	R	R	M
4. M. Sungsong	755	R	R	R	M
5. Keng Chi-ju	1540	R	R	R	M
6. Mortgage Lifter	1764	R	R	R	M
7. Early Prolific	1766	R	R	R	M

continuation

Variety	IRRI Acc. no.	Isolate			
		B2	B6	B15	KD
8. Early Prolific	1768	R	R	R	M
9. Early Prolific	1769	R	R	R	M
10. Early Prolific	1772	R	R	R	M
11. Lacrosse x Zenith	2001	R	R	R	M
12. Sel from 9210	2019	R	R	R	M
13. Lacrosse Zenith-Nira	2097	R	R	R	M
14. Bluebonnet x Rexark	2106	R	R	R	R
15. PI 162319	2396	R	R	R	M
	2773	R	R	R	M
17. PI 209938	2856	R	R	R	R
18. Tainan-iku 512	2993	R	R	R	R
19. Giza 38	3086	R	R	R	M
20. Balilla	3098	R	R	R	R
21. BJ 1	3711	R	R	R	R
22. Sigadis	4095	R	R	R	R
23. Semora Mangga	4181	R	R	R	M
24. Tainan 9	6883	R	R	R	R
25. 221C/BC111/Bn/62/	7668	R	R	R	R
26. DZ-78	8555	R	R	R	R
27. DZ-60	8558	R	R	R	R
28. DD-96	8647	R	R	R	R
29. DV-29	8816	R	R	R	R
30. DV-52	8828	R	R	R	R
31. JC-70 (susceptible checks)	9114	S	S	S	S
32. DV-2 (susceptible checks)	8806	S	S	S	S

The Seedboard varieties and IR8 were inoculated with two virulent strains of the blight organism at the seedling stage to compare their reactions. The data (Table 9) show that all Seedboard varieties as well as IR8 were susceptible to bacterial blight.

Segregation in F_2 populations of crosses between resistant and susceptible varieties

Many crosses were made among varieties with different degrees of resistance or susceptibility to obtain some general information on inheritance of resistance. Most of the F_1 populations showed a susceptible reaction in crosses between R and S. However, in a few crosses where the susceptible parents were less susceptible, the F_1s exhibited considerable resistance.

The F_2 populations segregated widely from highly resistant to very susceptible in crosses between R and S. From 30 to 40 percent of the population were in the resistant group (disease scale 0–3). In crosses between M and S, most of the populations were in the M (scale 4–6) and S (scale 7–9) group, very few in the resistant group. In crosses between R and M, most of the F_2s were resistant while in the S x S group almost all were susceptible. The results are presented in Fig. 1.

Yield losses caused by bacterial blight

The exact yield losses due to bacterial leaf blight in the field are difficult to assess. Two estimates (Table 10) showed that the disease could cause very heavy losses. In artificial inoculation experiments the average losses in yield for IR8 and Tainan 8 were 74.89 and 46.88 percent, respectively and, based on the 1,000-grain weight, the average losses were 22.03 and 9.34 percent, respectively. Under field conditions the average loss in yield of Taichung (N) 1 was 33.1 percent.

Reducing sugar:total nitrogen ratio of rice leaves in relation to resistance to bacterial blight

A chemical analysis made of varieties resistant and susceptible to bacterial blight showed that resistant varieties (Nagkayat, Takao 21, Wase Aikoku) had a low RS:N ratio while the susceptible ones (BPI-76, DV-2, JC-70) had a high ratio (Table 11).

Effect of temperature on disease development

In an experiment to determine the effect of high and low temperatures on the development of bacterial blight disease, six varieties, two each of R, M, and S groups, were grown in the growth chamber at high (28±2 C) and at low (21±2 C) temperatures and inoculated with two strains of the bacterium. High temperature favored disease development. The lesions were visible on susceptible varieties within 4 days at higher temperature and within 12 days at lower temperature. The "kresek" symptoms appeared within 14 days at high temperature but were not observed even after 40 days at low temperature. More leaves died and earlier at high than at low temperature in other varieties. This explains the higher virulence of the organism and the common appearance in the tropics of "kresek" symptoms which seldom occur in the temperate regions.

New weed host

Japanese workers reported that *Xanthomonas oryzae* has a limited host range. Studies were

Table 6. Pathogenic races of *Pyricularia oryzae* from monoconidial cultures from single lesions.

Philip- pine race no.	No. of monoconidial isolates Lesion no. 1	2	3	4	Inter- national race no.	No. of monoconidial isolates Lesion no. 1	2	3	4
P6		1			IA-45	9	2	1	
P8		24	1	34	IA-46	12		1	
P12		11		5	IA-98		1	1	
P15			1		IA-105		1		
P16	12		36		IA-108	1			
P17			3		IA-109	2	30	7	39
P26	4				IA-110	9	3	37	
P28			2		IA-111	2			
P30	8		3		IA-112	16		1	
P36		2			IA-126		1		
P38	1		1		IB-4		1		
P52	2				IC-36	1			
P54	1				ID-13		5		
P55	4				ID-14			1	
P56	4		1		ID-16	1		1	
P57	13		1		II-1	3			
P58	3				Total				
P59	1				Races	10	8	8	1
P62		2			Isolates	56	44	50	39
P63		1							
P64		2							
P69	1								
P70	1								
P71		1							
P73	1								
P83			1						
Total									
Races	14	8	10	2					
Isolates	56	44	50	39					

Table 7. Pathogenic races of *Pyricularia oryzae* from monoconidial subcultures.

Philip- pine race no.	No. of subcultures L-1-43	L-1-49	L-2-42	L-2-36	Inter- national race no.	No. of subcultures L-1-43	L-1-49	L-2-42	L-2-36
P8	6		18	25	IA-45		1	1	
P12			4		IA-46		4		
P16	4	9			IA-109	13	2	21	25
P17	2				IA-110	6	9	2	
P30	4	7			IA-111	1	3	1	
P47	1	2			IA-112	2	6		
P57	2	2			IA-126	2			
P62	1		2		ID-15	1			
P70	3				Total				
P73		1			Races	6	6	4	1
P76		1			Isolates	25	25	25	25
P77		1							
P78		1							
P79		1							
P80	1								
P81	1								
P82			1						
Total									
Races	10	9	4	1					
Isolates	25	25	25	25					

Table 8. The reducing sugar:total nitrogen ratio of blast-susceptible and resistant varieties grown under high (30±2 C) and low (20±2 C) temperatures and high (6 g $(NH_4)_2SO_4$/1 kg soil) and low (none added) soil nitrogen levels.

Variety	RS:N ratio			
	Temperature		Nitrogen	
	High	Low	High	Low
Khao-tah-haeng 17 (S)	0.909	0.439	0.514	0.765
Tjeremas (S)	0.978	0.621	0.589	0.910
Kataktara DA-2 (R)	1.060	0.732	0.825	1.408
Taichung 181 (R)	1.200	0.920	1.259	1.717

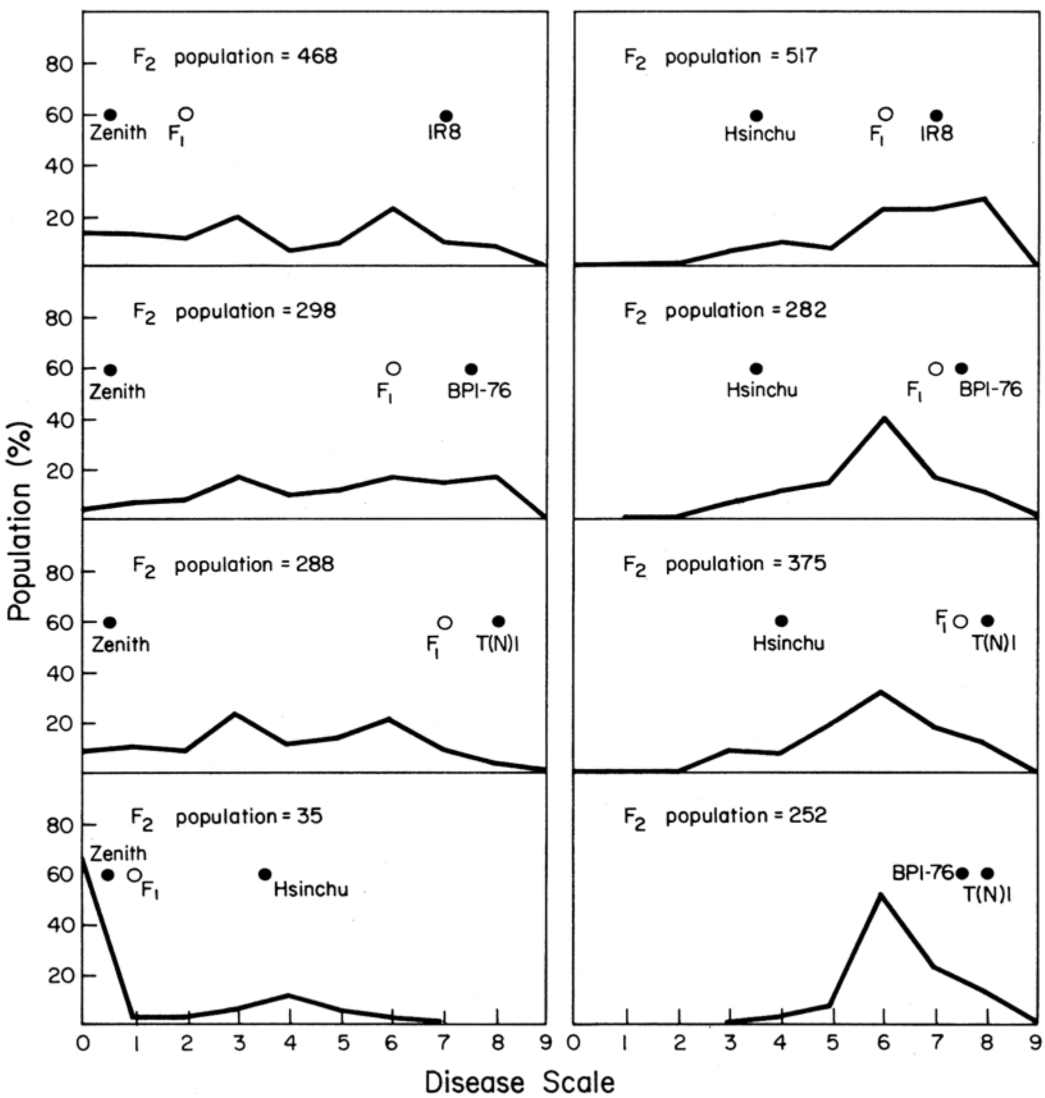


Fig. 1. Segregation of F_2 population in crosses between varieties resistant and susceptible to bacterial leaf blight (strain B15).

made to determine what grasses will serve as alternate hosts of the causal organism of the bacterial blight disease in the Philippines.

Twenty-eight species of grasses and weeds were collected from rice fields and inoculated with two strains of the bacterial blight organism using the needle inoculation technique. Among those inoculated, *Leptochloa chinensis, L. panacea* and *Zizania aquatica* were found to be susceptible. These constitute the new weed hosts of the organism.

On the two species of *Leptochloa* the lesions first appeared as water soaking around the points of inoculation followed by discoloration. The lesions elongated faster upward than downward parallel to the midrib. They expanded gradually in width and the color of the margins was dark orange.

The organism from the infected hosts, except *Zizania aquatica*, was reisolated and inoculated to the grass species as well as to seedlings of BPI-76. The reisolates likewise induced lesions on both the grass and rice seedlings 7 days after inoculation.

Table 9. Reaction of Philippine Seedboard varieties and IR8 at seedling stage to *Xanthomonas oryzae* 30 days after inoculation.

Variety	Reaction to strain	
	B6	B15
AC 2246 Mas	9	9
Azucena	9	9
C18	9	9
FK 178 A	9	9
Nang Thay	9	9
Palawan	9	9
Peta	9	9
Tjeremas	9	9
Mangares	9	8
BPI-76 (seasonal)	9	8
IR8	9	7
Dinalaga	8	8
Milpal	8	8
Bengawan	8	7
BPI-76 (non-seasonal)	8	7
HBDA	8	7
Norelon 340	8	6
Raminad Str. 3	7	7
SK 36 str. 422	7	7

Bacterial population in dry season in Central Luzon

In the tropics, there are areas with a distinct dry season which lasts for several months when no rice is planted and temperature is high. Central Luzon is one such area. How the organism survives in such areas and initiates the disease in the next crop season is an open question. The initial experiment was to determine by the bacteriophage technique the presence of the bacterium in remnant water in reservoirs and streams near the end of the 1967 dry season in the Central Luzon areas. Considerable phage populations of both bacterial leaf blight and bacterial leaf streak organisms were present in most of the samples (Table 12). This indicates that whenever there is water, the organisms are present and serve as primary inoculum for the next crop.

Variation in pathogenicity of single-colony subcultures from isolates B15 and B23

To determine whether or not pathogenicity varies among single-colony subcultures in bacterial blight organism, two isolates, B15 and

Table 10. Estimate of losses due to bacterial blight (effect on 1,000-grain weight, naturally infected Taichung (Native)1, 1964 wet season).

Hill no.	Plot E 36		Plot E 37	
	Slightly infected (g)	Severely infected (g)	Slightly infected (g)	Severely infected (g)
1	20.5	15.0	20.0	15.2
2	21.3	13.6	19.4	10.6
3	22.2	14.0	15.0	12.9
4	20.9	8.9	18.3	13.7
5	22.2	13.8	21.5	12.5
Average	21.4	13.1	18.8	12.9

Table 11. The reducing sugar: total nitrogen ratio of varieties resistant and susceptible to bacterial leaf blight.

Variety	RS:N ratio
BPI-76 (S)	0.800
DV-2 (S)	0.994
JC-70 (S)	0.969
Nagkayat (R)	0.378
Takao 21 (R)	0.389
Wase Aikoku (R)	0.331

B23, which differ extremely in their patterns of pathogenicity, were inoculated to seedlings of Zenith (R) and JC-70 (S) separately. One hundred four (104) single colonies for B15 (Pattern 1, very virulent) and 109 for B23 (Pattern 2, least virulent) were used and readings were taken 20 days after inoculation. The results showed a variation in pathogenicity among single-colony subcultures in both isolates (Fig. 2).

Bacterial Leaf Streak

Although bacterial leaf streak is very common and important in the tropics, little information about it is available. A program of study initiated in 1967 yielded basic information and inoculation techniques and methods of assessing varietal resistance.

Inoculation techniques

Bacterial streak organism may be inoculated on the rice plant by spraying the bacterial suspension in a closed chamber. Further experiments were made to determine the most effective and efficient methods of inoculation.

Age of plant. Plants 22 and 39 days after sowing were inoculated by spraying. The statistical analysis of the data showed no significant differences in the development of lesions. This indicated that plants may be inoculated when 22 days old.

Density of bacterial suspension. Since *Xanthomonas translucens* f. sp. *oryzae* is a fast-growing organism, 48-hour-old cultures from Wakimoto medium were used for inoculation. A strain of the bacterium was inoculated on two varieties using suspensions of 0.13, 0.26, 0.49, 0.85, 1.22 and 1.4 optical density. The results showed that the density of the suspension influences only in their extremes the infection rate. A bacterial suspension with an optical density of 0.80 ± 0.15

Table 12. Plaque counts of *Xanthomonas oryzae* and *X. translucens* f. sp. *oryzae* per ml of water samples from Central Luzon in May to June, 1967.

Place	Origin of water	Source of sample	Blight	Streak
1. Capihan, San Rafael, Bulacan	Angat Mountain	Creek	0	13
2. Garlang, San Ildefonso Bulacan	Creek	Creek	10	3
3. Lomboy, Talavera, Nueva Ecija	Dibabuyan creek	Creek	0	25
4. Maligaya Expt. Station, Muñoz, Nueva Ecija	Deep well	Irrigation canal	169	7
5. Ilog Baliuag, Santo Domingo, Nueva Ecija	Baliuag river	Irrigation ditch	240	1
6. Linek, Cuyapo, Nueva Ecija	Mountain	Drainage creek	156	12
7. Hda. Moreno, Sta. Clara, Cuyapo, Nueva Ecija	Deep well and mountain	Outlet of reservoir	181	5
8. San Nicolas, Villasis Pangasinan	San Manuel river	Creek	7	3
9. San Jose, Urdaneta, Pangasinan	Agno river	Irrigation ditch	120	3
10. Bamban, Tarlac	Layak mountain	Tarlac river	0	40
11. Mabiga, Mabalacat, Pampanga	Natural spring	Creek	5	23
12. Sampaloc, Apalit, Pampanga	Pampanga river	Irrigation canal	9	50

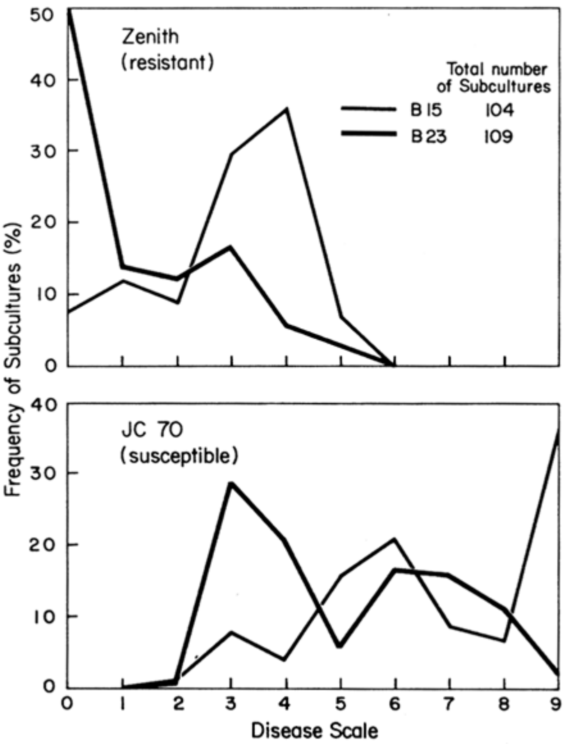


Fig. 2. Variation in pathogenicity among single-colony subcultures of isolates B15 and B23 of *Xanthomonas oryzae*.

was found sufficient for the inoculation experiment. Although repeated spraying for inoculation does not increase the infection rate, spraying twice with an interval of 1 hour to insure uniform distribution of the inoculum is recommended.

Conditions after inoculation. A study was made of the effect of conditions after inoculation on the infection rate. Three varieties—Peta, Kaohsiung 64 and Hsinchu 56—were inoculated with the strain S-74 and kept at a constant relative humidity of 100 percent for 15, 18, 21, 24, 27, 30 and 33 hours. Results showed that a period of 15 hours was sufficient. A prolonged period, even in a dark room, did not increase the infection rate. However, strong artificial light or day light during the first 5 to 6 hours after inoculation not only slightly increased the number of lesions but also resulted in a more uniform infection among the varieties used. This phenomenon most likely is due to stomata-mechanism which merits further investigation.

Date of reading. An experiment using four strains of the organism and five varieties of rice was made to determine the date most appropriate to take the reading after inoculation. The results showed no difference in rating between 12 and 20 days after inoculation, although the 20-day-old lesions were 25 to 30 percent larger than the 12-day-old ones. Late reading 3 to 4 weeks after inoculation is not advisable because of reinfection and other technical difficulties. Readings may, therefore, be taken 14 to 15 days after inoculation.

Number and size of lesions as criteria for disease reaction. Since the streak organism causes only local lesions, the severity of the disease is determined by the number as well as the size of lesions. A scale for severity of the disease must therefore consider both. A scale based on the number of lesions is advantageous in that readings can be taken early. But the number of lesions per leaf surface unit is extremely dependent upon environmental conditions. Experiments showed that the size of lesions is rather specific between strain and variety. Plants easily get wounded. Those exposed for 2 hours to strong wind exhibited 50 to 200 times more lesions per surface unit than those unexposed.

The variation in the number of lesions within the same variety and strain is rather large and is even larger at different times of inoculation. A scale based on the size of lesion would eliminate the problems and simplify readings.

Correlation in size and number of lesions between greenhouse artificial inoculation and field infection. To justify the use of a scale based on the size of lesions alone, an experiment was conducted to compare its reliability with that of a scale based upon number of lesions. Thirty-six varieties were tested simultaneously in the field and in the greenhouse. In the greenhouse, 36 varieties were replicated in eight sets, each of which was inoculated separately with a different strain. In the field a susceptible variety, Pah-Leuad, was inoculated 2 days before the 36 varieties were transplanted and used as a source of inoculum. Readings were taken weekly beginning in the third week after transplanting, using a scale of 1 to 9 based on visual criteria. Clear-cut differences in resistance among the varieties

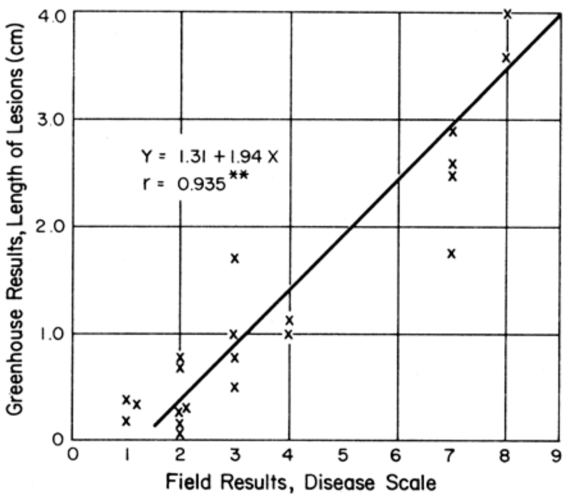


Fig. 3. Correlation between greenhouse and field results of the severity of bacterial leaf streak disease in different varieties.

appeared just before the flag leaves emerged. The greenhouse results and the field data were correlated. An example of correlation between field and greenhouse results on mean size of lesions is shown in Fig. 3. The correlation coefficient between greenhouse and field results in all eight sets were highly significant for the size of lesions. For the number of lesions the correlation coefficient was highly significant in four but not in the other four cases. Analysis of the data on the mean size and mean number of lesions shows that the information obtained through number of lesions is negligible.

Since wounded plants are more subject to streak disease, the question is whether or not the number of lesions to a certain degree indicates field, if not physiological, resistance. Recent observations showed that all varieties developed many young lesions after a very strong typhoon. However, on some varieties, the lesions did not enlarge and the plants remained green.

Factors affecting size of lesions

Temperature in relation to lesion development. Results of an experiment using two rice varieties, Peta and Pah-Leuad 111, and two strains of the organism, S-74 and S-77, conducted in the growth chambers to determine the effect of temperatures on lesion development, showed that temperature distinctly influences lesion development. High temperature (32 C) favors lesion development, whereas low temperature (22 C) retards it. This may explain the slight variations in the results of inoculations at different times.

Host nutrition. Three varieties—T-9, Peta, and Pah-Leuad—grown in culture solution with 5, 40, and 100 ppm N were inoculated with S-103 at the age of 34 days. The results showed that nutrition influences lesion development only slightly.

Stored culture. Isolates in cultures stored for a longer period have reportedly lost their virulence. To determine the effect of storage on isolates, 10 strains isolated by Goto in 1964 were stored in a deep freezer. These were inoculated on variety Kaohsiung 64 and then reisolated. Four of the reisolates were inoculated and reisolated for a second time. Isolates and their reisolates were tested on eight varieties. With some exceptions, there were no marked differences in virulence between old cultures and their reisolates using as criterion the mean size of the lesions. This suggests that isolates stored in a deep freezer can be used for a long period without reducing their virulence.

Preliminary scale for disease reaction. The length of lesions as well as the yellow halos which develop around the lesions are considered as criteria for evaluating disease reaction. The yellow halo is associated with long susceptible lesions. The lesions with irregular dark-brown margins may indicate a certain degree of resistance or weakness of the strain. The longest lesion observed on the most susceptible varieties being about 10 cm, the following 10-unit scale has been tentatively proposed:

Scale	Length of lesions 14 days after inoculation (mm)
0	0
1	<1
2	1 to 2
3	2 to 5
4	5 to 10
5	11 to 20
6	21 to 30
7	31 to 40
8	41 to 60
9	>60

Pathogenicity patterns of strains of Xanthomonas translucens f. sp. oryzae. Before screening varieties for resistance, virulent strains or races, if any, should be selected for use in inoculation experiments. To obtain information that will guide workers in the selection of resistant varieties, the pathogenicity behavior of 150 isolates was preliminarily tested on two varieties, Peta and Pah-Leuad 111. Less than 10 of the isolates were least virulent, developing lesions smaller than 0.5 cm. The other isolates were of intermediate virulence. From the different groups of isolates, four least virulent, three very virulent and one intermediate were selected and inoculated separately on 36 pre-selected varieties with various degrees of disease reaction. The resistant varieties were resistant to all strains. Susceptible varieties reacted with the largest lesions to all strains. Another 25 isolates inoculated on eight varieties showed the same results. Based on this information screening for resistance will need only one or a few virulent isolates.

Virus Diseases

Varietal resistance to tungro disease

In searching for sources of resistance to the tungro disease and identifying possible commercial varieties with a degree of resistance, 5,161 entries—855 rice varieties, 2,770 selections of IR-lines, 504 entries of genetic materials, and 1,002 entries of duplicates, check varieties, etc. —were tested in 1967 by the mass screening method described in the 1965 and 1966 Annual Reports.

Resistant varieties. Of the 855 varieties inoculated at 11 to 13 days after sowing, 1.7, 6.3, and 93.0 percent were resistant, intermediate, and susceptible to the tungro disease, respectively. The fifteen entries listed below recorded less than 30 percent infected seedlings in the preliminary screening tests.

IRRI acc. no.	Variety
177	Adday (sel.)
180	Adday local (sel.)
663	HR 21
721	6517
755	M. Sungsong
1113	Yi Shih Hsing
1274	Kai Lianh Hsung Tieng
1275	PI 160677-2
1277	PI 160677-4
1278	PI 160677-5
1456	Chung Ta 313 Hao x Binastian F_3
1463	Chung Ta 312 Hao x Binastian F_3
1464	Chung Ta 312 Hao x Binastian F_3
1537	Pien Chan Ying Tao
1557	Lang Chung Yi Lung Ju

Both Adday (sel.) and Adday local (sel.) were listed in the resistant group in the 1966 Annual Report.

Comparing the susceptibility of Adday local (sel.), Adday (sel.), HR21, and 6517, the average percentages of infected seedlings from eight replications were 8.5, 10.8, 11.9 and 21.3 percent, respectively.

To compare the susceptibility of Taichung (Native) 1 and that of Pankhari 203, more than 4,000 seedlings of each variety were inoculated. The average percentage of infected seedlings of the former was 98.79 percent whereas that of the latter was 4.61 percent (Fig. 4).

Resistance of IR lines. Some 317 selections from 27 IR lines and 2,453 selections from 117 IR lines were tested for their reaction to the tungro disease with inoculations at 11 to 13 and 20 days after sowing, respectively. A total of 265 selections from 46 lines was classified in the resistant group; the rest were either intermediate or susceptible to the disease (Table 13).

Inheritance of tungro resistance

Since 1966, a number of crosses have been made between varieties with different degrees of resistance or susceptibility to tungro .nd tests have been continued in F_2 and F_3 lines. To arrive at sensible genetic interpretations in the future, many difficulties have to be overcome. The percentage of infection at the seedling stage varies considerably from test to test. The ability of infected seedlings to "recover" from the disease at later growth stages varies among varieties. In the future, the seedling resistance and the ability to recover may have to be considered separately. Sometimes leaf discoloration and stunting of plants are caused by reasons other than the virus. No virus was recovered from the six diseased plants (by their symptoms) in Taichung (Native) 1 x Pankhari 203 cross in F_2 (Table 14). In addition, some crosses had a high sterility and many plants died of severe infection on very susceptible individuals.

Table 14 presents some of the data based on the second reading 45 days after inoculation.

These preliminary tests seem to show that

Table 13. Reaction to the tungro disease of IR lines tested by the mass screening method.

Line	No. of selections showing infection (%)		
	0-30	31-60	61-100
Inoculated at 11-13 days after sowing			
27 IR lines	6	52	259
Inoculated 20 days after sowing			
IR 11, FB 24 x Dee-geo-woo-gen	5	6	5
IR 84, Peta x PI 215936	13	7	13
IR 126, Bluebelle x Sigadis	4	2	4
IR 127, (CP231 x SLO17) x Sigadis	7	17	19
IR 140, (CP231 x SLO17) x Mas	11	8	10
IR 142, B581A6-545 x Mas	2	1	6
IR 272, (CP231 x SLO17)/2 x Sigadis	3	5	10
IR 276, B581A6-545/2 x Peta	8	5	35
IR 283, Peta/2 x Dawn	2	2	0
IR 300, Peta/2 x (CP231 x SLO17)	2	3	0
IR 328, DA31 x (Sigadis x T(N)1)	2	1	3
IR 407, Peta/3 x Dawn	28	5	0
IR 408, Peta/3 x Belle Patna	13	9	4
IR 447, Peta/4 x Belle Patna	2	2	5
IR 485, Peta/5 x Belle Patna	24	2	1
IR 534, (CP231 x SLO17/2 x Sigadis) x TKM-6	2	3	0
IR 578, IR8 x (Sigadis x T(N)1)	2	2	12
IR 604, Pankhari 203 x Fujisaka 5	5	12	1
IR 608, Pankhari 203 x T(N) 1	3	7	1
IR 748, IR8 x (Dawn x Pankhari 203)	9	58	50
IR 791, (Peta/4 x T(N)1) x Pankhari 203	3	3	1
IR 822, (IR8/2 x Pankhari 203)	51	159	63
IR 825, (IR8 x Pankhari 203) x (Peta/6 x T(N)1)	18	82	45
Other 94 IR lines	40	328	1177
Total (27 + 117 lines, 317 + 2,453 selections)	265	781	1724

resistance is a dominant character. The F_2 segregating populations in different crosses approach a 9:7 ratio but the data are not adequate to arrive at a conclusion.

Recovery of tungro virus from infected plants

In continuing the study of tungro virus distribution in the rice plant, the infectivity of insects was tested after they had been confined on (a) various parts of infected plants, (b) plants inoculated at different ages, (c) plants at various intervals after inoculation, and (d) different inoculated rice varieties.

Various plant parts. The tungro virus has been recovered not only from the leaf blades and leaf sheaths (Annual Report, 1966) but also from the root, stem, uppermost internode, flag leaf, rachis, young panicle, partially mature panicle, and midrib of the leaf blade of infected plants. The results revealed that the virus was widely distributed in the infected plants, and that all parts of the infected plant, except the mature panicle on which the insects died after confinement, could serve as a virus source.

Plants inoculated at different ages. Taichung (Native) 1 plants inoculated at 10, 20, 30, 60, and 90 days after sowing were used to study the effect of plant age on the ability of plants to act as virus sources. The results revealed that the virus could be recovered by *N. impicticeps* 2 to 3 days after inoculation in the seedlings inoculated at less than 30 days of age (Fig. 5). When the test of virus recovery was made within 8 days after inoculation, the percentage of plants acting as virus sources decreased with increased plant age at the time of inoculation. Plants inoculated at an old age took longer to develop into virus sources than those inoculated young. However, more than 50 percent of the inoculated plants, regardless of their age at testing, could become active virus sources 2 weeks after inoculation.

The fact that 40 percent of the seedlings

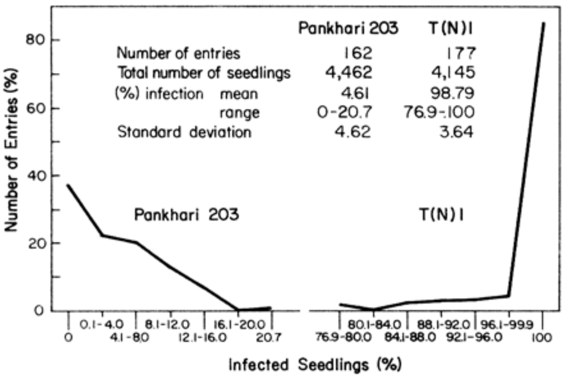


Fig. 4. Frequency distribution of Taichung (Native) 1 and Pankhari 203 by the percentage of tungro-diseased seedlings tested by the mass screening method.

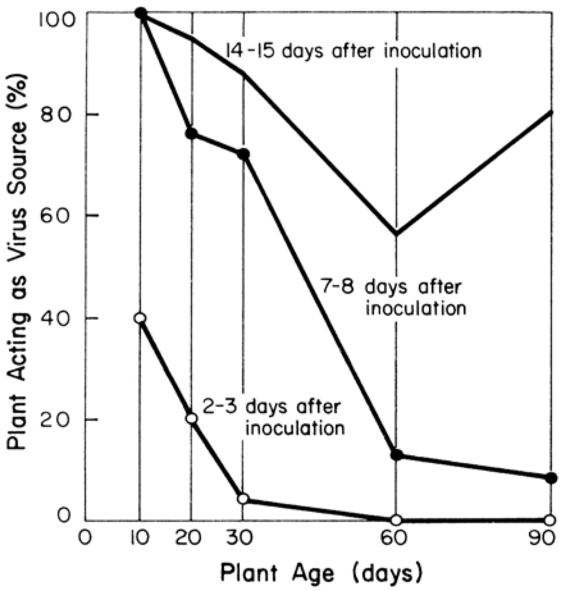


Fig. 5. Recovery of tungro virus from Taichung (Native) 1 plants of various ages after inoculation with 5 viruliferous insects/plant.

inoculated at 10 days of age were acting as virus sources after 2 to 3 days revealed that inoculated plants could serve as virus sources even before the virus symptoms became apparent. The study of the persistence of the virus in the vector by serial transmission must consider the possibility that the insect reacquires the virus from test seedlings. Shortening the interval between two transfers of insects would eliminate error in determining the retention period of the virus in the vector.

Shortest time between inoculation and virus recovery. The least time required by an inoculated seedling to serve as a virus source would reflect the rate of the virus translocation and its multiplication in the plant. Taichung (Native) 1 seedlings, 10 and 20 days old, were used in a study to determine the shortest time required by the plants to act as a virus source. The preliminary results showed that none of the 120 insects tested became infective after an acquisition feeding of 8 hours on forty 10-day-old seedlings inoculated by viruliferous insects 16 hours earlier. In other words, none of the 40 seedlings tested could serve as a virus source within 24 hours after inoculation. However, two and five out of 120 insects tested became infective after they had been confined for 9 and 24 hours, respectively, on seedlings inoculated 24 hours earlier. The insects allowed to feed on 20-day-old seedlings inoculated 24 hours earlier became infective after feeding for 24 hours. Therefore the shortest periods required by 10- and 20-day-old seedlings to act as virus sources were 33 and 48 hours, respectively, from inoculation to the end of insect acquisition feeding.

Different durations after inoculation. Attempts have been made to determine whether or not the inoculated plants can serve as virus sources throughout their growth stage. Taichung (Native) 1 plants inoculated at various ages were used as materials for studying virus recovery. The virus was recovered at 2-week intervals after inoculation until the plants were 120 days old. Within 2 weeks after inoculation, the percentages of plants acting as virus sources increased gradually regardless of plant age at the time of inoculation (Fig. 6). But 2 weeks after inoculation, the percentages of plants acting as virus sources fluctuated between 67 and 100 percent. The cause of such fluctuation was not clearly understood, but it seemed that the majority of the inoculated plants could serve as virus sources throughout growth. However, although 112 days was the longest period obtained in the test, it is possible that the infected plants could serve as virus sources for more than 16 weeks after inoculation.

Different varieties. Since rice varieties differ in their resistance to the tungro disease, the recovery of the virus by the insects from different

Table 14. Reactions to the tungro virus of hybrid progenies between resistant and susceptible varieties.

	F1		F2 / No. of plants	
Parent			Healthy	Diseased
Pankhari 203			54	0
Sigadis			17	4
221C/53/1/3/1			67	17
IR 8			71	71
Wagwag			0	71
T(N)1			0	84
Cross	Healthy	Diseased	Healthy	Diseased
Pankhari 203 x T(N)1	22	0	275	251
T(N)1 x Pankhari 203	7	6	132	90
IR8 x Pankhari 203	67	8	375	294
IR8 x Sigadis	53	57	438	325
221C/53/1/3/1 x T(N)1	73	43	281	184
T(N)1 x Wagwag	0	17	3	210
Pankhari 203 x T(N) 1 F_3 survived lines			Healthy	Diseased
T4-1-3			25	50
T4-1-11			45	11
T4-1-34			38	30
T4-1-66			82	3
T4-5-8			60	10
T4-5-15			73	1
T4-10-11			38	27
T4-10-15			20	47
T5-1-22			20	57
T5-1-41			14	14
T5-4-5			45	10
Backcross F_1				
IR8 x [IR8 x Pankhari 203]			45	32
IR8 x [IR8 x Sigadis]			31	19
Backcross F_2				
Pankhari 203 x [T(N)1 x Pankhari 203]			524	21
Pankhari 203 x [T(N)1 x Pankhari 203]			586	9
Pankhari 203 x [T(N)1 x Pankhari 203]			212	0
[T(N)1 x Pankhari 203] x Pankhari 203			266	25

varieties may also vary. A group of susceptible varieties—Taichung (Native) 1, IR8, BPI-76, and TKM-6—and a group of resistant varieties—Tjeremas, Peta, Sigadis, and Pankhari 203—were tested. The preliminary results showed that the resistant varieties had lower percentages of seedling infection, and that the percentages of diseased plants of resistant varieties acting as virus sources were lower than those of the susceptible varieties. The percentage of infective insects after they had fed on diseased plants of susceptible varieties was higher than that of insects that had fed on diseased plants of resistant varieties. It may be concluded that a susceptible variety may not only suffer severely from the disease but may also be a good source of the virus.

Hybrid vector of tungro virus

The tungro virus is transmitted by *Nephotettix impicticeps* but its transmission by the closely related *N. apicalis* needs to be verified. Attempts were therefore made to obtain the hybrids from interspecific crosses between these two species and to investigate the ability of the hybrids to transmit the virus.

Insects at the fourth or fifth instar stage were separated individually to prevent mating. At the adult stage, two insects of opposite sexes, one from each species, were transferred to rice plants for mating and oviposition. The hybrids were collected for morphological and virus transmission studies.

Morphological characteristics of the insects. The characteristics of *N. apicalis* include a submarginal black band on the vertex of the insect‡. Tegminal central black spots are conspicuous, often confluent along the clavus to apical black markings. The clavus often infuscates along the inner and hind margin. On each side of the aedeagus, there is a rudimentary paraphysis at about, or slightly below, the middle of the aedeagus, on the ventral surface of which there is a slender lamina of two series of seven acute teeth arranged longitudinally. In ventral view, the aedeagus is not so narrowed below the paraphysis. The style is long, distally subtruncated.

The male insects of *N. impicticeps* do not have a submarginal black band on the vertex. Tegminal central black spots may or may not be present. There is a fairly large elevated paraphysis on each side of the aedeagus at about the middle portion, and there are two series of four acute teeth arranged longitudinally on the central surface. In ventral view, the aedeagus is hardly constricted below the paraphyses. The length of the aedeagus is $547.50 \pm 7.65\mu$ for *N. apicalis* and $531.13 \pm 8.99\mu$ for *N. impicticeps**.

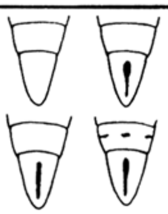
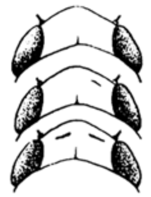
The nymphs of *N. apicalis* show a conspicuous "T" shaped mark on the dorsal side of the posterior portion of the abdomen. In the case of *N. impicticeps,* only a minute dot, or two dots united together in various ways, mark the dorsal side of the last segment of the abdomen (Fig. 7 and Table 15).

Results of an examination of the morphology of these two species agreed generally with the above descriptions. But in a very few cases, there were two series of six and five teeth on the aedeagus of *N. apicalis* and *N. impicticeps,* respectively (Table 15). The aedeagus differed

‡Ishihara, T. Revision of the genus Nephotettix (Hemiptera: Deltocephalidae). *Trans. Shikoku Entomol. Soc.* 8(2) : 39-44. 1964.

*Nasu, S. Studies on some leafhoppers and planthoppers which transmit virus diseases of rice plant in Japan. *Bull. Kyushu Agr. Exp. Sta.* 8:153-349, 1963.

Table 15. Morphological characteristics of ***Nephotettix impicticeps, N. apicalis,*** **and their hybrids.**

	Posterior portion of nymph	Anterior portion of adult	Style	Aedeagus ventral view	Aedeagus lateral view	Number of teeth/series
N. impicticeps						**4** (5)
N. apicalis						**7** (6)
F_1 *N. impicticeps* x *N. apicalis*						**5-8**

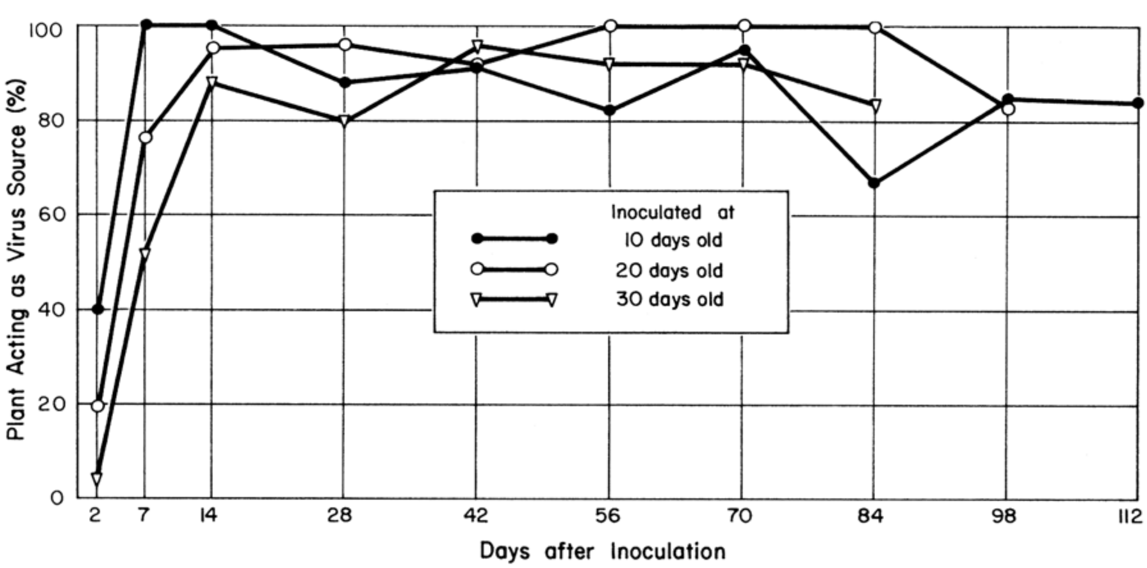


Fig. 6. Recovery of tungro virus by *Nephotettix impicticeps* from inoculated Taichung (Native) 1 plants at various ages.

slightly in length, 541μ in *N. apicalis* and 521μ in *N. impicticeps*.

In hybrid adults, the submarginal black band on the vertex varied from absent, as with *N. impicticeps,* to two separate thin black dashes (Fig. 8 and Table 15). The intermediates had only one thin dash on either the left or the right side of the vertex. However, in most cases, the hybrids from the same parents varied less or not at all. The structure characteristics of their male genitalia did not differ strikingly from those of their parents in size and location of paraphyses, and the constriction of the aedeagus below the paraphyses. The average length of the aedeagus was 539μ. But the number of teeth per series varied from five to eight, was mostly six, and therefore not identical with either parent (Table 15).

The markings on the posterior portion of the abdomen of hybrid nymphs varied from no dot to a short vertical dash on the last segment and a few dots arranged horizontally on the next-to-the-last segment (Table 15). However, in most cases, hybrid nymphs had a dark-brown, short, vertical dash on the dorsal side of the last abdominal segment (Fig. 7).

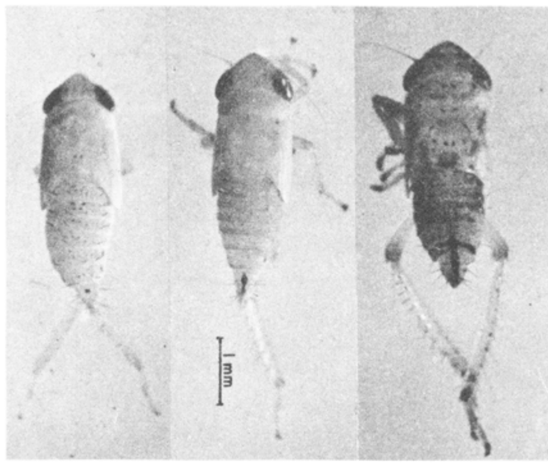


Fig. 7. Nymphs of *Nephotettix impicticeps* (left), *N. apicalis* (right), and their hybrid (middle) showing the difference in the markings on the posterior portion.

Transmission of tungro virus by the hybrids. The transmission study indicated that some of the hybrids, regardless of stage of development or sex, were able to transmit the tungro virus (Table 16). Of 113 individuals tested, 15 percent were active transmitters. There seemed to be no striking differences in the percentage of active transmitters between nymphs and adults nor between male and female individuals. All the infective hybrids were infective immediately after the 3- or 5-day acquisition period. The hybrids became non-infective on the second day after acquisition feeding. Some became reinfective immediately after the reacquisition feeding

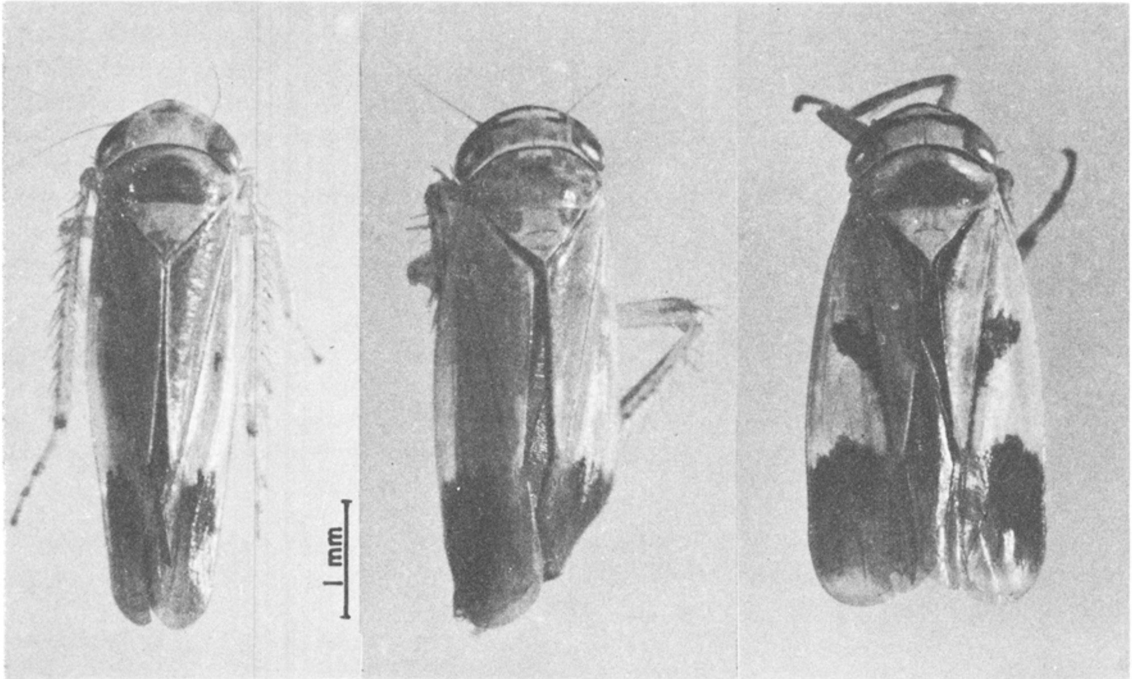


Fig. 8. Male adults of *Nephotettix impicticeps* (left), *N. apicalis* (right), and their hybrid (middle) showing the difference in submarginal black bands on the vertex.

on diseased leaves, whereas, those previously non-infective became infective. The reinfective hybrids did not retain infectivity longer than did the infective hybrids that had acquired the virus only once. The tungro virus-vector interaction of the hybrids did not differ from that of *N. impicticeps*.

Feeding of tungro vector

Pankhari 203 is a variety highly resistant to the tungro disease. The mechanism of its resistance to tungro is not fully understood. To determine whether or not the vector of tungro virus, *N. impicticeps*, is able to feed on Pankhari 203, studies were conducted on the feeding behavior of the vector.

Life span of N. impicticeps on Pankhari 203. Results (Fig. 9) obtained from confining adult *N. impicticeps* individually on seedlings of Pankhari 203 and Taichung (Native) 1 in test tubes indicated that the life span of the insect feeding on Pankhari 203 was significantly shorter than that of the insect feeding on Taichung (Native) 1. Apparently, Pankhari 203 is not a favorable host of *N. impicticeps* but the reason for the early death of the insect remains obscure. The early death might be interpreted as proof of the variety's resistance to tungro under natural conditions. But under artificial inoculation, the

Table 16. Ability of hybrids of *Nephotettix impicticeps* x *N. apicalis* to transmit rice tungro virus.

Growth stage and sex	No. individuals tested	No. infective insects	Transmitters (%)
Nymph	66	11	16.7
Female adult	23	3	13.0
Male adult	24	3	12.5
Total	113	17	15.0

Table 17. No. of feeding punctures/insect/hour on leaf blades of Taichung (Native) 1 and Pankhari 203 by *Nephotettix impicticeps*.*

Variety	Male adult	Female adult	Mean
Taichung (Native) 1	2.56	2.88	2.72
Pankhari 203	3.01	2.91	2.96

*10 insects, 2 to 10 p.m., 2 replicates each.

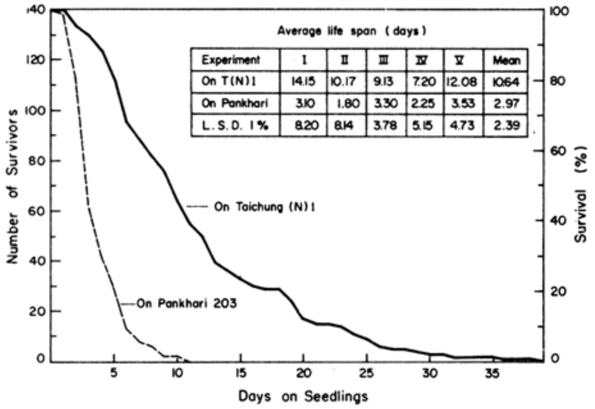


Fig. 9. Life span of adult *Nephotettix impicticeps* feeding on Taichung (Native) 1 and Pankhari 203 seedlings.

resistance of a variety may not be related to the early death of the insect unless the early death is only due to the inability of the insect to feed on the variety. In addition to the inability to feed, malnutrition, poisoning, etc. could also be possible reasons for the insect's early death.

To determine whether or not the early death of the insect on Pankhari 203 was due to its inability to feed on the variety, the insect's mouth parts were examined and its feeding behavior on Pankhari 203 was compared with that on Taichung (Native) 1.

Mouth parts of N. impicticeps. The main part of the beak of *N. impicticeps* is the labium (Fig. 10) and a part of it is covered by the labrum. Inside the labium is a needle-like structure composed of four stylets fitted closely together. But these stylets are not firmly united and can be separated. The outer pair of stylets are the mandibles and the inner pair are the maxillae. The tip portion of the mandibular bristle has several tooth-like projections (Fig. 11). The diameter of united stylets of the male adult is 15 to 22μ. The individual mandible measures 670 to 690 x 8 to 15μ (average 679 x 11μ) and the maxilla, 712 to 892 x 10 to 11μ (average 792 x 10.5μ) in size.

Feeding punctures. The feeding punctures on the leaves of Taichung (Native) 1 and Pankhari 203 after they had been stained are shown in Fig. 12. The puncture consisted of an opening, somewhat elliptical in shape, in the center, surrounded by insect salivary trace. The average size of the openings on the leaves of Taichung (Native) 1 was 13.9 x 5.5μ, whereas that of the openings on Pankhari 203 was 13.3 x 6.1μ. The punctures were not localized but distributed irregularly on the surface of the leaf blade and located between two veins, beside the vein, or on the vein. However, there was no apparent difference in the punctures between the two varieties. It can be concluded that *N. impicticeps* can make punctures on Pankhari 203.

The puncture openings on the leaves of both varieties were smaller than the diameter of the insect stylets (13.6 x 5.9μ vs 15–22μ). The size of the opening caused by a needle puncture on the leaf, measured immediately after puncturing, was smaller than the diameter of the needle. The same opening was even smaller when measured 10 minutes after. This might show why the opening made by an insect was smaller

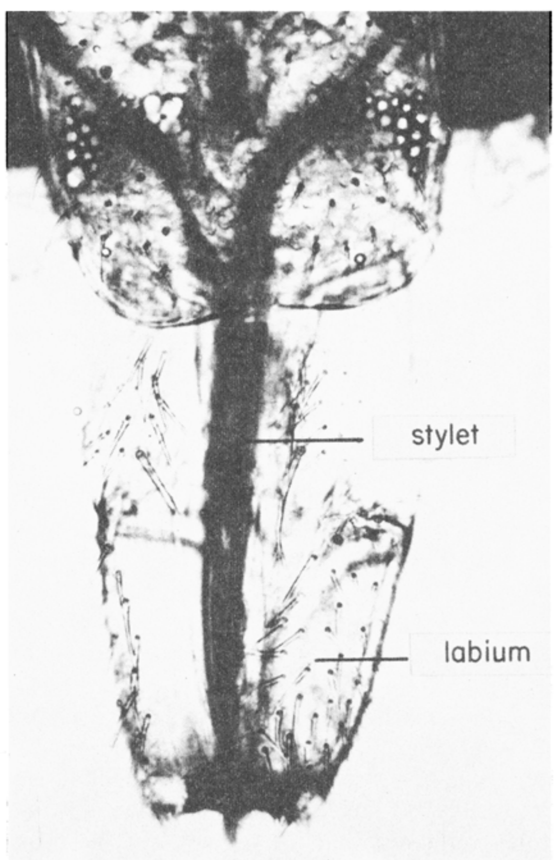


Fig. 10. Mouth part of *Nephotettix impicticeps*.

Table 18. Duration of a single feeding of *Nephotettix impicticeps* on Taichung (Native) 1.

Starvation (minutes)	No. of insects tested	Feeding duration (minutes)	
		Range	Average
0– 62	20	1 – 20	5.30
6– 29	10	1 – 85*	23.00*
10– 45	15	1 – 63*	16.93*
40– 100	30	1.5 – 366*	77.93*
120– 140	20	5 – 223*	39.05*
Total/Mean	95	1 – 366*	39.04*

* Insects were still feeding when the data were taken.

Table 19. Tissues of leaf blade in which feeding tracks of *Nephotettix impicticeps* terminate.

Variety	No. of tracks examined	Percentage of tracks			
		Phloem	Phloem and xylem*	Parenchyma	Across leaf blade
Taichung (N) 1	177	80	7	12	1
Pankhari 203	186	77	7	7	9
Total	363	78	7	10	5

*The feeding tracks might not be terminated at the xylem but the xylem was plugged with salivary sheath.

than the diameter of its stylet.

No. of feeding punctures. The number of punctures usually indicates the frequency of insect feeding. The average number of punctures on Pankhari 203 was almost identical to that on Taichung (Native) 1 (Table 17). If an insect can make a puncture on a variety, and cannot feed well on it, the frequency of insect feedings may not remain the same.

Duration of a single feeding. Table 18 shows that the duration of a single feeding of *N. impicticeps* on leaves of Taichung (Native) 1 varied tremendously, the shortest being about 1 minute and the longest, more than 366 minutes. Previous starvation might have been one of the factors which affected most the duration of a single feeding of the insect.

Feeding behavior. According to feeding behavior, the leafhopper species studied could be assigned to three categories: (1) primarily parenchyma feeders; (2) species whose tracks reach the phloem in 30 to 50 percent of cases but which apparently also feed on the parenchyma; and (3) primarily phloem feeders that reach the phloem more frequently than they would by chance.*

The feeding behavior of *N. impicticeps* was determined by examining the termination of feeding tracks on the cross sections of the leaf blade. The sections were prepared by the paraffin method. The results (Table 19) indicated that *N. impicticeps* is primarily a phloem feeder since more than 70 percent of the feeding tracks terminated at the phloem and more than 80 percent of the examined tracks reached the vascular bundle of the leaf blade. The feeding tracks usually curved from the entrance toward the vascular bundle and this could be regarded as evidence that *N. impicticeps* actually preferred that tissue. The length of the stylet, as mentioned above, exceeded the thickness of the leaf blade or the distance from the opening on the surface of the leaf blade to the vascular bundle on the undersurface of the leaf. Consequently, the stylet of the insect was long enough to reach the vascular bundle from any point of the leaf blade if the feeding track ran perpendicular to the vascular bundle. This may be the reason why the insect did not select for feeding a site on the rice leaf blade in which the vascular bundles were parallel.

*Day, M. F. *et al.* Observations on the feeding of the virus vector *Orosius argentatus* (Evans) and comparisons with certain other jassids. *Aust. J. Sci. Res.* B 5:128-142, 1952.

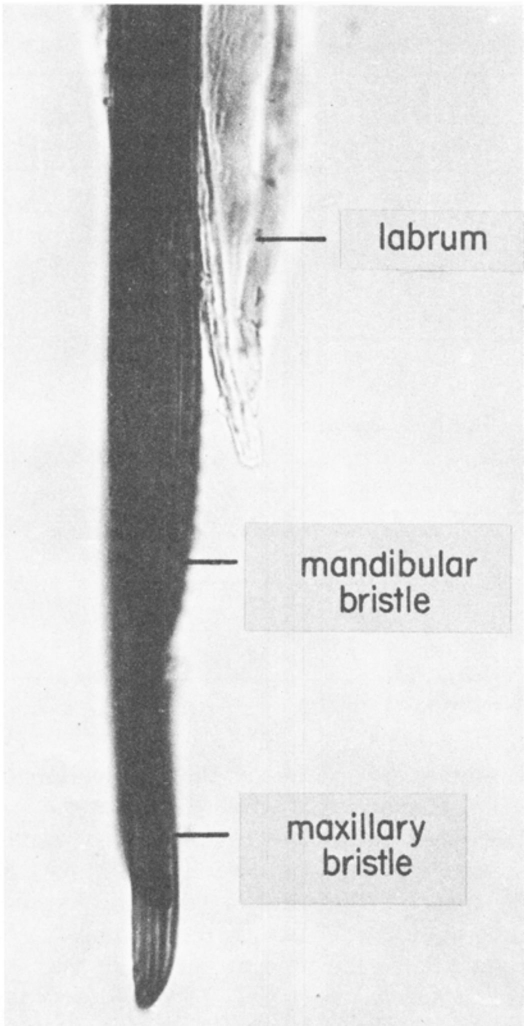


Fig. 11. Tip portion of mouth parts of *Nephotettix impicticeps* after the removal of labium.

The feeding tracks of *N. impicticeps* in leaves of Taichung (Native) 1 and Pankhari 203 are shown in Fig. 13. The feeding tracks in the leaf blade and leaf sheath of Pankhari 203 show the ability of the insects to feed on this variety. Since the insect was able to reach the vascular bundle of Pankhari 203, the differences in resistance to tungro between this variety and Taichung (Native) 1 might not have been due to the difference in the tissue reached by the vector, which might have accounted for the different infection rates for a given virus. Furthermore, the frequency at which each tissue was reached by a vector would have altered the infection rate. The results (Table 19) showed no striking difference in the percentage of feeding tracks terminated in each tissue between these two varieties. Therefore, it seems that the mechanism of tungro resistance in Pankhari 203 could not be due primarily to the deviation of feeding behavior of *N. impicticeps* on this variety, as compared with its feeding behavior on Taichung (Native) 1.

Inactivation of tungro vector

Since the tungro virus does not persist in *N. impicticeps,* it may not circulate or multiply in the insect. Hence, the infective insects may be inactivated by proper treatments.

Using the feeding technique described in the 1966 Annual Report, a few substances were tested for their effectiveness in inactivating viruliferous insects. The results showed that fresh

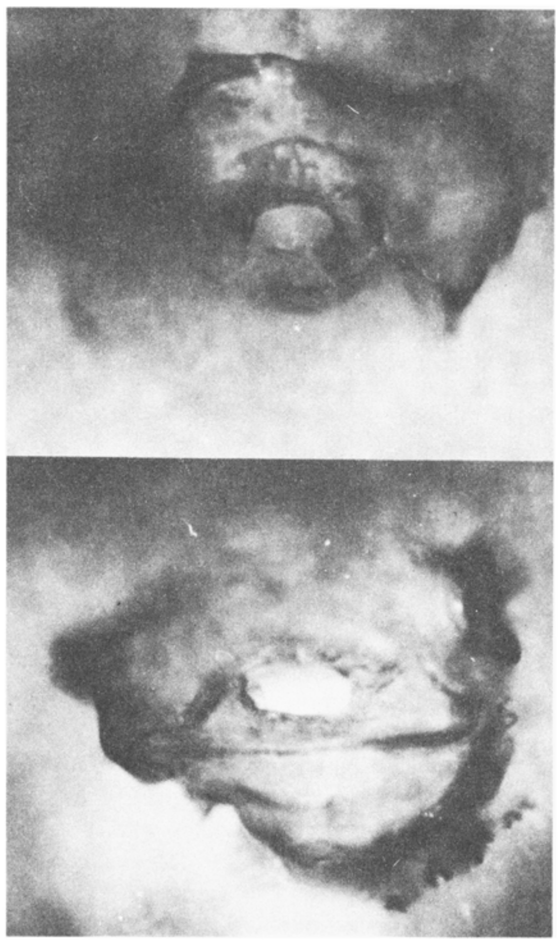


Fig. 12. Feeding punctures of *Nephotettix impicticeps* on leaves of Taichung (Native) 1 (top) and Pankhari 203 (bottom).

milk was not a favorable food for *N. impicticeps*. Nevertheless, the percentages of infective insects after being treated on milk for different lengths of time, or on Blasticidin-S emulsion at various concentrations, were similar to those of insects treated with water as controls. On the contrary, the percentage of infective insects was reduced when the viruliferous insects were treated with formalin. The reduction in percentage of infective insects was highly correlated with both the concentration of formaldehyde in the solution used for treating the viruliferous insects (Fig. 14) and the duration of the treatment. Consequently, the results seemed to indicate that the tungro-viruliferous insects can be inactivated and that formalin is effective in inactivating the insects. However, formalin would not alter the ability of the insects to transmit the virus because the treatment with 1 percent formaldehyde for 4 hours prior to acquisition feeding gave a similar percentage of infective insects as did the treatment with water.

Since formalin is toxic to the insect, it might affect the probing behavior of the insects and the time required for the first probing after treatment. Hence it cannot be assumed that the treatment does not affect the probability of inoculation. Consequently, the fact that formalin inactivated the viruliferous insects is an additional circumstantial evidence that the tungro virus is stylet-borne.

Infectivity of viruliferous *N. impicticeps* after feeding on Pankhari 203

The mechanism of tungro resistance in Pankhari 203 might not be due solely to the inability of the insect to feed on the variety. Attempts have been made to determine the probable existence in Pankhari 203 seedlings of a certain substance that may inactivate the virus or inhibit the multiplication of the virus. No technique is available for cultivating the tungro virus. for studying the inhibition of its multiplication. However, the inactivation of the virus could be determined indirectly through the infectivity of the viruliferous insects.

To test their infectivity, the viruliferous insects were fed on Pankhari 203 for various time periods. Simultaneously, the viruliferous insects feeding on Taichung (Native) 1 were used as checks. The results of the test, which used about 2,300 viruliferous insects, are summarized in Fig. 15.

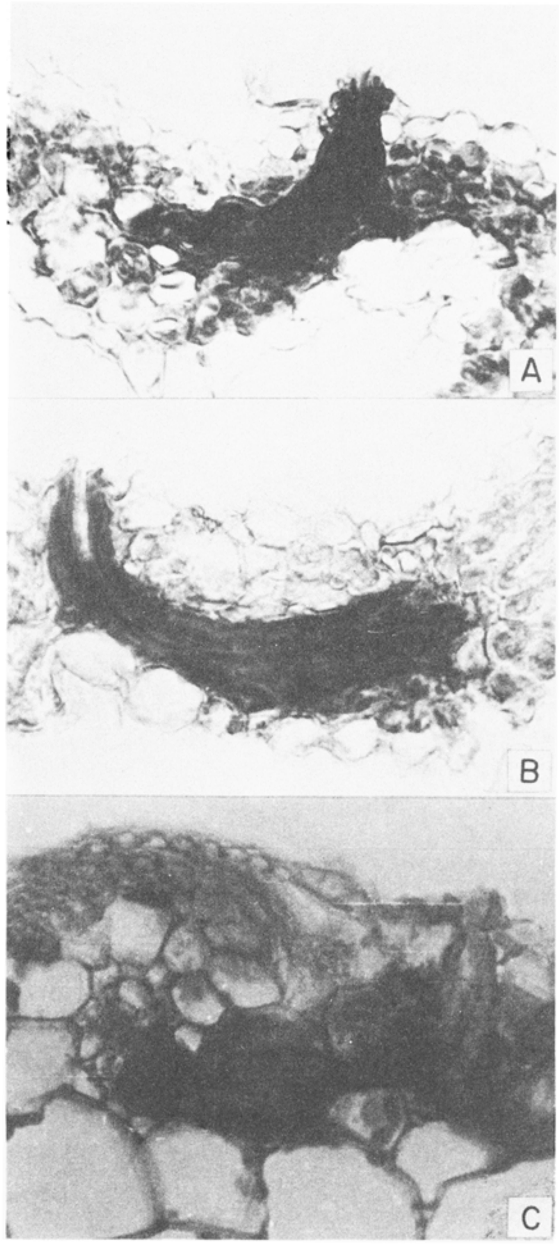


Fig. 13. Cross sections of leaf blades of Taichung (Native) 1 (A) and Pankhari 203 (B) and leaf sheath of Pankhari 203 (C) showing feeding tracks of *N. impicticeps*.

Nine out of 29 experiments showed that there were 1 to 10 percent (4.9% on the average) more infective insects among those fed on Pankhari 203 than among those fed on Taichung (Native) 1. In contrast, 19 out of 29 experiments showed

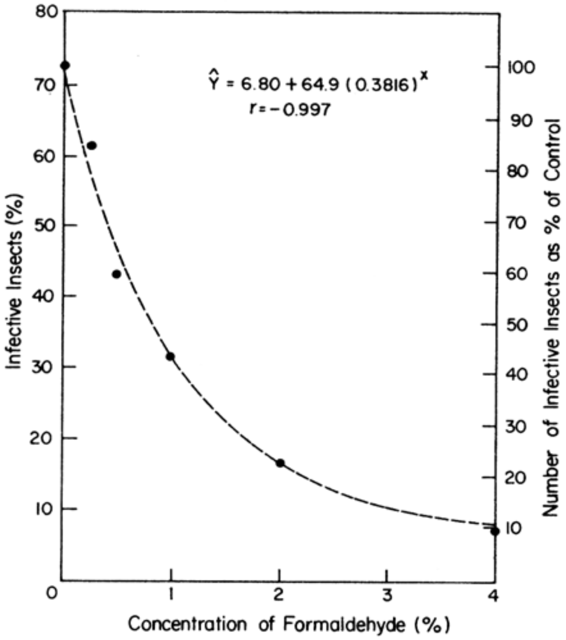


Fig. 14. Infectivity of tungro-virus-viruliferous *Nephotettix impicticeps* feeding on various concentrations of formaldehyde for 1 hour.

that there were 1 to 39 percent (10.4% on the average) more infective insects among those fed on Taichung (Native) 1 than among those fed on Pankhari 203. The average percentage of infective insects after feeding on Taichung (Native) 1 was 40.07 whereas that of infective insects fed on Pankhari 203 was 34.76. The difference was 5.31 percent but it was about 13 percent in reduction in percentage of infective insects. The difference was statistically significant.

Since the viruliferous insects can be inactivated by formalin, it is reasonable to suspect that the reduction in percentage of infective insects after feeding on Pankhari 203 might have resulted from the inactivation of the viruliferous insects during the feeding by a certain substance existing in Pankhari 203. In fact, the effectiveness of the substance in inactivating the viruliferous insects was rather low because the reduction in percentage of infective insects was low. Nevertheless an inactivator is often a good inhibitor. Therefore, it is possible that the substance which lowered the infectivity of insects might be able to inhibit the multiplication of the virus introduced by the insects into the plant. Accordingly, it could be tentatively hypothesized that the mechanism of tungro resistance in Pankhari 203 might have been caused by the inhibition of the multiplication and/or by the inactivation of the virus by the substance or substances in the plant.

Effect of tungro virus on its vector

The effect of plant virus on its insect vector may be either harmful or beneficial. The harmful effects may be manifested by reduced life span of the insect, shortened duration of diapause, higher percentage of sterile females, lowered fecundity, premature death of eggs, increased nymphal mortality, changes in internal organs, abnormal metabolism, etc. Since the tungro virus does not persist in its vector, *N. impicticeps,* it would be expected to have no effect on its vector. However, only experimental results can verify this expectation.

Life span. Since the tungro virus does not persist in its vector, an investigation of the effect of the virus on the life span of the insect might involve the factor of insect nutrition. The nutritive value of the diseased plant to the insect cannot be expected to be identical to that of the healthy plant. Therefore, the first experiment was made to compare the difference in life span between insects fed continuously on a healthy plant and insects fed previously on a diseased plant for only 1 day. The 1-day feeding on a diseased plant was intended to allow the insect to acquire the virus and minimize the nutritional problem. The resulting average life span was 13.3 days for virus-free insects and 14.0 days for viruliferous ones. The difference was not statistically significant.

In the second experiment the insects were confined continuously on healthy and on diseased detached leaves in test tubes. The average life span was 13.5 and 14.3 days for insects fed on healthy and diseased leaves, respectively (Fig. 16). The difference was again non significant.

The results seemed to indicate that the tungro virus did not alter the life span of *N. impicticeps.*

Fecundity. The effect of the tungro virus on the fecundity of *N. impicticeps* was determined

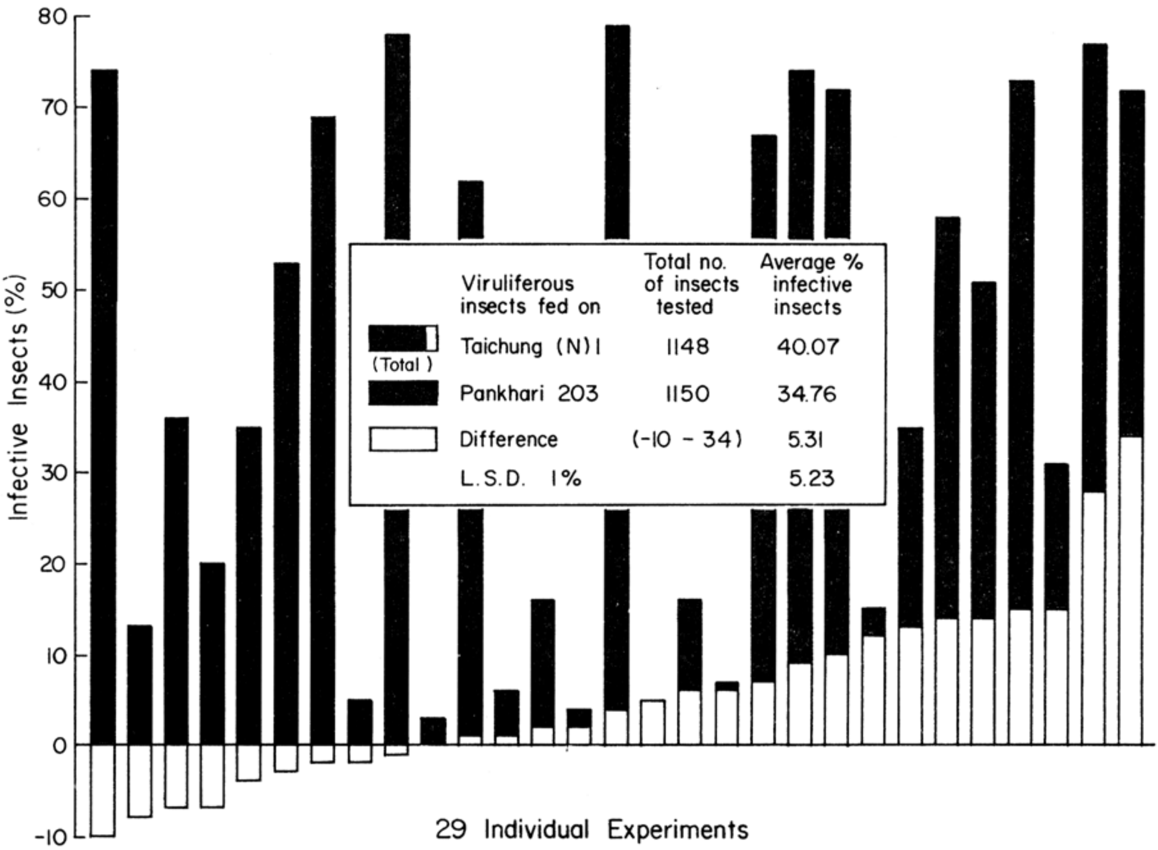


Fig. 15. Infectivity of tungro-virus-viruliferous *Nephotettix impicticeps* after feeding on Taichung (Native) 1 or Pankhari 203.

by the number of egg masses and of eggs collected from healthy rice plants after the insects had fed previously on diseased plants for 5 days. The results from five replications, with five mated females for each replication, are shown in Figs. 17 and 18. Both the number of egg masses and the number of eggs varied considerably among replications within the treatment. The ranges were 18.2 to 33.2 and 16.2 to 31.6 egg masses and 240.6 to 439.4 and 230.2 to 447.8 eggs per female adult of virus-free and viruliferous insects, respectively. However, the variation in the number of eggs per mass was small (13.5 vs 14.1). The viruliferous female adult laid slightly fewer eggs but the number was within the variation of individual females, and therefore could not be used to show the effect of of the tungro virus on the fecundity of *N. impicticeps*.

Fecundity on diseased plants. The average number of egg masses laid by *N. impicticeps* on healthy plants was 13.9 and on diseased plants, 11.2. The number of eggs on diseased plants was about 23 percent less than that on healthy plants (Fig. 19). The smaller number of eggs on diseased plants might not have been the direct

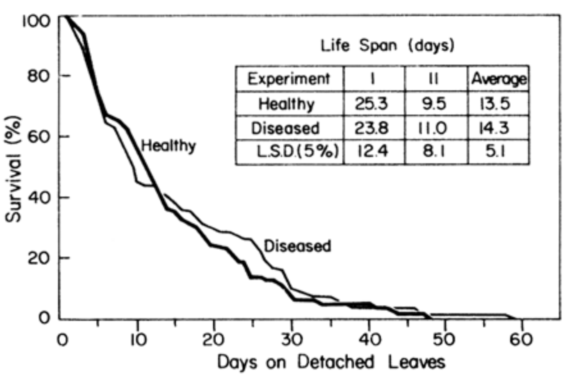


Fig. 16. Mortality of adult *Nephotettix impicticeps* feeding on detached leaves of healthy and tungro virus-infected Taichung (Native) 1 plants.

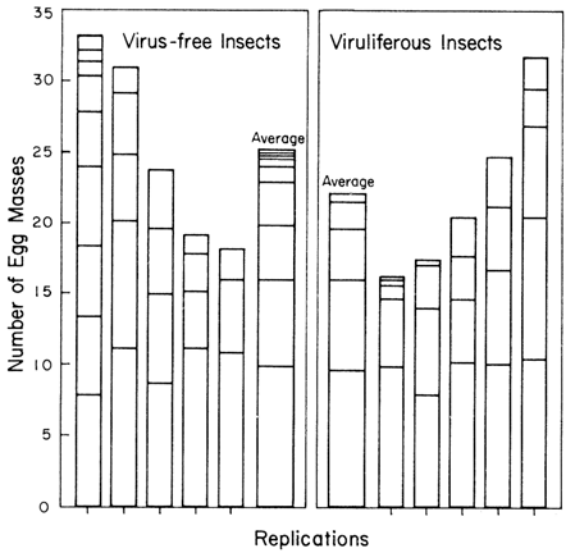


Fig. 17. Number of egg masses laid by virus-free and tungro-viruliferous *Nephotettix impicticeps* in consecutive weeks.

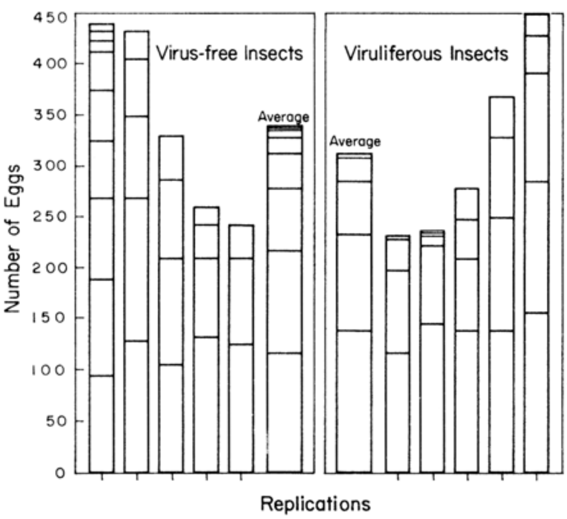


Fig. 18. Number of eggs laid by virus-free and tungro-viruliferous *Nephotettix impicticeps* in consecutive weeks.

effect of the tungro virus on the fecundity of the insect alone since the factors of physical and chemical difference between healthy and diseased plants had not been eliminated from the experiment.

Number of Nymphs. The number of nymphs yielded by virus-free and viruliferous *N. impicticeps* is shown in Fig. 20. The viruliferous insects were those which had fed on diseased plants for 5 days before being caged on healthy plants for laying eggs. The nymphs were first collected from the plants 2 weeks after caging. There was no difference in the average number of nymphs between virus-free and viruliferous insects. This result indicated indirectly that the virus did not affect significantly the factors related to the number of nymphs, such as number of eggs, hatching rate of eggs, mortality of newly hatched nymphs, etc.

Transmission of tungro disease of rice in Indonesia

The mentek disease of rice, known for a century in Indonesia, recently had been suspected to be a viral disease. The cooperative study between the Institute and the Central Research Institute for Agriculture was conducted in Bogor, Indonesia. Unfortunately, there seemed to be considerable confusion among authorities as to what constituted the mentek disease. The present study was confined to a disease syndrome, observed in the field in several districts of West Java, Bandung, Bogor, Krawang, Tjerebon, and Tjiandjur, and in Palembang, South Sumatra, which appeared to be the tungro disease of rice.

Eight rice varieties were tested for their reactions to the disease in transmission experiments conducted in insect-proof mylar cages in the greenhouse. Four of the varieties were from the Institute, with known resistance or susceptibility to the tungro virus, and the other four were commercially grown in Indonesia. FK-135, a rice variety used to differentiate the two strains of tungro virus in the Philippines, was used as an indicator plant.

Field-collected insects of *Nephotettix impicticeps* were fed on diseased plants for 2 days and caged on healthy plants for 2 to 3 days. A total of 10 insects was introduced to each cage which contained five healthy plants at the 2- to 3-leaf stage. The diseased plants were taken from South Sumatra and West Java. Virus was recovered from all of the five samples. Of the 105 test plants inoculated, 59 percent (62) developed symptoms of the disease 7 to 10 days

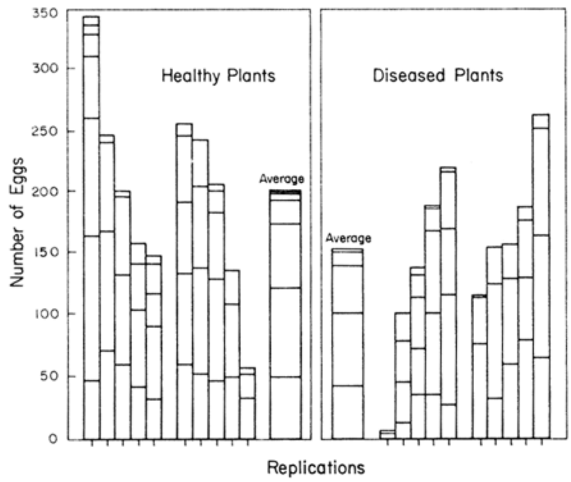


Fig. 19. Number of eggs laid by *Nephotettix impicticeps* on healthy and tungro virus-infected Taichung (Native) 1 in consecutive weeks.

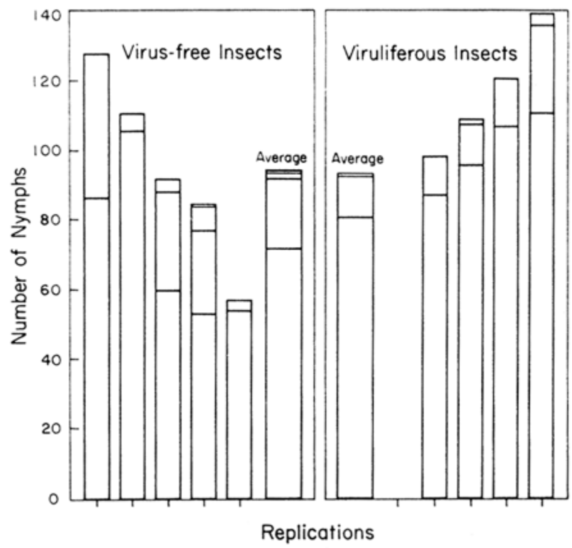


Fig. 20. Number of nymphs yielded by virus-free and tungro-viruliferous *Nephotettix impicticeps*.

after caging. Healthy plants (control) exposed to the same number of insects from the natural population did not show symptoms of the disease, indicating that the field insects used were disease-free.

After acquiring the virus, *N. impicticeps* retained its infectivity for 1, 2, and 3 days when given acquisition feeding periods of 6, 24, and 48 hours, respectively (Table 20). A 1-hour inoculation feeding was sufficient to cause infection to an appreciable number of test plants.

Table 20. Infectivity of *N. impicticeps* in 12 daily transfers after acquisition feeding on diseased plants.

Acquisition feeding (hours)	No. of plants infected/no. inoculated each day					
	1	2	3	4	5	6 to 12
6	3/20	0/20	0/18	0/15	0/15	0/48
24	6/20	1/19	0/19	0/16	0/16	0/39
48	8/19	2/19	1/18	0/18	0/17	0/54

Of the eight varieties inoculated for resistance, Pankhari 203 and Peta, which are resistant to tungro in the Philippines, and the Indonesian improved varieties, Dara and Syntha, were found resistant to the disease. Taichung (Native) 1, FK-135, Marhaen, and Sukanandi were found susceptible. Dara and Syntha were selections from a cross between Bengawan and Sigadis, both of which, like Peta, have known resistance to tungro.

This study indicated that, based on symptoms, virus-vector interaction, and varietal reactions, the disease observed in South Sumatra and West Java was caused by the tungro virus.

Although the cause of mentek disease of rice in Indonesia is not definitely known, the present data indicate that tungro is present in Indonesia and may be involved in the disease syndrome of mentek.

Yellow Dwarf

Taichung (Native) 1 seedlings inoculated at the second leaf stage of growth showed the first symptom of yellowing on the youngest leaf 23 to 66 days after inoculation. As the disease progressed, the leaf turned from light green to yellowish green. Later, the diseased plant became stunted, tillered excessively, and its leaves narrowed and shortened and changed in color from yellowish green to greenish yellow. An infected plant produced as many as 162 tillers, while a healthy one produced 18 under the same environmental conditions. The infected plant never recovered and produced no or a few panicles bearing mostly unfilled grains. Plants

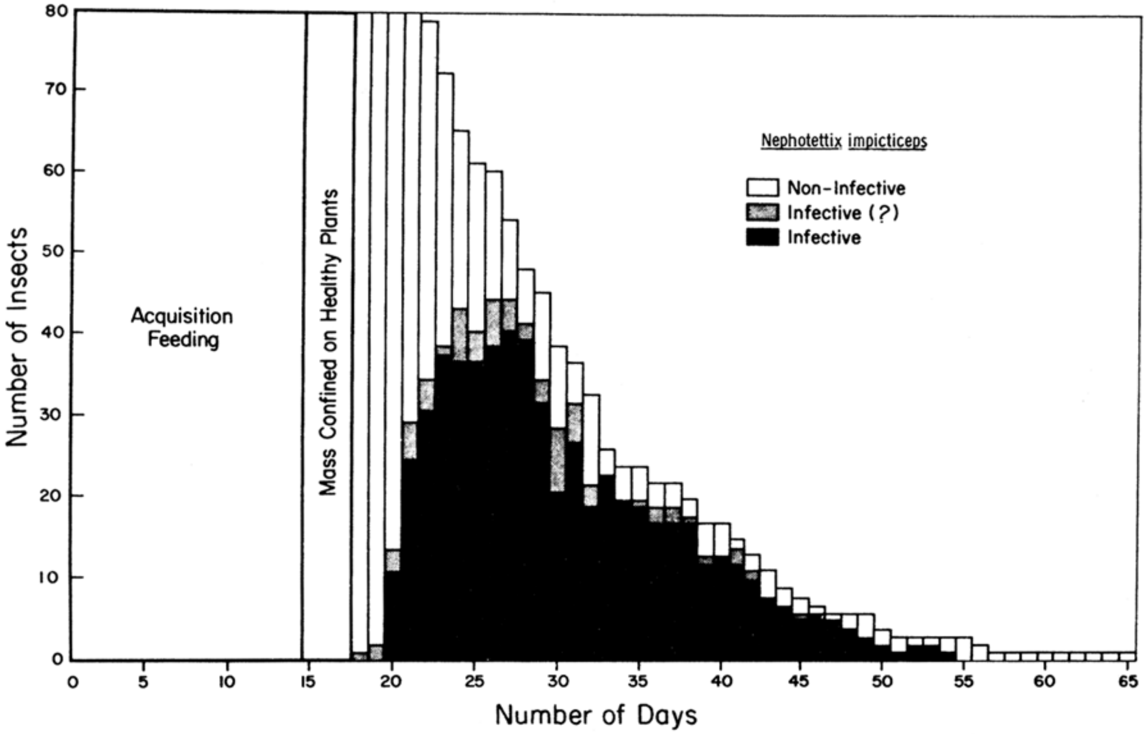


Fig. 21. Serial transmission of yellow dwarf by *Nephotettix impicticeps*. (Infective (?) indicates that the test seedling died before showing symptoms).

infected during the later growth stages did not show the characteristic symptoms before harvest. However, the symptoms were conspicuous on the regenerated growth from cut stubbles.

Transmission of yellow dwarf. Both *N. impicticeps* and *N. apicalis* transmitted the disease in the Philippines. However, the former had a higher percentage of active transmitters than the latter (83 % vs 69 %). The minimum incubation period in these two species was 20 days. But it was usually 20 to 26 days for *N. impicticeps* and 22 to 27 days for *N. apicalis*. The infective insects remained infective almost until their death (Fig. 21). The minimum acquisition and inoculation feeding periods for *N. impicticeps* were 30 and 2 to 3 minutes, respectively. No significant difference was found between the transmission efficiency of female and male adults of *N. impicticeps*. However, the female insects had a longer life span than the male and thus the female had a longer average retention period of infectivity.

Effect on growth and yield. The reductions in height of infected BPI-76 plants were 51 and 45 percent for those inoculated at 10 and 30 days of age, respectively. These plants produced more tillers and panicles but no grains. No reduction in height or grain yield was observed in plants inoculated at 60 days after sowing, although some of them showed symptoms on the regenerated growth when ratooned.

The causal agent of yellow dwarf. Rice yellow dwarf was originally assumed to be caused by a virus because of its symptoms and its transmission by leafhoppers. Recently, by electronmicroscopic examination of the ultra-thin section of a diseased specimen, Japanese scientists found that mycoplasma-like organisms are constantly associated with diseased tissues of mulberry dwarf, Paulownia witches' broom and aster yellows, which are known or suspected to be caused by viruses and transmitted by leafhoppers. Consequently, the new notion seems to prevail that some diseases previously known as rice virus diseases might be caused by mycoplasma. Rice yellow dwarf in Japan has been found associated with the mycoplasma. In collaboration with Dr. E. Shikata of the Botanical Institute, Faculty of Agriculture, Hokkaido University, Japan, the specimen of rice yellow dwarf in the Philippines was examined under the electron microscope (Fig. 22) and found to

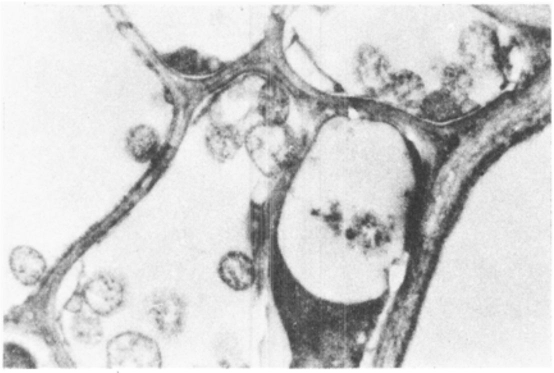


Fig. 22. Electron micrograph of a diseased leaf of Philippine rice yellow dwarf showing mycoplasma-like bodies (by Dr. Shikata).

have mycoplasma-like bodies in the cells. To confirm the nature of the causal agent, however, the reproducibility of the disease by the mycoplasma and the cultivation of the mycoplasma on media need to be studied.

Synthesis of short-statured, disease-resistant varieties and isogenic disease-resistant varieties

The short-statured, stiff-strawed, nitrogen-responsive varieties used in the Institute breeding program often are susceptible to common diseases. Studies to incorporate disease resistance in these varieties by hybridization were continued. In the process of determining inheritance of resistance to blast, bacterial blight and tungro diseases, isogenic resistant varieties are being developed by repeated backcrossing to recurrent susceptible parents. These isogenic resistant varieties will be further used in studies to understand the nature of disease resistance. The available genetic material incorporating resistance to different diseases are listed below.

Blast disease resistance

Cross	Material	
Dawn (R) x Taichung (N)1 (S)	F_6 seeds	4th backcross
Chianung 280 (R) x Taichung (N)1 (S)	F_6 seeds	4th backcross
Ta-poo-cho-2 (R) x Taichung (N)1 (S)	—	6th backcross
Dawn (R) x BPI-76 (S)	—	6th backcross
IR8 (S) x Taichung 181 (R)	F_2 seeds	1st backcross
IR8 (S) x Kataktara DA 2 (R)	F_3 seeds	2nd backcross
IR8 (S) x Dawn (R)	F_3 seeds	2nd backcross
(IR8 x KA F_2) x (IR8 x Dawn F_2)	F_1 seeds	
(IR8/2 x Ka) x (IR8/2 x Dawn)	F_1 seeds	

Bacterial blight resistance

Cross	Material	
BPI-76 (NS) x Zenith	F_4 seeds	2nd backcross
IR8 x Zenith	F_4 seeds	2nd backcross
Taichung (N)1 x Zenith	F_4 seeds	2nd backcross
IR8 x TKM-6	F_1 seeds	—
Taichung (N)1 x TKM-6	F_1 seeds	—
PI 162319 x Taichung (N)1	F_1 seeds	—
Taichung (N)1 x PI 162319	F_1 seeds	—
Wase Aikoku 3 x BPI-76 (NS)	F_1 seeds	—
BPI-76 (NS) x Wase Aikoku 3	F_1 seeds	—
BPI-76 (NS) x Early Prolific (no. 1769)	F_1 seeds	—
IR8 x Early Prolific (no. 1769)	F_1 seeds	—
IR8 x Early Prolific (no. 1772)	F_1 seeds	—
IR8 x CI 9210 sel	F_1 seeds	—

Tungro disease resistance

Cross	Material	
Taichung (N)1 x Pankhari 203	F_4 seeds	2nd backcross
221C/53/1/3/1 x Taichung (N)1	—	3rd backcross
221C/BC111/BN/62/2 x Taichung (N)1	—	3rd backcross
IR8 x Pankhari 203	F_3 seeds	2nd backcross
IR8 x Sigadis (Tall)	F_3 seeds	2nd backcross
Remadja x Taichung (N)1	F_3 seeds	2nd backcross
I-geo-tze x Pankhari 203	F_3 seeds	1st backcross
IR8 x Sigadis (dwarf)	F_2 seeds	1st backcross

effect. At wide spacings, both increased weed competition and decreased panicle density depressed yield.

Pre-planting Weed Control and Row Spacing

Upland rice yields of more than 4,000 kg/ha have been reported in several parts of the world including the Philippines (La Granja, Negros) in years of favorable rainfall distribution. The Institute has produced yields near this level and, considering the prospects for mechanization, low-cost production of upland rice is possible.

The Institute has tried pre-planting sprays and minimum tillage techniques on a small scale for 2 years. Although minimum-tillage practices have not succeeded, the evidence indicates that pre-planting sprays of non-selective chemicals can achieve adequate weed control when combined with dry land preparation.

In the 1964 dry season, land was rotovated to give a clean, fine-textured seedbed. When the rains began and grassy weeds were 3-4 inches tall, a broadcast spray of 7.5 kg/ha PCP (pentachlorophenol) as an oil emulsion was made; this completely killed the weeds. A variety and spacing experiment was sown, using a two-row hand drill. Fertilizer was incorporated during the last rotovation (30-30-30) and a top-dressing of 30-0-0 made at panicle initiation. A spray of 4 kg/ha of propanil was made about 25 days after planting, and 1 kg/ha of 2,4-D was applied at the late tillering stage.

Although rats destroyed two of the eight varieties planted, the remaining six produced adequate yields (Table 23). No significant differences in yield were measured but some plots of Milfor 6(2) yielded 4,100 kg/ha, indicating the potential. Weed control costs were about $50 per hectare but fewer than 20 man-hours of labor per hectare were used to control weeds.

Timing of Weed Control and Grain Yield

The time of weeding upland rice is as important as any of the other cultural practices used to obtain satisfactory yields. Where close spacing provides rapid "closing-in" of a vigorous *indica* variety, a single weeding, if done thoroughly by hand, may be sufficient. In a wet season experiment the variety Palawan was drilled in 30 cm rows at 80 kg/ha in a clean-tilled, fine seedbed and fertilized with 30-30-30 at planting and 30 kg/ha N top-dressed 6 weeks later. A single weeding 2 weeks after planting (Fig. 15) gave the best yield, while each day's delay in weeding reduced yield by 24 kg/ha.

This yield loss from delayed weeding results from physical breakage of leaves and tillers and accidental removal of rice plants by careless weeders as well as early competition for nutrients and light. This factor, alone, is sufficient reason for continued efforts to find substitute means of controlling upland weeds.

Directed Spray Techniques and Materials

To maintain good weed control and to lower costs in upland rice, techniques for directing sprays or protecting rice plants from toxic chemicals may be valuable. This technique may permit the use of non-selective herbicides which normally are cheaper than selective ones.

To test a number of selective and non-selective herbicides as directed sprays, a field that had been in a weed fallow during the dry season was rotovated and drilled to rice in 30 cm rows at 80 kg/ha of viable seed. Two rice varieties with different characteristics were used: (a) Palawan which is a tall, medium-tillering, heavy-panicle, Philippine *indica* variety, is moderately resistant to lodging and has yielded well as upland rice; (b) PI 215936 which is a short, stiff-strawed, high-tillering *ponlai* variety also has yielded

Soil Chemistry

The main areas of research comprised mineral equilibria in reduced soils, chemical kinetics of flooded soils, chemical analysis of submerged soils, nutrient availability in flooded soils, and water regime in rice soils.

Experimental verification of the theoretical equations describing the $CaCO_3$-H_2O-CO_2 equilibrium was completed and evidence was found for the presence of $CaCO_3$ even in strongly acid soils after reduction. The $Fe_3(OH)_8$-H_2O-CO_2 system appeared to behave like a hydroxy carbonate system; so did reduced soils high in iron. Aqueous suspensions of reduced soils in equilibrium with pure CO_2 were found to have characteristic pH's, Eh's, and iron (II) hydroxide potentials, and the significance of this to soil testing was investigated.

The study of the influence of temperature on the chemical kinetics of flooded soils indicated that a soil temperature of 25 C was optimum for rice, while 15 C and 45 C were lethal, perhaps largely for chemical reasons.

Advances in the analysis of the solutions of flooded soils included: (a) direct gas chromatographic determination of CO_2 in aqueous solutions, (b) application of atomic absorption spectrophotometry to the determination of iron, manganese, and calcium, (c) ultraviolet spectrophotometry of nitrate and silica, and (d) potentiometric assay of sulphide and sodium.

Phosphate extracted from aerobic soils by Olsen's reagent was as good a measure of phosphorus availability to lowland rice as phosphate extracted from the reduced soils. The concentrations of N, P, and Fe in the active center leaves of the rice plant at maximum tillering and at panicle primordia initiation were highly correlated with the concentrations of these elements in the soil solutions at these two stages.

Outdoor drum studies with an acid soil, a nearly neutral soil, and a calcareous soil revealed that (a) mid-season soil drying caused substantial losses of nitrogen without compensating chemical benefits, and depressed the yield of rice, (b) flood fallowing between successive crops benefited rice, and (c) percolation at 1 cm per day caused a considerable loss of nitrogen without increasing yield significantly.

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Mineral Equilibria in Reduced Soils

Because of the tremendous role that carbon dioxide plays in mineral equilibria in flooded soils, theoretical and experimental studies of carbonate equilibria in simple systems and in reduced soils were continued with greater emphasis on their practical applications.

Experimental verification of the theoretical equations describing the $CaCO_3$-H_2O-CO_2 equilibrium was completed and the applicability of some of them to reduced soils was tested. Thermodynamic evidence was found for the presence of $CaCO_3$ even in strongly acid soils (after reduction). In spite of serious practical difficulties, the systems, $Fe_3(OH)_8$-H_2O-CO_2 and $FeCO_3$-H_2O-CO_2, were studied to shed light on the behavior of reduced soils. The $Fe_3(OH)_8$-H_2O-CO_2 system behaved like a hydroxy carbonate system rather than a hydroxide system in the CO_2 concentration range of 1 to 100 percent, while pure white $FeCO_3$ did not deviate appreciably from theory. Reduced soils high in iron behaved almost exactly like $Fe_3(OH)_8$.

Reduced soils equilibrated with pure CO_2 had pH values, redox potentials, and iron (II) hydroxide potentials which were characteristic of each soil. These values were used to derive the partial pressure of CO_2 and the concentration of Fe^{++} from the pH values of the solutions of submerged soils.

The $CaCO_3$-H_2O-CO_2 system

Of the theoretical equations that describe this equilibrium, two were confirmed experimentally and shown to apply to calcareous soils, both aerobic and anaerobic (Annual Report, 1964, 1965, 1966). They are:

$$pH = 5.99 - \tfrac{2}{3}\log P_{CO_2} + \tfrac{1}{3}(\log \gamma_{HCO_3^-} - \log \gamma_{Ca^{++}}) \quad (1)$$

$$pH + \tfrac{1}{2}\log Ca^{++} = 4.92 - \tfrac{1}{2}\log P_{CO_2} \quad (2)$$

This year, the validity of three more equations was tested experimentally. Also thermodynamic proof was found of the presence of $CaCO_3$ transitorily even in strongly acid soils (after reduction).

The following equations show that, in pure systems, the activities of Ca^{++} and HCO_3^- are single valued functions of the partial pressure of CO_2:

$$\log a_{Ca^{++}} = -2.15 + \tfrac{1}{3}\log P_{CO_2} - \tfrac{2}{3}(\log \gamma_{HCO_3^-} - \log \gamma_{Ca^{++}}) \quad (3)$$

$$\log a_{HCO_3^-} = -1.85 + \tfrac{1}{3}\log P_{CO_2} + \tfrac{1}{3}(\log \gamma_{HCO_3^-} - \log \gamma_{Ca^{++}}) \quad (4)$$

Under the same conditions the activities of HCO_3^- and Ca^{++} can be expressed as functions of pH:

$$\log a_{Ca^{++}} = 0.83 - \tfrac{1}{2}pH - \tfrac{1}{2}(\log \gamma_{HCO_3^-} - \log \gamma_{Ca^{++}}) \quad (5)$$

and

$$\log a_{HCO_3^-} = 1.13 - \tfrac{1}{2}pH + \tfrac{1}{2}(\log \gamma_{HCO_3^-} - \log \gamma_{Ca^{++}}) \quad (6)$$

To test the validity of these equations, aqueous suspensions of $CaCO_3$ (calcite) were equilibrated with varying concentrations of CO_2. pH and the concentrations of HCO_3^- and Ca^{++} were determined for each equilibration. The activity coefficients of HCO_3^- and Ca^{++}

Table 1. Experimental values of the constants in equations 3 to 6 at different partial pressures of CO_2 at 25 C.

$\log P_{CO_2}$	pH	$\log a_{HCO_3}$	$\log a_{Ca^{++}}$	K_3	K_4	K_5	K_6
−0.015	6.06	−1.793	−2.291	−2.16	−1.85	0.83	1.14
−0.442	6.32	−1.954	−2.430	−2.16	−1.86	0.83	1.13
−0.617	6.41	−2.001	−2.464	−2.15	−1.86	0.82	1.13
−1.001	6.71	−2.151	−2.595	−2.16	−1.86	0.83	1.14

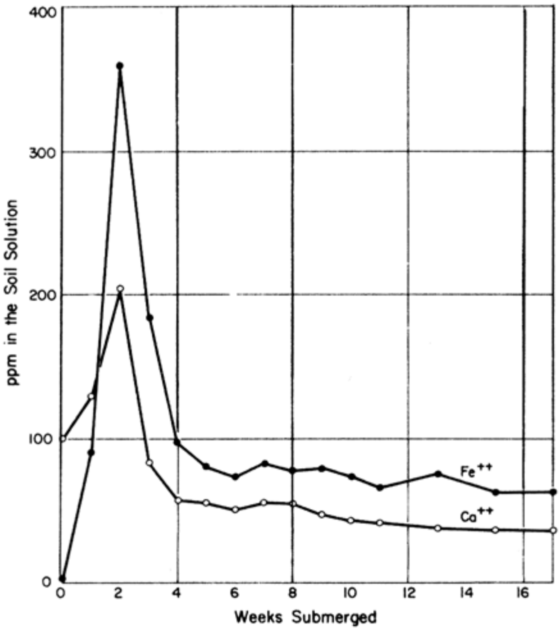

Fig. 1. Kinetics of water-soluble Fe^{++} and Ca^{++} in a submerged latosolic soil.

were derived from the ionic strengths. The good agreement between the theoretical and experimental values of the constants in the CO_2 range of 0.1 to 1 atm. can be seen in Table 1.

The chemical kinetics of flooded soils shows that the concentrations of metallic cations in the soil solution reach roughly coincident maxima 2 to 4 weeks after flooding and then decline. The increase in concentration of Fe^{++} and Mn^{++} is due to soil reduction, and the subsequent decrease to precipitation of $Fe_3(OH)_8$, $FeCO_3$, and $MnCO_3$ (Annual Report, 1964). The parallel changes in concentrations of Mg^{++}, Ca^{++}, K^+, and Na^+ in acid soils reflect cation exchange reactions (Fig. 1). The temporary increase in water-soluble Ca^{++}, the pH increase following soil reduction, and the increase in P_{CO_2} may all combine to bring about a $(Ca^{++}) \times (CO_3^{--})$ product exceeding $10^{-8.33}$, the solubility product (Ks) of $CaCO_3$. Unless the solution is supersaturated with respect to $CaCO_3$, or forms more soluble than calcite are involved, a pKs of 8.33 or slightly less or a pH $+ \frac{1}{2}$ log Ca^{++} $+ \frac{1}{2}$ log P_{CO_2} value slightly exceeding 4.92 implies the presence of solid phase $CaCO_3$ in the system. Table 2 shows that $CaCO_3$ may be present in Maahas soil from 1 to 15 weeks of submergence, barring the 6 to 8-week period, and 2 to 8 weeks after flooding in Albay fine sandy loam. Table 3 shows that $CaCO_3$ appears early and lasts longest in the nearly neutral soils, followed by sandy soils high in organic matter. Even in a strongly acid soil like Luisiana clay (Soil no. 21), $CaCO_3$ made a transitory appearance at the peak of water-soluble Fe^{++} and Ca^{++}. But the slight effervescence observed with reduced Luisiana clay treated with dilute HCl could have been due to $CaCO_3$, $MnCO_3$, or $FeCO_3$, not necessarily to $CaCO_3$.

The presence of $CaCO_3$ in reduced soils poses a problem in the nomenclature of soils. Strongly acid soils, after undergoing reduction may have a pH which is more than 7; they may also contain solid phase $CaCO_3$; and if CO_2 is expelled, the pH may rise to 8.5 (Annual Report, 1965). Can such soils be called calcareous?

The $Fe_3(OH)_8$-H_2O-CO_2 and $FeCO_3$-H_2O-CO_2 systems

Ten to 100 tons of $Fe_3(OH)_8$ may be present in the root zone of a hectare of flooded rice fields. This substance gives reduced soils their grey color, buffers pH's at 6.5 to 7.2, and markedly influences equilibria in these soils through its interaction with CO_2. Because little is known about this interaction, a theoretical and experimental study of the $Fe_3(OH)_8$-H_2O-CO_2 system

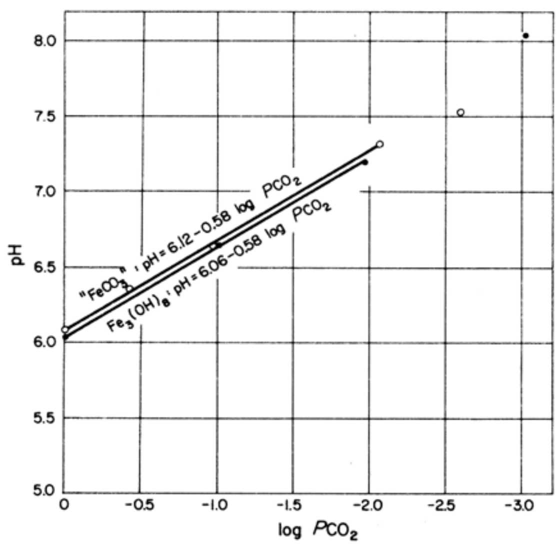

Fig. 2. Relationship between P_{CO_2} and the pH of aqueous suspensions of "$FeCO_3$" and $Fe_3(OH)_8$ at 25 C.

Table 2. Influence of the kinetics of pCa^{++} and pCO_3^{--} of the solutions of two submerged soils on $pK_{s_{CaCO_3}}$.

Weeks submerged	Maahas clay, pH 6.6, O.M. 2.0%			Albay fine sandy loam, pH 5.7, O.M. 8.0%		
	pCa^{++}	pCO_3^{--}	$pK_{s_{CaCO_3}}$	pCa^{++}	pCO_3^{--}	pK_s
1	2.52	5.78	8.30	2.55	6.08	8.63
2	2.57	5.44	8.01	2.52	5.76	8.28
4	2.86	5.31	8.17	2.58	5.62	8.20
6	3.11	5.42	8.53	2.51	5.64	8.15
8	2.82	5.55	8.37	2.61	5.67	8.28
10	2.69	5.52	8.21	2.89	5.79	8.68
15	2.78	5.45	8.23	2.76	5.68	8.44

Table 3. Influence of soil properties on the residence time of $CaCO_3$ in flooded soils.

Soil no.	Texture	pH	O.M. %	Weeks after flooding
1	fine sand	7.6	2.8	0–17
26	clay loam	7.6	1.5	0–17
17	clay	7.0	1.8	0–17
4	clay	6.9	2.0	1–11
27	clay	6.6	2.0	1–15
7	clay	5.9	3.3	4–11
23	fine sandy loam	5.7	8.0	3–15
3	clay	5.7	1.3	4–6
24	sandy loam	5.3	3.8	2–9
25	fine sandy loam	4.8	4.4	2–9
21	clay	4.6	4.1	2–3

was undertaken.

If $Fe_3(OH)_8$ is the only solid phase present, the following equations should describe the $Fe_3(OH)_8$-H_2O-CO_2 equilibrium:

$$pH = 6.19 - \tfrac{1}{3} \log P_{CO_2} + \tfrac{1}{3} (\log \gamma_{HCO_3^-} - \log \gamma_{Fe^{++}}) \quad (7)$$

$$pH + \tfrac{1}{2} \log Fe^{++} = 5.20 \quad (8)$$

$$\log a_{Fe^{++}} = -1.94 + \tfrac{2}{3} \log P_{CO_2} - \tfrac{2}{3} (\log \gamma_{HCO_3^-} - \log \gamma_{Fe^{++}}) \quad (9)$$

To test the validity of these equations, aqueous suspensions of $Fe_3(OH)_8$ were prepared by washing (until free from sulphate) the green precipitate obtained by adding 0.1N NaOH to a 1 : 5 mixture of 0.05M $Fe_2(SO_4)_3$ and 0.05 M $FeSO_4$. Portions of the suspension were equilibrated with CO_2-N_2 mixtures at 25 C and pH, Eh, and the concentration of water-soluble Fe^{++} determined. Figure 2 shows that the regression of pH on log P_{CO_2} deviates from the theoretical equation: the intercept is smaller while the gradient is considerably bigger numerically than the theoretical slope of 0.33. The concentrations of water-soluble Fe^{++}, however, are of the order predicted by equations (8) and (9) (Table 4). Apparently, $Fe_3(OH)_8$ was behaving like a hydroxy carbonate. The presence in the equilibration vessel of a solid that effervesced with dilute HCl confirmed this.

Because of high concentrations of CO_2, $Fe_3(OH)_8$ tends to form ferrous carbonate, and $FeCO_3$ is sometimes found in flooded soils, the $FeCO_3$-H_2O-CO_2 system was next studied. $FeCO_3$, obtained as a pale-green precipitate by adding a solution of sodium carbonate to a solution of ferrous sulphate, was washed free of sulphate and equilibrated with CO_2-N_2 mixtures. The pH-log P_{CO_2} relationship for this system is shown in Fig. 2. In this case, the intercept is bigger and the gradient is numerically smaller than required by the theoretical equation:

$$pH = 5.21 - \tfrac{2}{3}\log P_{CO_2} + \tfrac{1}{3}(\log \gamma_{HCO_3^-} - \log \gamma_{Fe^{++}}) \qquad (10)$$

The near identity of the observed relationship with that of $Fe_3(OH)_8$ (Fig. 2 and Table 4) suggested that the pale-green precipitate of "$FeCO_3$" was behaving like a hydroxy carbonate.

To eliminate hydroxide interference, pure white $FeCO_3$ was prepared by another method: fine iron powder was swirled magnetically with de-aerated water in a stream of CO_2 and the suspension of the fine white $FeCO_3$ particles was siphoned off. Equilibration of this suspension with CO_2-N_2 mixtures gave results in reasonably good agreement with theory (Table 5). The pH, the hydroxide potential, and the concentrations of water-soluble Fe^{++} are slightly higher than the theoretical values. This may be due to the greater solubility of the very fine $FeCO_3$ particles prepared by this method. Considering this and the long time required for equilibration (18-21 days), these figures may be taken as proof of the validity of the theoretical equations describing the $FeCO_3$-H_2O-CO_2 system.

Carbonate systems in reduced soils

Earlier (Annual Report, 1965, 1966), it was shown that aqueous suspensions of sodic and calcareous soils equilibrated with CO_2 behaved like the corresponding pure systems. This year, a similar study of acid soils (after reduction)

Table 4. Comparison of theoretical and observed values of pH and the concentrations of water-soluble Fe^{++} in aqueous suspensions of $Fe_3(OH)_8$ and "$FeCO_3$", each at two concentrations of CO_2, at 25 C.

CO_2 %	$Fe_3(OH)_8$-H_2O-CO_2				"$FeCO_3$"-H_2O-CO_2			
	pH		Fe^{++} (mmoles/l)		pH		Fe^{++} (mmoles/l)	
	Theo.	Obs.	Theo.	Obs.	Theo.	Obs.	Theo.	Obs.
99.99	6.27	6.05	16.8	14.2	5.24	6.05	1.25	14.6
13.91					5.80	6.54	0.93	4.00
10.31	6.90	6.64	3.08	4.27				

Table 5. Comparison of observed and theoretical pH, hydroxide potential, and concentration of water-soluble Fe^{++} in a suspension of $FeCO_3$ equilibrated with CO_2, at 25 C.

Log P_{CO_2}	pH		pH + ½ log Fe		Fe^{++} (mmoles/l)	
	Theo.	Obs.	Theo.	Obs.	Theo.	Obs.
−0.016	5.24	5.29	3.76	3.80	1.43	1.57
−0.673	5.69	5.83	4.09	4.28	0.25	0.95
−5.000	8.54	8.40	6.25	6.44	0.03	0.12

Table 6. Influence of duration of submergence of a latosolic soil on the pH, Eh, concentration of water-soluble Fe^{++} and the thermodynamic properties, Eh + .059 pH and pH + $\frac{1}{2}$ log Fe^{++}, of aqueous suspensions of the soil equilibrated with 100% CO_2.

Days submerged	pH	Eh (mv)	Fe^{++} (mmoles/l)	Eh + .059 pH (volts)	pH + ½ log $a_{Fe^{++}}$
15	5.70		0.45	(solid $Fe_3(OH)_8$ absent)	
54	6.10	176	16.3	0.535	5.08
61	6.10	163	16.2	0.522	5.09
72	6.10	165	15.9	0.524	5.08
110	6.10	165	15.5	0.524	5.09

Table 7. The characteristic pH values, Eo's and iron (II) hydroxide potentials ($pFe(OH)_2$) of five reduced soils.

Soil no.	Texture	pH	O.M. (%)	Fe (%)	Mn (%)	pH_O	Eo (volts)	$pFe(OH)_2$
14	clay	4.6	2.8	2.1	0.06	6.13	0.53	5.21
28	clay	4.7	3.2	2.9	0.05	6.10	0.52	5.13
7	clay	5.9	3.3	1.7	0.33	6.12	0.56	5.09
27	clay	6.6	2.0	1.6	0.31	6.11	0.57	4.90
26	clay loam	7.6	1.5	0.3	0.06	6.11	0.65	4.83

Table 8. Redox potentials and the concentrations of Fe^{++} in the solutions of four submerged soils at two pH values.

Soil no.	pH: 6.60			pH: 6.40		
	Eh	Fe (ppm)		Eh	Fe (ppm)	
	(mv)	Exp.	Calc.	(mv)	Exp.	Calc.
14	66	100	108	121	319	334
28	59	78	72	112	308	291
27	118	32	27	(No sample at this pH)		
26	212	24	18	255	56	67

showed that those high in iron behaved like $Fe_3(OH)_8$. Further, it was found that (a) reduced soils equilibrated with pure CO_2 had characteristic pH values, redox potentials, and iron (II) hydroxide potentials, and (b) these values could be used to predict the concentrations of CO_2 and Fe^{++} in reduced soils from their pH's.

Last year (Annual Report, 1966), thermodynamic evidence was provided for the presence of $Fe_3(OH)_8$ in reduced soils after the peak of water-soluble Fe^{++}. In view of the current interest in continuous rice culture in continuously saturated soils, the persistence of $Fe_3(OH)_8$ (a metastable substance with a tendency to change to Fe_3O_4) assumes importance. Table 6 shows that there is no significant change in the thermodynamic properties (associated with $Fe_3(OH)_8$ of the latosolic soil, pH: 4.6; O.M.:

3.2%; Fe: 2.9%) over a 110-day period of submergence. Two other latosolic soils behaved similarly. This means that though $Fe_3(OH)_8$ changes easily to Fe_3O_4 *in vitro,* it is stable in reduced soils, apparently because crystallization, as with $Fe(OH)_3$, is retarded by soil organic matter.

Two reduced latosolic soils, whose properties are in Table 7, equilibrated with 1 to 100 percent CO_2 behaved almost like $Fe_3(OH)_8$ as seen below.

System	Regression	Fe^{++} (mmoles/l) (for 100% CO_2)
$Fe_3(OH)_8$	$6.10 - 0.58 \log P\text{co}_2$	14.2
Soil No. 14	$6.13 - 0.57 \log P\text{co}_2$	16.7
Soil No. 28	$6.10 - 0.5 \log P\text{co}_2$	15.9
Soil No. 21	$6.10 - 0.58 \log P\text{co}_2$	—

The pH-log$P\text{co}_2$ relationships for the solution of another reduced latosolic soil (Soil No. 21) sampled at eight fortnightly intervals was identical with that for $Fe_3(OH)_8$.

Thus, carbonate equilibria, like redox equilibria (Annual Report, 1965) in reduced soils rich in iron, are regulated by $Fe_3(OH)_8$.

Application of carbonate equilibria to soil testing

The studies of the equilibration of reduced soils with CO_2 revealed certain features of flooded soils that may prove useful in soil testing.

Each of the five reduced soils, sampled at intervals during a 110-day submergence period and equilibrated with pure CO_2, gave pH, Eh, and Fe^{++} activities in the soil solution which were reproducible to 0.01 unit, but differed from soil to soil. The pH, Eh, and Fe^{++} activities of reduced soils, in equilibrium with pure CO_2, appeared to be basic properties characteristic of each soil. As (Eh + .059 pH = Eo) and pH + $\frac{1}{2}\log a_{Fe^{++}}$ or the iron (II) hydroxide potential are thermodynamically more meaningful than Eh and $a_{Fe^{++}}$, these values, along with the characteristic pH values of five soils, are given in Table 7.

The pH_O of all five soils, regardless of initial pH or other soil properties, is about 6.1, the pH of an aqueous suspension of $CaCO_3$ or $Fe_3(OH)_8$ in equilibrium with pure CO_2. But E_O increases and the characteristic hydroxide potential decreases as the iron content of the soils falls and the manganese content rises. This means that at a given pH, the soils high in Fe and low in Mn (Nos. 14 and 28) will have lower redox potentials and higher concentrations of water-soluble iron than the other soils. Table 8 confirms this. It also shows a fairly good agreement between the observed Fe^{++} concentrations and those derived from the pH and the characteristic hydroxide potentials. Table 9 shows that the experimental relationship between pH and $P\text{co}_2$ of an aqueous suspension of $Fe_3(OH)_8$ can be used to deduce the $P\text{co}_2$ of the solution of a reduced latosolic soil from its pH. Similarly, the $P\text{co}_2$ of a calcareous soil can be deduced from its pH using the expression pH = 6.1 — $\frac{2}{3}\log P\text{co}_2$, as seen below for Soil no. 26, a calcareous clay loam.

pH	$P\text{co}_2$ (atm) Exptl.	Calc.
6.40	0.34	0.36
6.45	0.32	0.30
6.60	0.15	0.18
6.82	0.086	0.083

These studies show that the pH and iron (II) hydroxide potential of a reduced soil in equilibrium with pure CO_2 may be used to predict the concentration of Fe^{++} and the partial pressure of CO_2 in the soil solution at any observed pH.

Table 9. Comparison of the observed $P\text{co}_2$'s of the solutions of a submerged acid clay high in iron with the $P\text{co}_2$'s derived from the pH of the solutions using the equation, pH = 6.1—0.58 log $P\text{co}_2$.

Weeks submerged	pH	$P\text{co}_2$ in atm. Obs.	Calc.
2	6.57	0.15	0.16
4	6.63	0.13	0.12
6	6.68	0.12	0.10
8	6.60	0.13	0.14
10	6.70	0.10	0.09
12	6.72	0.08	0.09

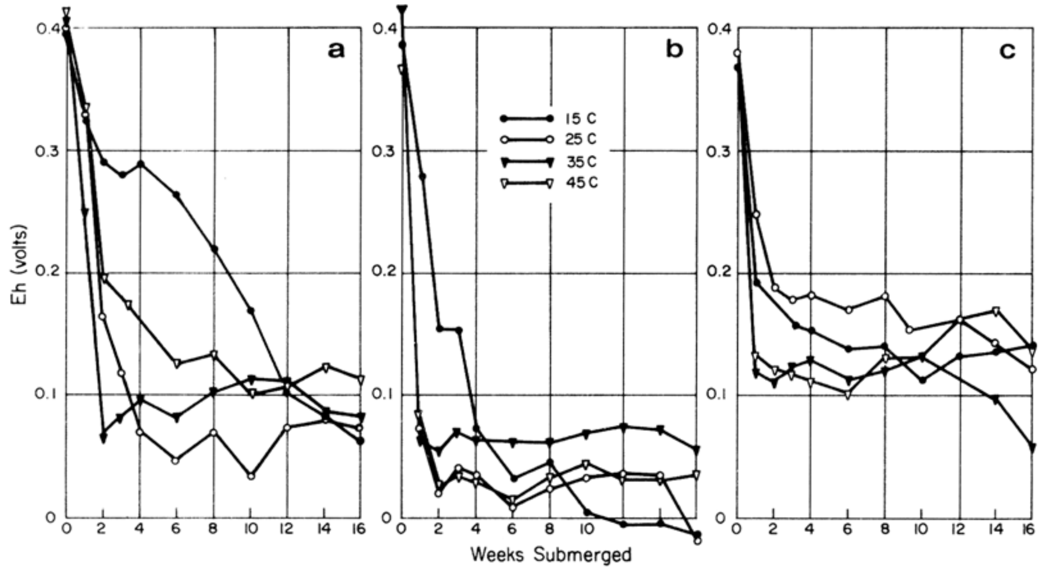

Fig. 3. Kinetics of solution Eh in (a) Luisiana clay, (b) Tungshan silt loam, and (c) Casiguran sandy loam.

Temperature and the Chemical Kinetics of Flooded Soils

The temperature of flooded rice soils at transplanting may range from 15 C in northern latitudes to 40 C in equatorial lowlands. In the temperate zone, soil temperature rises with the maturing crop and may reach 40 C in late summer, and indeed some physiological disorders of rice have been attributed to this temperature regime. In the tropics, at sea level, soil temperature is relatively constant around 30 C.

Soil temperature markedly influences the biochemical processes that release plant nutrients or produce substances toxic to rice; it also affects the rate of water and nutrient absorption. Because of the paucity of information on the effect of temperature on the chemical environment in flooded soils, a study of the chemical and electrochemical kinetics of 8 flooded soils maintained at 15, 25, 35, and 45 C in the greenhouse for 16 weeks was undertaken.

The soils were mixed with 0.16 percent of a 1:4 mixture of chopped straw and fresh *Glyricidia setium* and placed in 15-liter pots fitted with soil solution sampling tubes. The pots were placed in the constant temperature waterbaths and a single 20-day-old IR8 seedling planted in each pot. The soil solutions were sampled weekly for 4 weeks and fortnightly thereafter. Redox potential, pH, and specific conductance were determined at 25 C. Chemical analyses included NH_4^+, K^+, Fe^{++}, Mn^{++}, Ca^{++}, Mg^{++}, HCO_3^-, $H_2PO_4^-$, and reducing substances.

Temperature profoundly influenced the chemical and electrochemical kinetics of the soils and the growth of the rice plants. Soil reduction and the accompanying chemical changes were slowest at 15 C, fastest at 25 C and 35 C, and intermediate at 45 C. However, a marked interaction of soil with temperature, which may have a bearing on certain physiological disorders of rice, was observed. The optimum temperature for the growth of rice was 25 C. At 15 C and 45 C, measurable growth was observed only on two fertile soils (Maahas clay and Casiguran sandy loam).

Eh of the soil solutions

The rate of Eh decrease during the first 2 weeks after flooding was in the order 25 C > 35 C > 45 C > 15 C for most soils but the extent of retardation by too low or too high a temperature varied with the soil (Fig. 3a, b, c). The fairly stable potentials attained after 12 weeks of submergence were (with two exceptions) in the following order: 45 C > 35 C > 15 C > 25 C.

Although the initial decline in the Eh was slow at 15 C, after 16 weeks' submergence Eh's at this temperature were as low as those at 25 C. Both rate and intensity of reduction were highest at 25 C.

pH of the soil solution

The increase in pH of acid soils or the decrease in pH of sodic and calcareous soils, with the accompanying release of nutrients and removal of injurious substances, is one of the important

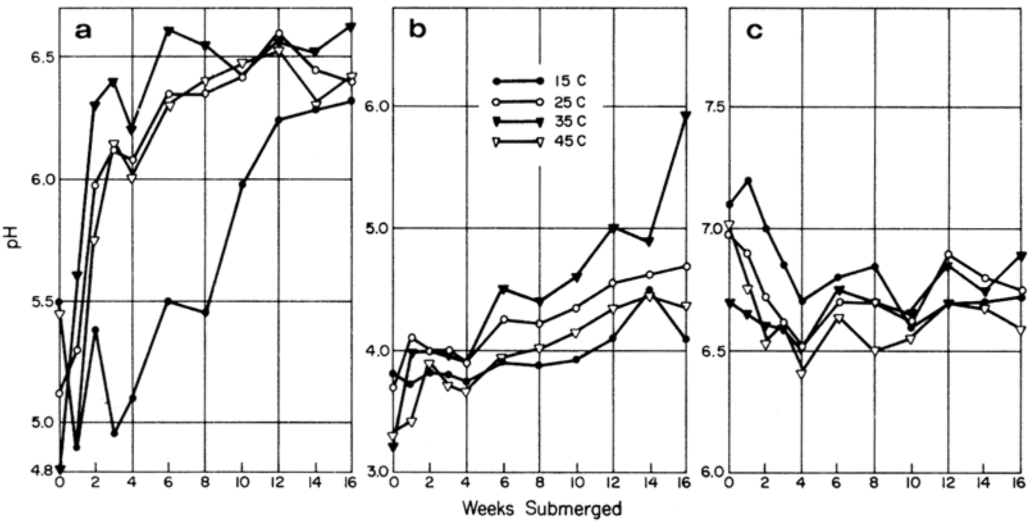

Fig. 4. Kinetics of solution pH in (a) Luisiana clay, (b) acid-sulfate clay, and (c) Pila clay loam.

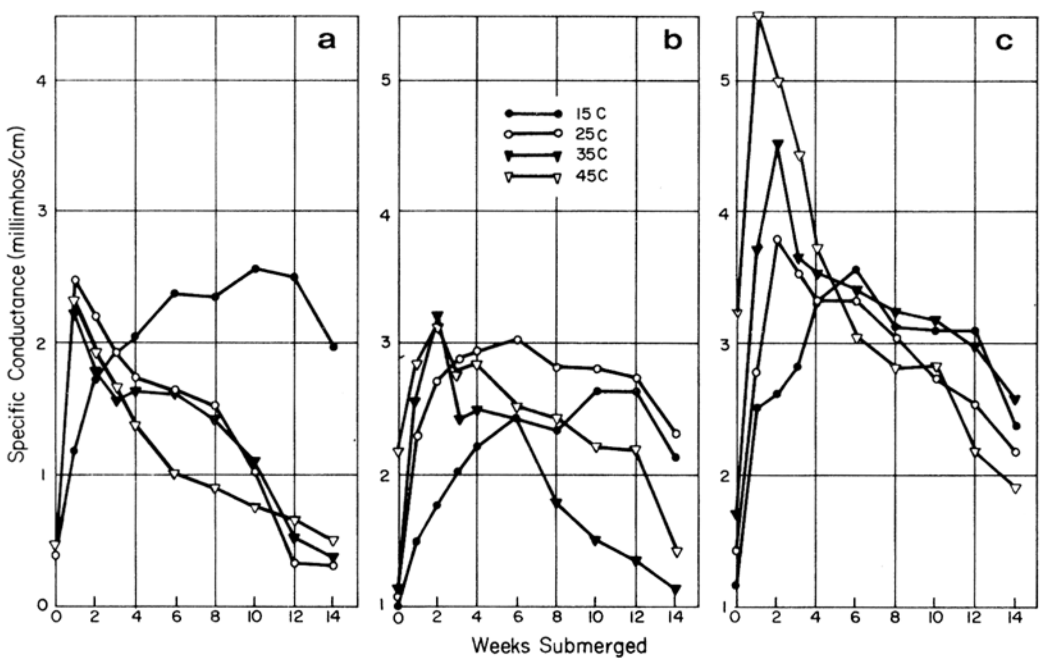

Fig. 5. Kinetics of specific conductance in (a) Casiguran sandy loam, (b) Pila clay loam, and (c) Tungshan silt loam.

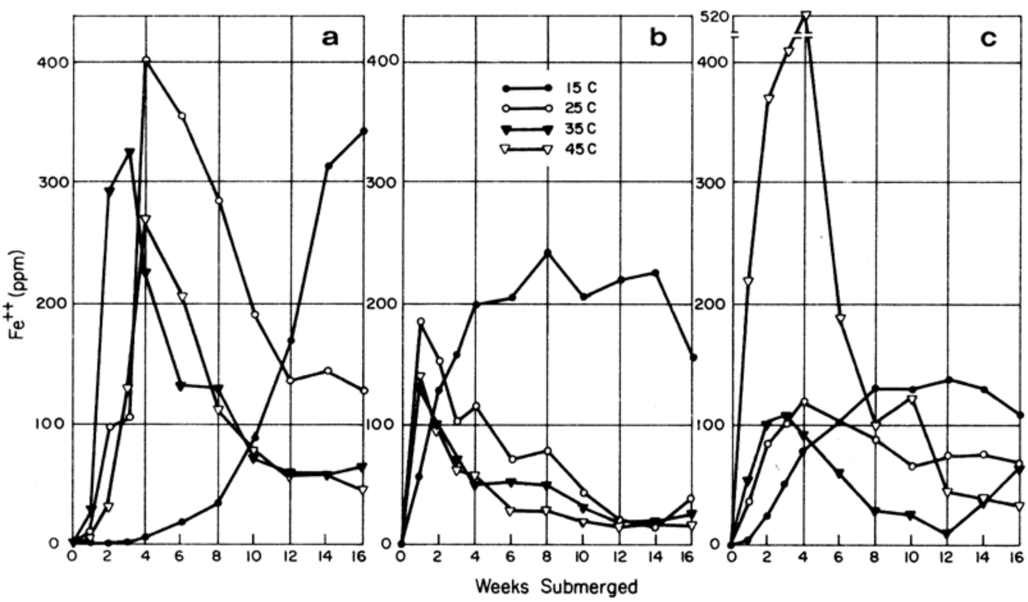

Fig. 6. Kinetics of water-soluble Fe^{++} in (a) Luisiana clay, (b) Casiguran sandy loam, and (c) Akiochi soil from Korea.

benefits of flooding rice soils. In fact, it is the pH increase on flooding that enables rice to avert aluminum toxicity on acid-sulfate soils (Annual Report, 1965). As these changes depend on soil reduction and CO_2 production, both of which are biochemical processes, temperature should markedly influence pH kinetics.

All soils, at all temperatures, except the three strongly acid soils at 15 C, attained their maximum (or minimum in the case of the calcareous soil) fairly stable pH, within 6 weeks of submergence. The rate of change was generally in the order: 35 C > 25 C > 45 C > 15 C. The influence of temperature was marked in the Luisiana clay and in the acid-sulfate clay and least in the calcareous clay loam (Fig. 4a, b, c). In acid-sulfate soils a rapid increase in pH is advantageous because aluminum toxicity disappears above a pH of 4.1 (Annual Report, 1965). Fig. 4a shows that this critical pH was attained within a week of flooding at 25 C and 35 C; at 15 C, it took more than 10 weeks.

Specific conductance

Temperature markedly influenced the kinetics of specific conductance (Fig. 5a, b, c). In most soils, peak values were highest at 45 C. Specific conductance exceeding 4 millimhos per cm (the threshold at which rice seedlings show injury) were observed in the acid-sulfate soil at all temperatures during the entire period of submergence and during the first 4 weeks in Tungshan silt loam at 45 C.

Water-soluble iron

The kinetics of water-soluble iron is a good example of the interaction between soil and temperature. Although the rate of mobilization of Fe^{++} generally was slowest at 15 C and fastest at 25 C or 35 C, Fe^{++} kinetics did not follow consistent patterns. In Casiguran sandy loam, 15 C produced the highest and 45 C, the lowest concentrations of Fe^{++}; in the silt loam from Korea, this relationship was reversed (Fig. 6b, c). At 25 C, 35 C, and 45 C, Fe^{++} kinetics followed the usual pattern of a rapid increase in Fe^{++} concentrations to a peak value followed by a decline to considerably lower levels (Fig. 6a); 15 C markedly delayed the peak in Luisiana clay, less so in Korean soil, and hardly in Casiguran sandy loam (Fig. 6a, b, c). A temperature of 15 C delayed the release of water-soluble iron, but did not prevent the build-up of high, persistent concentrations. The

Table 10. Concentrations of NH_3 in the solutions of seven soils (kept submerged at four temperatures), at times corresponding to peak NH_3 at 45 C for each soil.

Temperature (C)	Soil no.						
	37	25	28	58	40	26	13a
	(ppm NH_3-N)						
45	155	90	72	65	53	17	12
35	91	64	49	22	44	14	10
25	52	52	42	14	36	11	9
15	34	14	14	5	30	5	5

anomalous behavior of the Korean soil at 45 C is noteworthy (Fig. 6c). Could this high concentration of water-soluble Fe^{++} be a contributory cause of Akiochi or autumn decline, frequently attributed to high soil temperature?

Water-soluble manganese

The kinetics of water-soluble Mn^{++} were similar to those of Fe^{++} (Fig. 7a, b, c) but low-temperature retardation was less severe and the differences among 25 C, 35 C, and 45 C less marked.

Water-soluble ammonia

The influence of temperature on the kinetics of water-soluble NH_3 is difficult to interpret because of cation exchange reactions and differential plant growth. However, the peak values of NH_3 for all soils followed this order: 45 C > 35 C > 25 C > 15 C (Table 10).

As temperature increased, the concentration of NH_3 in the soil solution increased. The absolute difference was most marked in Tungshan silt loam (Soil no. 37) while the relative increase was highest in the Korean soil (Soil no. 58).

A temperature of 25 C retards nitrogen release without appreciably slowing down the growth of rice. Therefore, rice fields in cool regions may require more nitrogen fertilizer at planting than in warmer areas. By contrast, in the tropics,

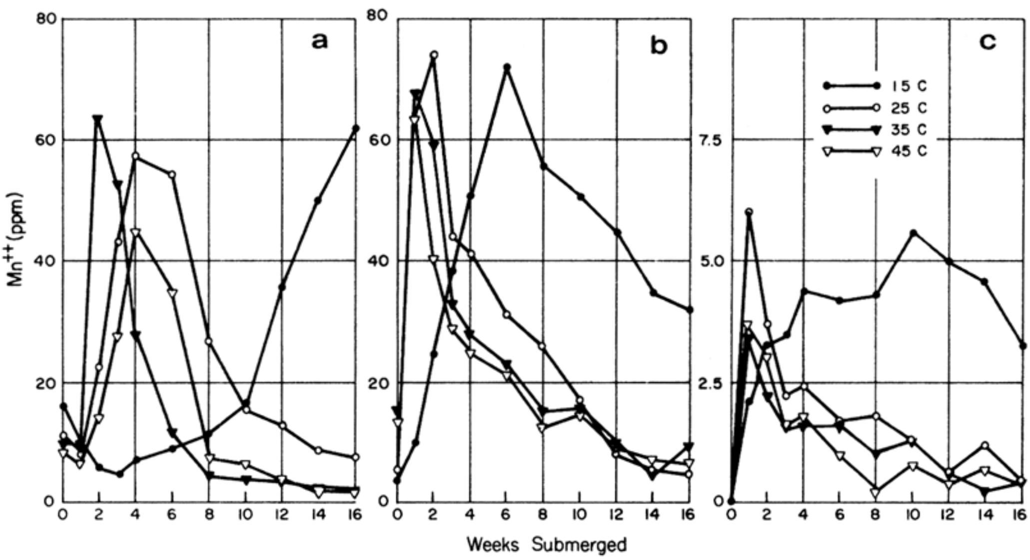

Fig. 7. Kinetics of water-soluble Mn^{++} in (a) Luisiana clay, (b) Maahas clay, and (c) Casiguran sandy loam.

excessive nitrogen fertilization at planting may injure rice seedlings on low cation exchange capacity soils high in organic matter.

Reducing substances

The concentration of substances in the soil solution that reduce potassium permanganate under mild conditions may be regarded as a measure of the reduction stress on rice roots.

Temperature markedly influenced the kinetics of reducing substances. The concentrations were highest and remained so longest at 45 C in all soils, in contrast to those of Fe^{++}; at other temperatures they ran parallel to Fe^{++} (Fig. 8a, b, c).

High concentration of reducing substances may be one of the causes of physiological disorders of rice attributed to high soil temperature.

Partial pressure of carbon dioxide

The partial pressure of CO_2 of a soil solution is a good measure of its H_2CO_3 concentration. As excess H_2CO_3 is reported to hinder water and nutrient uptake by rice, the kinetics of P_{CO_2} in the soils (derived from pH and methyl orange alkalinity of the solutions) was followed.

Soil properties influenced the mean P_{CO_2} more than did temperature. The highest P_{CO_2}'s at all temperatures were in the three acid soils high in organic matter. Two of these (Soil nos. 58 and 25) were sandy soils low in active iron. Maahas clay (Soil no. 27) had the lowest mean P_{CO_2} at all temperatures except at 45 C. The effect of temperature was not consistent; in the three acid soils (nos. 58, 28, and 25), P_{CO_2}'s at 15 C and 45 C were higher than those at 25 C or 35 C; in the other soils (except no. 13a) they tended to increase with temperature (Table 11).

Harmful concentrations of H_2CO_3 were present in the acid soils at 15 C and 45 C during the first 6 to 8 weeks after flooding.

Growth of rice

To observe the response of rice to differences in soil temperature, a single 20-day-old IR8 seedling was planted per pot in the eight flooded soils maintained at 15 C, 25 C, 35 C, and 45 C. The tops were exposed to the greenhouse temperature.

Within 3 days of transplanting, seedlings in the acid-sulfate soil and the Akiochi soil from Korea at 45 C were dead; at the end of 3 weeks, only the plants on Maahas clay and Casiguran sandy loam, though severely stunted, were alive. The symptoms preceding death were leaf roll, followed by drying and death of the lower leaves. Three weeks later, the plant on Casiguran sandy loam made a dramatic recovery while that on Maahas clay eked out a miserable existence.

At 25 C and 35 C, rice plants on all soils except the acid-sulfate soil and Tungshan silt loam (a

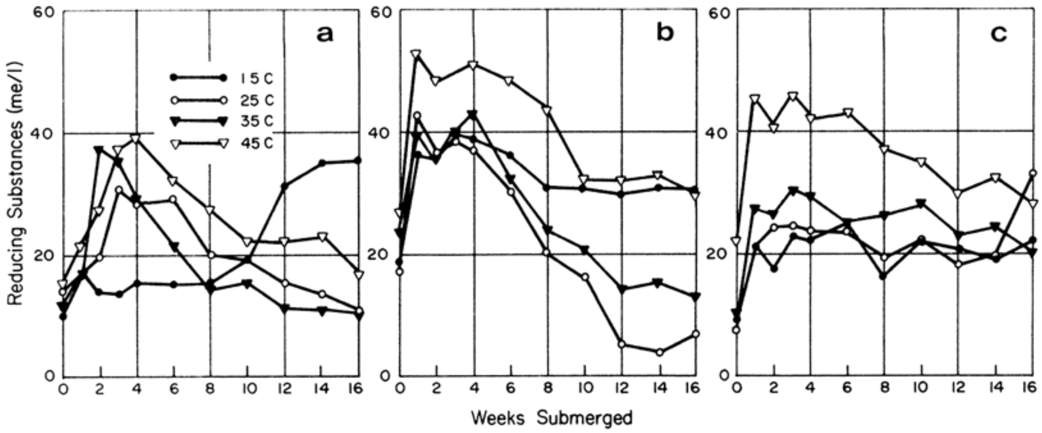

Fig. 8. Kinetics of water-soluble reducing substances in (a) Luisiana clay, (b) Casiguran sandy loam, and (c) Tungshan silt loam.

Table 11. Influence of temperature on the mean partial pressure of CO_2 over a 16-week period in seven submerged soils.

Temperature (C)	Soil no.						
	58	28	25	13a	37	26	27
	Mean P_{CO_2} (atm)						
15	0.58	0.59	>1*	0.34	0.19	0.20	0.12
25	0.40	0.49	0.42	0.33	0.25	0.31	0.19
35	0.30	0.32	0.44	0.22	0.34	0.24	0.20
45	>1*	0.44	0.39	0.20	0.30	0.35	0.25

* Unreliable because of the error caused by the presence of organic acids.

problem soil from Taiwan) grew normally and produced grain.

At 15 C, growth on all soils was uniformly and severely retarded, but the foliar symptoms varied with the soil. Leaf roll and drying of the older leaves were the striking symptoms on Casiguran sandy loam, Luisiana clay, the acid-sulfate soil, and the Akiochi soil from Korea; on Pila clay loam and Marilao clay loam, they were yellowing of the older leaves. In addition, a reddish discoloration of the tips was observed in all plants except on Maahas clay. Eight weeks after planting, the plants on the acid-sulfate soil, Tungshan silt loam, and Marilao clay loam were dead.

Although this is not a replicated experiment, the yield differences in Table 12 are so striking as to warrant the following conclusions: (a) the optimum soil temperature was 25 C; (b) 45 C was lethal on all soils except Casiguran sandy loam and Maahas clay; (c) 15 C killed the plants on three soils and severely stunted them on the others; (d) plants on Maahas clay and Casiguran sandy loam withstood the adverse effects of 15 C and 45 C much better than the other soils; and (e) the plants fared worst at all temperatures on the two problem soils (the acid-sulfate soils and Tungshan silt loam).

It is difficult to interpret plant performance in terms of the chemical kinetics of the soils alone because of the complications caused by temperature effects on nutrient absorption and root metabolism. But the fact that the rice plant on Maahas clay produced a total of 44 g dry matter at 15 C and that on Casiguran sandy loam 67 g at 45 C indicates that temperature *per se* did not kill the plants on the other soils at 15 C and 45 C; the lethal factor must have been the chemical environment.

The component of the chemical environment that retarded growth or killed the plants apparently varied with the soil and temperature. On Pila and Marilao clay loam at 15 C, the limiting factor appeared to be nitrogen deficiency induced by a low level of water-soluble NH_3 (Table 10) coupled with slow absorption, while ammonia toxicity might have been a retarding factor on Luisiana clay and Casiguran sandy loam at 45 C. The level of water-soluble P at 15 C was less than those at 25 C and 35 C (Table 13). This along with retardation of absorption at low temperature may have been a limiting factor in some of the acid clays.

Rolling and drying of the leaves was observed on the acid-sulfate clay, the Korean soil, Luisiana clay, and Casiguran sandy loam, at both 15 C and 45 C. As excess electrolyte was present only in the acid-sulfate soil, the apparent water-stress in the other soils may be attributed to excess CO_2. Table 11 shows high P_{CO_2}'s for these soils at 15 C and 45 C. The dramatic recovery of the plants on Casiguran sandy loam at 45 C may be associated with the steep drop in the partial pressure of CO_2 that occurred 6 weeks after planting, as seen below.

	Weeks submerged						
	1	2	4	6	8	10	12
P_{CO_2} (atm)	>1	0.67	0.60	0.17	0.18	0.18	0.16

Table 12. Influence of soil temperature on the growth and yield of rice on eight submerged soils.

Soil No.	Soil Name	pH	O.M. (%)		Temperature (C) 15	25	35	45
					(g/pot)			
27	Maahas clay	6.6	2.0	straw	27	95	97	0.5
				grain	17	93	81	0
28	Luisiana clay	4.6	3.2	straw	1.0	35	16	0
				grain	0	37	15	0
26	Pila loam	7.6	1.5	straw	1.2	42	33	0
				grain	0	27	36	0
25	Casiguran sandy loam	4.8	4.0	straw	4.7	64	63	28
				grain	0.9	83	94	39
40	Acid-sulfate clay	3.6	9.6	straw	0	0.8	0	0
				grain	0	0.4	0	0
37	Tungshan silt loam	5.8	3.4	straw	0	0.4	1.2	0
				grain	0	0	0	0
13a	Marilao clay loam	4.7	1.3	straw	0	21	17	0
				grain	0	27	18	0
58	Silt loam (Korea)	5.8	4.3	straw	0.1	21	31	0
				grain	0	31	40	0
					Mean			
				straw		34.9	29.8	
				grain		37.3	35.5	

Conclusions

A soil temperature of 15 C is chemically unfavorable for the growth of rice in flooded soils because (a) it slows down the release of N and P, (b) it retards the increase in pH of acid soils, and (c) it permits the build-up of high concentrations of H_2CO_3. At 45 C the adverse chemical factors may be an excess of one or more of the following: NH_3, Fe^{++}, H_2CO_3, reducing substances. A soil temperature of 25 C to 35 C is optimum for rice from the standpoint of the chemical kinetics of flooded soils because nutrient release is adequate and high concentrations of harmful substances are shortlived.

The adverse effects of low soil temperature may be partially countered by applying more N and P fertilizer at planting, while high-soil-temperature injury may be averted by keeping the soil moist, not flooded, during the period of high temperature.

Table 13. Water-soluble P in eight submerged soils at four temperatures, 4 weeks after submergence.

Soil	Temperature (C) 15	25	35	45
	P (ppm)			
Luisiana clay	0.2	—	0.3	0.2
Maahas clay	0.3	1.0	0.6	0.8
Pila clay loam	1.3	1.6	2.9	2.4
Casiguran sandy loam	0.7	0.7	1.0	1.1
Acid-sulfate clay	0.2	0.3	—	0.2
Tungshan silt loam	0.2	1.2	1.3	1.0
Marilao clay loam	0.1	0.2	0.7	0.8
Silt loam (Korea)	0.1	0.1	0.3	0.1

These conclusions are based on a study of soils maintained at constant temperatures with shoots at uncontrolled air temperatures. In the field, the temperature regime and the temperature profile in the soil are different; so is the soil-air temperature relationship. Hence, these recommendations must be applied cautiously.

Chemical Analysis of the Solutions of Flooded Soils

Chemical analysis of the solutions of soils, at frequent intervals after flooding, proved a valuable tool in the study of the physical chemistry of flooded soils and physiological disorders of rice (Annual Report, 1964, 1965, 1966). These studies, however, were handicapped by the lack of rapid and accurate analytical methods suited to the colored solutions of flooded soils, with their high concentrations of NH_3, HCO_3^-, Fe^{++}, Mn^{++}, and organic substances. So the possibility of improving or simplifying the methods of analysis was investigated.

Total CO_2

The partial pressure of carbon dioxide (Pco_2) in a flooded soil is chemically and ecologically an important soil property. Because the derivation of Pco_2 from pH and methyl orange alkalinity is subject to serious interference, in some soils, by organic acids and their salts, alternative methods were examined. The Pco_2 electrode, so successfully used in clinical chemistry, was found unsatisfactory because of the interference by NH_3 and slow response at 25 C.

The derivation of Pco_2 from pH and total CO_2 (for solutions whose pH is less than 8) using the equation

$$\text{Total } CO_2 = KPco_2 \left[1 + \frac{K_1 \times 10^{pH}}{\gamma_{HCO_3^-}} \right]$$

(where $K = 10^{-1.47}$, $K_1 = 10^{-6.38}$, and γHCO_3^-) is the activity coefficient of the HCO_3^- ion in the solution), has none of these drawbacks and as pH can be accurately measured, the possibility of determining total CO_2 in aqueous solutions by direct gas chromatography was explored.

Gas chromatography is routinely employed in this laboratory for calibration of CO_2-N_2 mixtures used in carbonate equilibria studies, but direct injection of aqueous solutions required the use of devices to insure: (a) complete and instantaneous liberation of CO_2 into the stream of carrier gas, and (b) complete exclusion of moisture from the silica gel used as the stationary phase. After much trial and error, contact with syrupy phosphoric acid on glass wool heated to 100 C was found to liberate CO_2 quickly and efficiently, while magnesium perchlorate (Anhydrone) barred the entry of water vapor into the silica gel column.

One hundred microliter samples of a standard solution of CO_2 (0.01N Na_2CO_3 equilibrated with pure CO_2 at 25 C) were injected through a rubber septum into a thick-walled T-tube (int. diam., 1 cm; length, 12 cm) packed with glass wool wetted with 85 percent phosphoric acid and heated electrically to 100 ± 2 C. The CO_2 liberated was swept by helium through a 1 x 20 cm tube packed with Anhydrone and connected to the base of the silica gel column maintained at 100 ± 0.1 C. Carbon dioxide emerged 6 minutes after injection, producing a mean peak area of 11.7 cm^2 with a standard deviation of 0.16 for 13 runs at a recorder setting of 0.21 mv/cm. A single charge of phosphoric acid and the drying agent was good for 16 determinations with 100 μl samples.

Preliminary results of studies with the solutions of flooded soils indicate that (a) 100 μl samples give peak areas comparable with 0.01N Na_2CO_3 saturated with CO_2 and (b) Pco_2's were generally lower (as expected) than those derived from pH and methyl orange alkalinity.

Atomic absorption spectrophotometry

In recent years, atomic absorption spectrophotometry has replaced colorimetric methods of analysis for several elements because of its rapidity, accuracy, sensitivity, and freedom from interference. As no information was available on the suitability of this method for the analysis of the solutions of flooded soils, the precision and accuracy of this method for the assay of manganese, iron, and calcium in the solutions of three representative flooded soils were studied.

Because of the high sensitivity of this method, the first requirement was dilution of the solutions from flooded soils (after treatment with a

Table 14. Comparison of the observed and expected concentrations of Mn in the solutions of three submerged soils to which known amounts of Mn^{++} were added.

Soil	ml of solution	ml of 20 ppm Mn^{++} added	ppm	
			Expected	Observed
Luisiana clay	50	20	10.6	10.7
	50	30	12.5	12.5
	50	40	14.5	14.3
	50	50	16.5	16.3
Maahas clay	25	40	15.5	15.4
	25	50	17.5	17.6
Pila clay loam	50	30	6.9	6.8
	50	40	8.9	8.8
	50	50	10.9	10.8

few drops of concentrated H_2SO_4 to prevent oxidation of Fe and Mn) to give concentrations less than 20 ppm for Fe and Mn and 10 ppm for Ca in the test solution. Thereafter, aspiration and meter reading took less than 5 seconds per sample.

Twenty-nine samples of the solutions of three flooded soils containing 8 to 60 ppm Mn, suitably diluted and run in triplicate gave a standard deviation of 0.18 percent, demonstrating the high precision of the method. To ascertain the influence of interferences, known amounts of Mn^{++} were added to the solutions of these soils and the observed and expected concentrations compared. Table 14 shows very good agreement between the two sets of figures.

The precision and accuracy of this method for the determination of iron concentrations ranging from 5 to 600 ppm in the solutions of flooded soils were equally good.

The EDTA and flame photometric methods of the assay of the calcium in the solutions of flooded soils are not reliable because of interferences by iron, manganese, and sometimes aluminum. Atomic absorption spectrophotometry was tested and found to be much quicker and also superior to these methods. As with Fe^{++} and Mn^{++}, the solutions had to be acidified and diluted 10 to 20 times before aspiration into the flame.

Ultraviolet spectrophotometric determination of nitrate and silica

The colorimetric determination of nitrate by the phenol disulphonic acid or the brucine method is an inconvenient operation involving the use of concentrated H_2SO_4. Besides, it is unreliable in the presence of organic matter. To simplify and improve the assay of nitrate in the solutions of flooded soils, direct ultra-violet spectrophotometry of soil solutions by the method proposed by Cawse (Analyst 92: 311-315, 1967) was tested with solutions of three flooded soils.

The solutions were clarified with $ZnSO_4$ and NaOH and a suitable aliquot treated with sulfamic acid to destroy NO_2^-. After dilution with 5 percent $HClO_4$ to minimize interferences, the absorbance was measured at 210 mμ and the concentration read from a standard curve. Recovery of added NO_3^- to these solutions ranged from 99.1 percent with Pila clay loam to 99.6 percent with Luisiana and Maahas clays.

Ultraviolet absorption is an accurate, sensitive, rapid, and convenient method for the assay of nitrate in the solutions of flooded soils.

Ultraviolet absorption spectrophotometry of an ethyl acetate extract of the silico-molybdate complex, as described by Schink (Anal. Chem. 37: 764-765, 1965), was found to be a sensitive and sufficiently accurate method for the determination of silica in the solutions of flooded soils.

Potentiometric determination of H_2S

The current methods of determining H_2S in the solutions of flooded soils are unreliable because of the inclusion of varying amounts of solid phase sulfides. As potentiometric methods avoid this error, the recently introduced sulfide ion activity electrode was tested with the solutions of flooded soils.

This electrode develops a potential which depends on the activity of S^{--} ions in the solution. The activity of H_2S can be derived from S^{--} activity and pH, using the equation

$$\log a_{H_2S} = pK_1 + pK_2 + \log a_{S^{--}} - 2\,pH$$

where K_1 and K_2 are the first and second dissociation constants of H_2S. The total soluble sulfide concentration at pH's of 7 or less is given by

$$\text{Total sulfide} = a_{H_2S}\left[1 + \frac{K_1 \times 10^{pH}}{\gamma_{HS^-}}\right]$$

The method gave excellent results with sodium sulfide solutions in the concentration range 0.1 to 0.0001 molal and was sensitive enough to detect the presence of 0.003 ppm H_2S in a solution of reduced Luisiana clay.

Potentiometric determination of Na^+

The use of the Na^+ ion electrode offers a simple and rapid method of determining the activity of Na^+ in solutions of flooded soils concurrently with Eh, pH, and specific conductance (Annual Report, 1964). As the pH of these soils was about 7, no pre-treatment to minimize the H^+ ion error was necessary.

Excellent recovery of 5 to 20 ppm of added Na^+ was obtained in solutions of flooded Maahas clay and Luisiana clay; with Pila clay loam it was not as good, but acceptable.

Potentiometric determination of Ca^{++}

The Orion calcium electrode which measures Ca^{++} activity in a solution may be used to distinguish ionic from chelated Ca. It gave satisfactory readings with solutions of a flooded calcareous loam but broke down with Maahas and Luisiana clays apparently because of divalent ion interference.

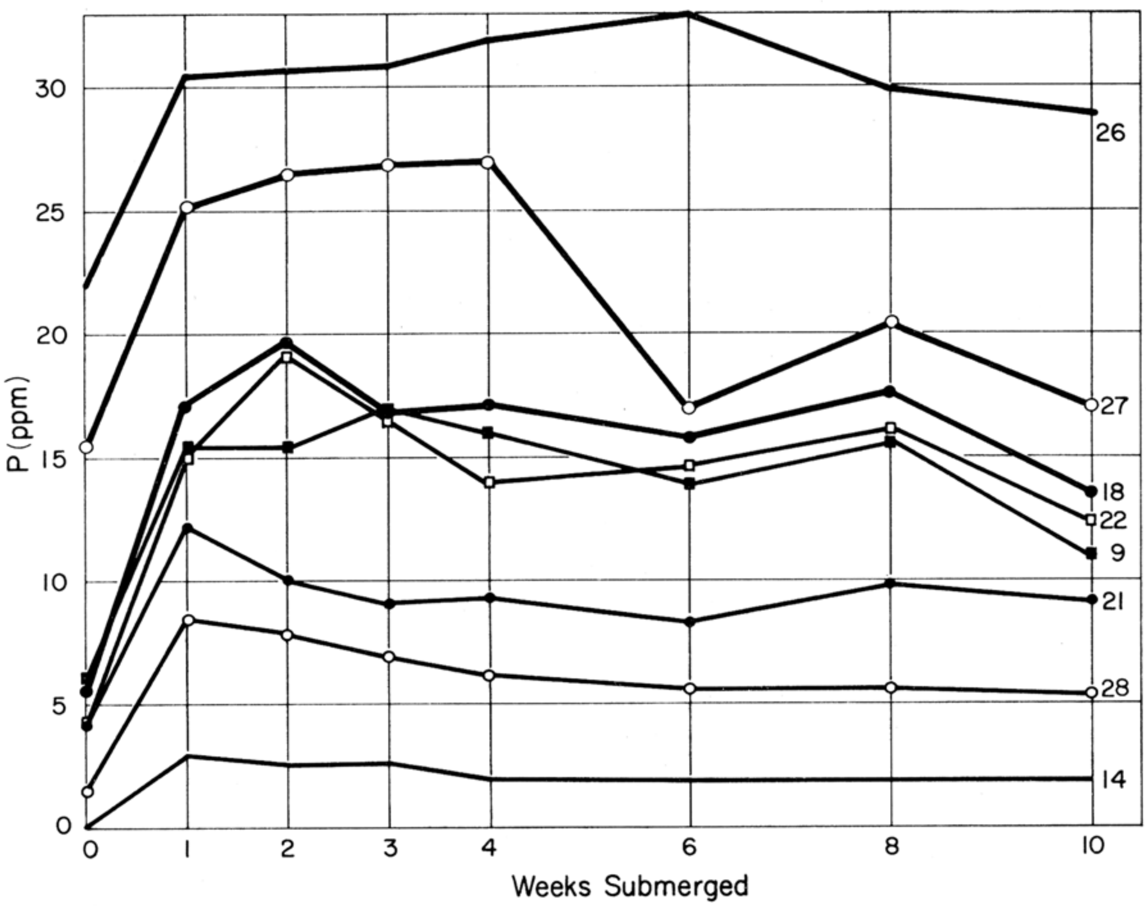

Fig. 9. Kinetics of *P* extractable in pH 2.7 acetate buffer.

Table 15. Correlation coefficients (r) of soil test values with grain yield and P in grain.

Days submerged	Grain yield			
	r (all soils) n = 17	r (clayey soils) n = 13	r (sandy soils) n = 4	P in grain n = 13
0		0.929**		0.941**
15	0.821	0.903**	.975*	0.894**
30	0.801	0.968**		0.962**

Table 16. Coefficients of linear correlation between the concentration of an element in the active center leaf and its concentration or activity in the soil solution, at three stages of the development of the rice plant.

Stage	N		P		Fe	
	conc.	act.	conc.	act.	conc.	act.
Max. tillering	0.53**	0.57**	0.32*	0.22	0.32**	0.35**
Panicle initiation	0.74**	0.53**	0.70**	0.67**	0.76**	0.83**
Flowering	0.44**	0.33**	0.36*	0.34*	0.87**	0.89**

Nutrient Availability in Flooded Soils

Availability of P in flooded soils

Increase in availability of P is recognized as one of the benefits of flooding rice soils but the influence of soil properties on the magnitude of this increase is not sufficiently appreciated. As an acetate buffer at a pH of 2.7 extracts calcium, ferrous, and manganous phosphates, P extractable in this buffer should be a good measure of available P in flooded soils.

Figure 9 shows that both before and after flooding, the content of available P was highest in Pila clay loam (Soil no. 26, pH 7.6, O.M. 1.5%, Fe 0.3%) and Maahas clay (Soil no. 27, pH 6.6, O.M. 2.0%, Fe 1.6%), intermediate in the sandy loams high in organic matter (Soil nos. 9, 18, 22) and low in active iron, and lowest in the acid clays high in active Fe (Soil nos. 14, 21, 28). The increase in available P on flooding was highest and most stable in the sandy soils high in organic matter; the increase was least in the acid clays low in organic matter (Soil nos. 14, 28, 21).

The increase in the availability of P brought about by flooding latosolic clays may not be as high as supposed. Also, available P after flooding appears to be correlated with available P before flooding.

It is often stated that the P test value of an aerobic soil is not a satisfactory index of P availability after flooding. To test this, available P (Olsen) in 17 Philippine lowland rice soils was determined at 0, 15, and 30 days after flooding and correlated with grain yield and P uptake by rice plants on these soils, in a pot experiment. Olsen's method was employed because it is widely used in this country.

Table 15 shows that soil test values at each sampling date (except 0 time for the sandy soils rather high in organic matter) are highly correlated with grain yield and P uptake, as measured by the P content of the grain. This means that there is no advantage in testing medium- to fine-textured soils after reduction, if the extractant is Olsen's.

Chemical composition of soil solution as an index of nutrient availability to rice

The mineral composition of the active center leaf of a rice plant is believed to be a good index of its nutritional status. If this can be correlated with the concentration or activities of NH_4^+, $H_2PO_4^-$, K^+, and $Si(OH)_4$ in the soil solution, analysis of the soil solution at critical stages of the development of the rice plant may provide an index of the need or surplus of these nutrients.

A greenhouse study of the chemical composition of the solutions of three flooded soils, treated with the factorial combinations of 0, 50, and 100 ppm of N, P, and K, along with the analyses of the active center leaves at maximum tillering, panicle primordia initiation, and flowering, revealed the relationships shown in Table 16. The best correlations were obtained at panicle primordia initiation. The use of activities in place of concentration did not improve the correlations, except with Fe^{++}

The regressions of the concentration of the element (% dry wt. for N and P, ppm for Fe) in the active center leaf and ppm of the element in the soil solution at panicle primordia initiation were as follows:

N:	$y = 2.00 + 0.084x$	$r = 0.74^{**}$
P:	$y = 0.45 + 0.087x$	$r = 0.70^{**}$
Fe:	$y = 91.3 + 1.45x$	$r = 0.76^{**}$

If the critical concentrations for N, P, and Fe in the active center leaf at primordia initiation are established, it may be possible to predict the need of these elements from their concentrations in the soil solution at this time.

Water Regime in Rice Soils

Flood fallow vs. dry fallow between rice crops with and without mid-season drainage

Although rice fields often are (a) drained and re-flooded in mid-season, (b) allowed to remain dry or moist, but not saturated, between successive crops, the nutritional consequences of these practices have not been evaluated from the standpoint of chemical kinetics of the soil. Because the advent of short-duration, photoperiod-insensitive varieties renders year-long rice production possible where water is available, information was sought on the long-term effects of different water management practices on (a) the chemical changes in the soils, (b) the nutrient supply, and (c) the rice plant.

This study was made outdoors in thirty-six 55-gallon steel drums filled with 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%). Rice had been grown on these soils, twice a year, for the 5 previous years. Fertilizers at the rate of 100 ppm each of N, P, K, and 0.16 percent of a 1 : 4 mixture of chopped straw and fresh *Glyricidia setium* leaves were incorporated with the top 20 cm of the soils. The soils were submerged in 5 cm of water and four IR8 seedlings per drum were planted at four hills.

The water treatments were:

1. Dry fallow between crops, no mid-season soil drying
2. Dry fallow between crops, mid-season soil drying
3. Flood fallow between crops, no mid-season soil drying
4. Flood fallow between crops, mid-season soil drying

The mid-season drying treatment consisted of withholding water from the drums till the layer of water evaporated, the excess water in the soil was transpired, and the Eh indicated that the soil was aerobic. This took about a week. The

Table 17. Effect of mid-season soil drying (m.s.d.) on the kinetics of NO_3-N in the soil solutions.

Soil		Weeks submerged			
		0	4*	6	10
Luisiana clay	m.s.d.	14.6	3.8	22.0	0.1
	no m.s.d.	15.7	2.0	0.3	0.2
Maahas clay	m.s.d.	23.9	6.2	19.7	0.2
	no m.s.d.	21.8	6.7	0.2	0.3
Pila clay loam	m.s.d.	16.6	2.8	6.3	0.2
	no m.s.d.	19.0	2.3	0.2	0.2

* Start of soil drying in m.s.d. treatment.

Table 18. Influence of four water treatments on the yield of straw and grain of IR8 on three soils in two successive seasons.

Water treatment	February-May 1967*		June-October 1967	
	straw	grain	straw	grain
	(g/drum averaged for 3 soils)			
1. Dry fallow, no mid-season drying	322	367	303‡	273
2. Dry fallow, with m.s.d.	294	310	318†	254
3. Flood fallow, no m.s.d.	318	371	323§	280
4. Flood fallow, m.s.d.	290	310	352	298
LSD 5%	18	35		

* During this season (the first), treatment 1 = 3 and 2 = 4.
†, ‡, § Increasing severity of grassy stunt.

soil was kept aerobic but moist for 1 more week and reflooded.

Mid-season soil drying reversed the chemical and electro-chemical changes brought about by flooding and restored the soils to the aerobic state, 2 weeks after watering ceased. On reflooding, the reduction process was repeated with a substantial loss of nitrogen by denitrification (Table 17). In Luisiana and Maahas clays the loss worked out to 50 kg/ha. Analysis of the soil solutions revealed no chemical benefit from mid-season soil drying of these soils.

Mid-season soil drying depressed the yield of both straw and grain significantly and consistently on all soils. The yields averaged for soils are in Table 18. An inadequate supply of nitrogen and root pruning due to soil cracking appeared to be the disadvantages of mid-season soil drying.

Two weeks before harvest, the water supply to the dry fallow treatment was cut off while the flood fallow soils continued to be submerged. After harvest, when the redox potentials indicated that the soils were aerobic, the dry fallow soils were flooded; roots, stubble, weeds, and fertilizer were incorporated in all soils, and IR8 seedlings planted.

Although the continuously flooded soils were greyish-green (Luisiana clay) or black (Maahas clay, Pila clay loam) and fresh organic matter in the form of stubble, roots, and some weeds were mixed and rice immediately planted, the seedlings showed no signs of distress. A severe attack of grassy stunt virus disease spoiled the second experiment, but the yield data suggested that the flood fallow was beneficial (Table 18).

Percolation in flooded soils and growth of rice

The influence of internal drainage at 1 cm a day on the chemical kinetics and the growth and yield of IR8 on three soils was investigated, outdoors, in 55-gallon drums. The soils were treated as in the preceding experiment. The drainage tubes were fitted at a depth of 20 cm below the soil surface.

Drainage depressed the concentration of water-soluble CO_2, Fe^{++}, Mn^{++}, NH_4^+, Ca^{++}, and Mg^{++}, but produced no significant difference in the yield of straw or grain, although, in the first 4 weeks, it appeared to benefit the rice plants on Luisiana clay and the calcareous clay loam.

Drainage at 1 cm per day for 12 weeks caused a loss of 56 kg of N (on a hectare basis) from Luisiana clay and 29 kg from Maahas clay without compensating benefits.

Soil Microbiology

The attention of the department during the year was focused upon two major lines of investigation, namely: 1) pesticide residues, and 2) nitrogen transformations in submerged soils.

No major shift of emphasis of study was therefore made from the previous year's program. Both lines of research were considered valuable in supporting and augmenting the programs of other departments more closely concerned with rice cultivation and production.

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Pesticide Residues

There is no doubt that protection of the rice plant from insect damage through the use of suitable insecticides in rice production can lead to significant increases in rice yields in the tropics. Ample evidence for these increases can be found in the appropriate sections of previous Institute annual reports. The experiments from which these results were obtained represent a careful screening of numerous insecticides which show promise of usefulness in rice production. Among the factors considered for evaluation in these tests are: a) effectiveness against the target insect or insects, b) level of mammalian toxicity of the parent insecticide molecule, c) response of the crop to the protective agent, viz., increased yield when compared to the unprotected crop, and d) the economic aspects involved in the use of the insecticide, embracing initial cost of insecticide, cost of applications required for protection, and profit versus input margins.

An insecticide favorably surviving such tests is one which has a) low mammalian toxicity, b) a broad spectrum of insect pest control, c) low capital input, and d) the ability to offer efficient protection to the rice crop, and the use of which results in consistently higher yields of rice when compared to untreated crops.

Over the last 4 years, two insecticides have emerged from these tests which offer great promise for the protection of tropical rice crops from insect infestation. These insecticides are lindane (γ-isomer of hexachlorocyclohexane) and diazinon (0,0-diethyl 0- (2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate).

In addition to satisfying the above criteria, neither of these insecticides appears to exert unnecessarily prolonged activity in insect control in the field. This is a most desirable property as it indicates that problems of residue accumulation from repeated applications will not arise. A definite role for the microflora of submerged soils in the degradation of lindane has been established (Annual Report, 1966). It was concluded that microbial degradation was a major factor in controlling the persistence of lindane in submerged soils.

The general awareness of the possible dangers which may arise from the widespread use of pesticides in agriculture—an awareness founded separately upon scientific understanding and upon prejudice—requires that further information be obtained before the widespread use of these chemicals, which have passed the screening tests, can be recommended.

From the microbiological point of view, information must be sought from two different directions. Firstly, because of the importance of the soil microflora in maintaining the fertility of soils, it must be determined whether the introduction of the pesticide into the soil will adversely affect microbiological activity.

Fortunately, only rarely have applications of insecticides to soil, at recommended pest control rates, been shown to inhibit microbiological activity. No deleterious effect of applications of lindane, up to ten times the recommended rate, upon the microflora of submerged soils could be demonstrated (Annual Report, 1965, 1966). Nevertheless, each new pesticide must be tested for antimicrobial activity.

The second question that the microbiologist must answer is: What effect does the soil microflora have upon the pesticide? Most modern pesticides are synthetic organic compounds, and as such may be susceptible to enzymatic change or degradation by the soil microflora. Complete degradation of the pesticide molecule by the soil microflora is desirable as it eliminates residue problems. Partial degradation, although resulting in the loss of pesticidal activity, may result in the accumulation of some fragment of the pesticide molecule in the soil. Such accumulations may be sufficient to adversely affect the soil microflora or perhaps the crop. Complete lack of susceptibility of the pesticide molecule to microbial attack is most undesirable as it may cause residue problems with far-reaching effects.

Having demonstrated a role for the soil microflora in controlling the persistence of a pesticide, it is the responsibility of the soil microbiologist to examine the pattern of degradation of the pesticide by the soil microflora. Therefore, attempts were made during the year to determine the pathway of degradation of lindane. The effect of diazinon applications upon the microflora of flooded soils was examined and a role for the microflora in diazinon degradation was found.

Benzene hexachloride

A definite role for the microflora of flooded soils in the degradation of the γ-isomer of benzene hexachloride (γ-BHC) has been established and reported previously (Annual Report, 1966). Not only the γ-isomer, but also the α, β, δ-isomers—all commonly found in commercial preparations of the γ-isomer—were shown to be degraded by the microflora of flooded soils.

A large number of cultures of bacteria were isolated from flooded soils and tested for their ability to decompose γ-BHC. One of these isolates proved to be exceedingly active in the degradation of γ-BHC and was therefore kept for detailed studies on the degradation of γ-BHC, the results of which are reported here.

As the active isolate was found to be a facultative anaerobe—a bacterium capable of growing under either anaerobic or aerobic conditions—it was considered desirable to find out under which conditions the organism was most active in the degradation of γ-BHC. The organism was cultured, harvested, washed, concentrated to give a dense population and finally exposed to γ-BHC in a phosphate buffer under aerobic and anaerobic conditions at 30 C for 24 hours. During this time, aliquots were removed periodically and the amount of γ-BHC remaining in the reaction mixtures determined by gas chromatography. The results (Table 1) clearly indicate that the isolate degraded γ-BHC most actively under anaerobic conditions. However, no information on the extent of degradation of the γ-BHC molecule was obtained. Gas chromatographic analysis was used only for the quantitative determination of γ-BHC. Gas chromatograms from these analyses revealed only one peak of electron absorption, namely γ-BHC. Further experiments of a similar type were performed in which the reaction mixture was kept only under anaerobic conditions and this was sampled for γ-BHC analysis more frequently. The results of a typical experiment are given in Table 2. Only a small amount of γ-BHC was detected in the reaction mixture by the end of 24 hours of incubation. By the end of the first hour of incubation, a second peak of electron absorption appeared on the gas chromatograms obtained in the determination of γ-BHC. The retention time of this peak was 0.7 minute, while that for the γ-BHC peak was 1·5 minutes. After reaching a maximum between 3 and 4 hours of incubation of the reaction mixture, the peak of electron absorption declined. By 24 hours this peak had completely disappeared from chromatograms obtained for γ-BHC determinations. Presumably, the unidentified substance causing the peak of electron absorption was a degradation product of γ-BHC metabolism by the bacterium. It accumulated in the reaction mixture briefly, and was further metabolized by the bacterium. Because the unidentified substance showed strong electron affinity, it seemed logical that it possessed some (if not all) of the six chlorine atoms present in the γ-BHC molecule. Attempts were made to match the retention time of the unidentified substance with substances which could be predicted as intermediates in γ-BHC degradation, e.g., pentachlorocyclohexene, and the trichlorobenzenes.

Table 1. Degradation of γ-BHC by a washed suspension of an anaerobic bacterium incubated at 30 C, under aerobic and anaerobic conditions.

Time of incubation (hours)	γ-BHC in reaction mixture (ppm)	
	Aerobic	Anaerobic
0	1.78	1.82
2	1.91	0.07
4	1.80	0
24	1.45	0

Table 2. Degradation of γ-BHC by a washed suspension of an anaerobic bacterium incubated at 30 C under an atmosphere of oxygen-free nitrogen.

Time of incubation (hours)	γ-BHC remaining in reaction mixture (ppm)	Peak height of unidentified derivative of γ-BHC (mm)
0	3.80	0
1	3.70	70
2	2.10	102
3	1.70	120
4	1.50	120
5	1.10	115
6	0.70	107
24	$<$0.08	0
27	$<$0.02	0

*Retention time of unidentified derivative=0.7 minute

Table 3. Degradation of γ-BHC by a washed suspension of an anaerobic bacterium, incubated at 30 C for 24 hours under different gas phases.*

Gas phase	Amount of γ-BHC degraded (μg/ml)	Detector response to unidentified derivative of γ-BHC (mm)	Chloride release (% theoretical)
Nitrogen	3.08	0	140
Nitrogen+0.3% Oxygen	2.62	85	78
Air	0.17	0	0

*Cell nitrogen in reaction mixture — 0 86 mg cell nitrogen per ml.

By controlled chemical degradation of γ-BHC in alkali, a sample of γ-pentachlorocyclohexene was prepared and gas chromatograms of this substance and the unidentified compound obtained. The retention times of the two substances were dissimilar and the unidentified compound was therefore not γ-pentachlorocyclohexene. Nor was the unidentified substance shown to be one of the trichlorobenzenes.

Evidence obtained showed that the unidentified substance was a derivative of γ-BHC. Suspensions of the active organism were exposed to C^{14}-labelled γ-BHC, and the course of γ-BHC degradation under anaerobic conditions followed. When the peak of the unidentified substance reached a maximum height in sample gas chromatograms, the effluent from the gas chromatograph column was trapped on anthracene crystals, and the radioactivity of progressive samples of the effluent was determined. The peaks of radioactivity coincided with the unidentified peak on the gas chromatograph and the γ-BHC peak.

Future work should be aimed at the collection of a convenient-sized sample of the purified unknown derivative of γ-BHC degradation for its chemical characterization.

It is possible that some atmospheric oxygen may have entered into the anaerobically-incubated reaction mixture at sampling despite the extreme care taken to prevent its entry. Because of the obligate requirement for molecular oxygen to participate in the microbial disruption of cyclic organic molecules, preliminary studies were performed to determine the effect of small quantities of oxygen in the atmosphere above the reaction mixture upon the degradation of γ-BHC. For this study, dense suspensions of the active bacterium were supplied with γ-BHC and maintained at 30 C for 24 hours under three separate atmospheres, viz., oxygen-free nitrogen, a mixture of nitrogen and oxygen (99.7% N_2:0.3% O_2) and air. Samples for γ-BHC and inorganic chloride determination were taken at the beginning of the experiment and after 24 hours of incubation. The results are shown in Table 3.

In keeping with the earlier experiments, the amount of γ-BHC degraded was greatest when the reaction mixture was incubated under anaerobic conditions, and negligible under aerobic conditions. The activity of the bacterial suspension incubated under the N_2/O_2 mixture was high but was less than that for the anaerobic system. The unidentified derivative of γ-BHC (retention time, 0.7 minute) appeared to persist longer in the reaction mixture incubated under the N_2/O_2 mixture. This fact may prove useful in later experiments designed to obtain sufficient unknown derivative for its chemical characterization. While the results obtained for chloride release obviously are of no great quantitative value, they indicate the relative amounts released under the three conditions of incubation and that the bacterium requires anaerobic (or partially anaerobic) conditions to bring about the detoxication of the insecticide. Future work should be aimed at obtaining a more accurate assay of released chlorine. Such information would be valuable in predicting the chemical nature of the unidentified derivative. Also, the role of oxygen in the metabolism of γ-BHC deserves further study.

Published information on the metabolism of the α, β, γ and δ-isomers of benzene hexachloride by insect tissues indicates that these isomers have varying degrees of susceptibility to enzymatic attacks. An experiment was therefore designed to see whether the same was true for the active bacterium.

Heavy suspensions of the bacterium were supplied with the α, β, δ and γ-isomers of benzene hexachloride, and incubated anaerobically at 30 C for 8 hours. Samples were removed from each reaction mixture at the start of the experi-

Table 4. Degradation of alpha, beta, gamma and delta isomers of hexachlorocyclohexane by an anaerobic bacterium incubated under an atmosphere of oxygen-free nitrogen.*

Time of incubation (hours)	Isomer					
	Gamma		Alpha		Beta	Delta
	ppm in reaction mixture	detector response to unidentified derivative of γ-BHC† (mm)	ppm in reaction mixture	detector response to unidentified derivative of α-BHC‡ (mm)	ppm in reaction mixture	ppm in reaction mixture
0	6.9	0	1.5	0	0.2	4.6
2	6.2	7.5	1.6	0	0.2	8.4
4	3.0	19	1.4	3.7	0.2	8.3
6	2.5	26	1.2	12.5	0.3	8.5
8	1.5	21	1.0	16.0	0.2	8.1

* Cell nitrogen in reaction mixture=0.24 mg cell nitrogen per ml.
†Retention time for peak of unidentified derivative=0.7 minute.
‡Retention time for peak of unidentified derivative=0.5 minute.

ment and at 2-hour intervals thereafter, and the amount of each isomer of BHC remaining in the reaction mixture determined by gas chromatography. The results of this experiment are given in Table 4. Only two of the isomers, viz., the α and γ-isomers proved to be degraded. No evidence for degradation of the β and δ-isomers was obtained. Peaks of electron absorption appeared on gas chromatograms of samples from the α and γ-BHC containing reaction mixtures. However, as the retention time for the unknown derivative of γ-BHC differed from that for the derivative of α-BHC, it seems likely that two different pathways of degradation of these two isomers by the active bacterium may exist.

Future work on these aspects of benzene hexachloride degradation may provide information useful not only to a knowledge of pesticide decomposition but also to an understanding of isomer effects in microbial metabolism.

Diazinon

During the year, studies were initiated on the effect of diazinon (0,0-diethyl 0- (2-isopropyl-4-methyl-6-pyrimidinyl) phosphorothioate) upon the microflora of flooded soils. These studies were developed along lines similar to those conducted with γ-BHC (Annual Report, 1965, 1966).

Effect of diazinon upon the microflora of submerged soils. Applications of diazinon at the rates of 2 and 20 kg/ha to two Philippine soils (Maahas clay, pH 6.6, organic matter 2.0% and Luisiana clay, pH 4.7, organic matter 3.2%) had no effect upon the mineralization of the native nitrogen of these soils. The higher rate of diazinon used in this study was far in excess of the rate normally used in the field for insect control.

The development of algal growth in the standing water of these soils was noted periodically and compared with that in untreated samples of the two soils. Algal growth was more abundant in the standing water of the two insecticide-treated soils than in the untreated controls. The increase in algal growth following diazinon applications was not nearly as striking as that reported earlier for γ-BHC (Annual Report, 1965). Presumably the increased algal growth was due to the toxic effect of diazinon upon small animals which feed on algae.

The most striking effect of diazinon was shown by the actinomycete section of the soil microflora. Samples of soil treated with diazinon after flooding developed a distinct zone of brown pigmentation in the surface layer (1 cm) of the soil (Fig. 1). The pigmented zone was not visible in the untreated soils. When samples of soil from the pigmented zone were transferred to an

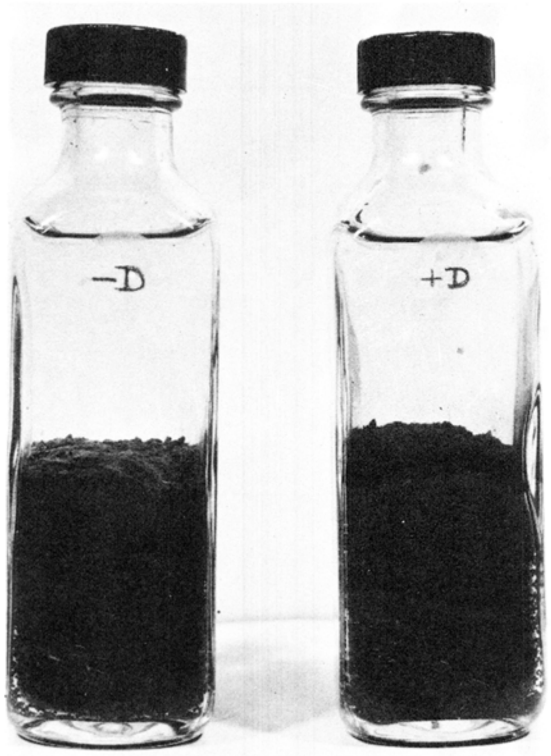

Fig. 1. Effect of diazinon upon the appearance of the "profile" of flooded Maahas clay. Soil at right received diazinon; soil at left, no diazinon. Note heavy pigmentation on top portion of diazinon-treated soil.

agar medium and incubated, a profuse growth of actinomycetes developed.

The actinomycete population was larger in the treated soil (Table 5). The real reasons for the increased actinomycete population are not known, but it seems likely that these organisms are able to utilize diazinon as a source of carbon for growth.

Microbial degradation of diazinon

Information on the fate of diazinon in non-flooded soils indicates that the initial step in the degradation of the insecticide involves a chemical hydrolysis resulting in the formation of 2-isopropyl-4-methyl-6-hydroxy pyrimidine and the ethyl phosphorothioate moiety. The participation of the soil microflora in diazinon degradation appears to be largely in the decomposition of the products of hydrolysis rather than in the attack on the parent insecticide molecule.

As no information was available on the fate of diazinon in flooded soils, the studies described were aimed at determining: a) the persistence of diazinon in three Philippine soils, and b) the role of the microflora of these soils in the degradation of diazinon.

Table 5. Effect of diazinon upon the actinomycete population of submerged Maahas clay.*

Diazinon applied	Time after application (days)		
	15	30	45
nil	13.4	21.6	5.7
2 kg/ha	54.0	35.3	44.8
20 kg/ha	24.4	54.3	51.1

* Populations are in thousands and represent the means of six replicate determinations.

The three soils used in this study were: Maahas clay (pH, 6.6; O.M., 2.0%; total N, 0.14%), Luisiana clay (pH, 4.7; O.M., 3.2%; total N, 0.21%) and a clay loam from Pila, Luzon (pH, 7.7; O.M., 1.5%; total N, 0.09%). Sterilized and non-sterilized samples of the three soils were treated with diazinon and incubated in the greenhouse for 50 days. The soils were sampled periodically and analyzed quantitatively for diazinon by gas chromatography. Diazinon disappeared more rapidly from the non-sterilized samples

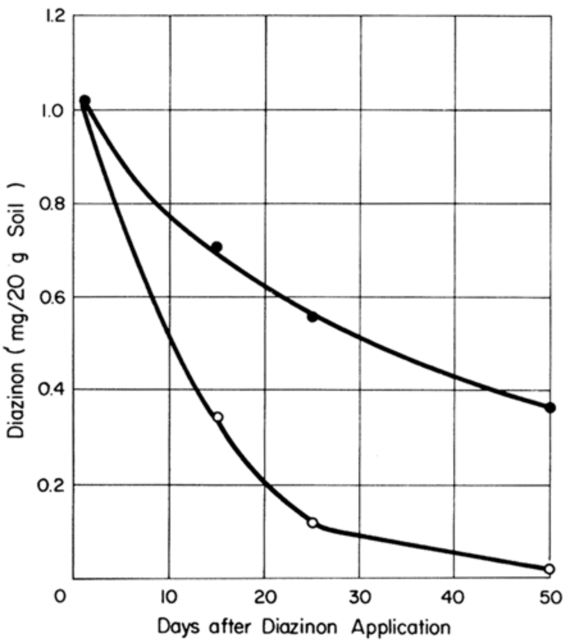

Fig. 2. Persistence of diazinon in sterilized (●——●) and non-sterilized (o——o) Maahas clay.

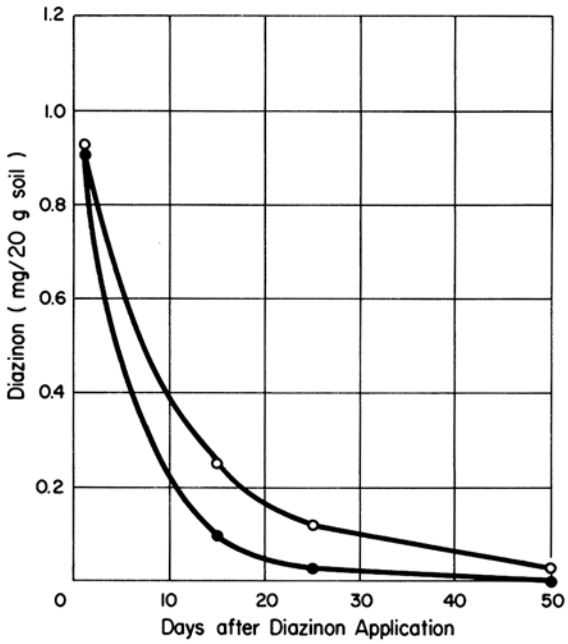

Fig. 3. Persistence of diazinon in sterilized (●——●) and non-sterilized (0——0) Luisiana clay.

than from the sterilized samples of Maahas clay and the clay loam. The results obtained for Maahas clay are shown in Fig. 2. More rapid loss of the insecticide from non-sterilized soils indicates a role for the soil microflora in the degradation of diazinon. There was a significant loss of diazinon from the sterilized soils, and this could be attributed to: a) volatilization, and b) chemical hydrolysis of the insecticide molecule.

The results obtained for the Luisiana clay (Fig. 3) were quite different. The loss of diazinon was greater from its sterilized samples. This could be explained by the instability of diazinon in acid solutions, and the fact that the aerobic pH of Luisiana clay is quite acid (pH 4.7). The sterilized samples of Luisiana clay would not undergo reduction, and therefore, in spite of flooding, the pH would remain at 4.7. The non-sterilized samples would undergo reduction following flooding, the pH would rise and retard the chemical hydrolysis of diazinon.

Whereas the microflora seems to play a significant role in the degradation of diazinon in Maahas clay and the clay loam from Pila, little can be said for a microbial role in diazinon degradation in Luisiana clay. The extremely rapid loss of diazinon from Luisiana clay by chemical action indicates that diazinon may not very effectively protect crops grown on this or similar soils. However, it may be more effective if applied after the soil has undergone reduction and the pH has risen. A more stable insecticide, e.g., γ-BHC, might protect the crop until the soil pH is more favorable for diazinon persistence.

Table 6. $C^{14}O_2$ **evolution from** C^{14}**-labelled diazinon applied to submerged soils.***

Soil	C^{14}, cpm/20 g soil	
	15 days	30 days
Maahas clay	2,700	6,500
Pila, calcareous clay loam	1,700	4,400

*All counts have been adjusted for background and sterilized soil controls, and the figures represent cumulative counts.

Attempts were made to define more clearly the role of the microflora of Maahas clay and the clay loam from Pila in the degradation of diazinon. To do this, C^{14}-labelled diazinon (labelled at the 2 position on the pyrimidine ring) was added to flooded sterilized and non-sterilized samples of Maahas clay and clay loam from Pila. Carbon dioxide-free air was drawn over the surface of the water, the evolved carbon dioxide trapped, and the radioactivity determined. Table 6 shows the results obtained up to 30 days of incubation.

These results give further evidence of the biological degradation of diazinon. The pyrimidine ring nucleus was ruptured and some of the carbon in the labelled position on the ring oxidized to carbon dioxide.

The results of the diazinon studies may be summarized as follows:

(1) Applications of diazinon to flooded soils at rates approximately 20 times those used for pest control in the field had no adverse effect upon the mineralization of native soil nitrogen and algal populations in flooded soils. Populations of actinomycetes in flooded soils increased following applications of diazinon.

2) Microbial degradation of diazinon or its products and chemical hydrolysis play an important role in eliminating residues from flooded soils.

3) The persistence of diazinon in flooded soils of low aerobic pH is shorter than in neutral soils.

Nitrogen Transformations

In previous years (Annual Report, 1964, 1965, 1966) a large section of the research program of this department had been directed toward obtaining an understanding of the transformations of nitrogen in flooded soils. The cycling of nitrogen by the microflora, and the losses and gains of this element in flooded soils by microbiological activity have been examined. Also, losses due to such non-biological means as volatilization of ammonia have been studied. Because of the key position of nitrogen in rice production, and the importance of the microflora in controlling the availability of this element, studies of nitrogen transformations were continued during 1967 to obtain the following information: a) the extent of nitrogen losses from flooded soils due to volatilization of ammonia following urea applications, b) the efficiency of conversion of urea nitrogen to extractable ammonium, c) the effect of soil submergence upon urea-hydrolyzing microorganisms, and d) the extent of nitrification in flooded soils in relation to possible losses of this element due to denitrification.

Volatilization of ammonia

In 1966, studies on non-biological losses of nitrogen from flooded soils, i.e., volatilization of ammonia, showed that considerable losses can occur even from soils that have a low aerobic pH. Such losses were presumably due to the diffusion of the ammonia to the soil surface, and to high localized pH values.

A comparison of two methods of application of ammonium sulfate to flooded soils, viz., surface application versus incorporation of the ammonium sulfate into the flooded soils, revealed that losses were much greater when the ammonium sulfate was applied to the soil surface. Apparently such losses have not before been considered significant, since the practice of incorporation of ammonium fertilizer has been aimed primarily at reducing nitrogen losses due to denitrification.

Because urea is widely used as a source of nitrogen in rice production, the extent of nitrogen losses by volatilization of ammonia produced from it after its addition to flooded soils was determined.

To determine the significance of ammonia losses through volatilization from flooded soils following applications of urea, experiments similar to those conducted in 1966 on the volatilization of ammonia following ammonium sulfate applications to flooded soils were conducted. The same four soils with the following characteristics were used: 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 South Vietnam) pH 3.5, O.M. 10%. The soils were placed in glass containers to provide a column approximately 15 cm long. Nitrogen in the form of urea was applied to the soils at levels approximating 50 and 200 kg/ha. In one series of containers the fertilizer was applied to the soil surface just before flooding, and in another series the soil was kept saturated for 3 days, after which the urea was applied and mixed thoroughly with the wet soil before flooding. 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 for a total period of seven weeks.

For illustrative purposes, the results obtained for one of the soils (Maahas clay) are shown in Fig. 4. Small losses of ammonia were detected for the unamended Maahas clay (Fig. 4a). This was true for all four soils, and is in keeping with the results reported earlier (Annual Report, 1966). Increasing the rate of urea application to the soils resulted in increased losses of urea nitrogen through volatilization of ammonia. The major loss of urea nitrogen by this process occurred after the first week following urea application, and may have been due to either or both of the following reasons: a) the gradual rise in pH of acid soils following submergence, and b) the rate of ammonia production from the microbiological hydrolysis of urea, reaching a maximum at about a week after urea application.

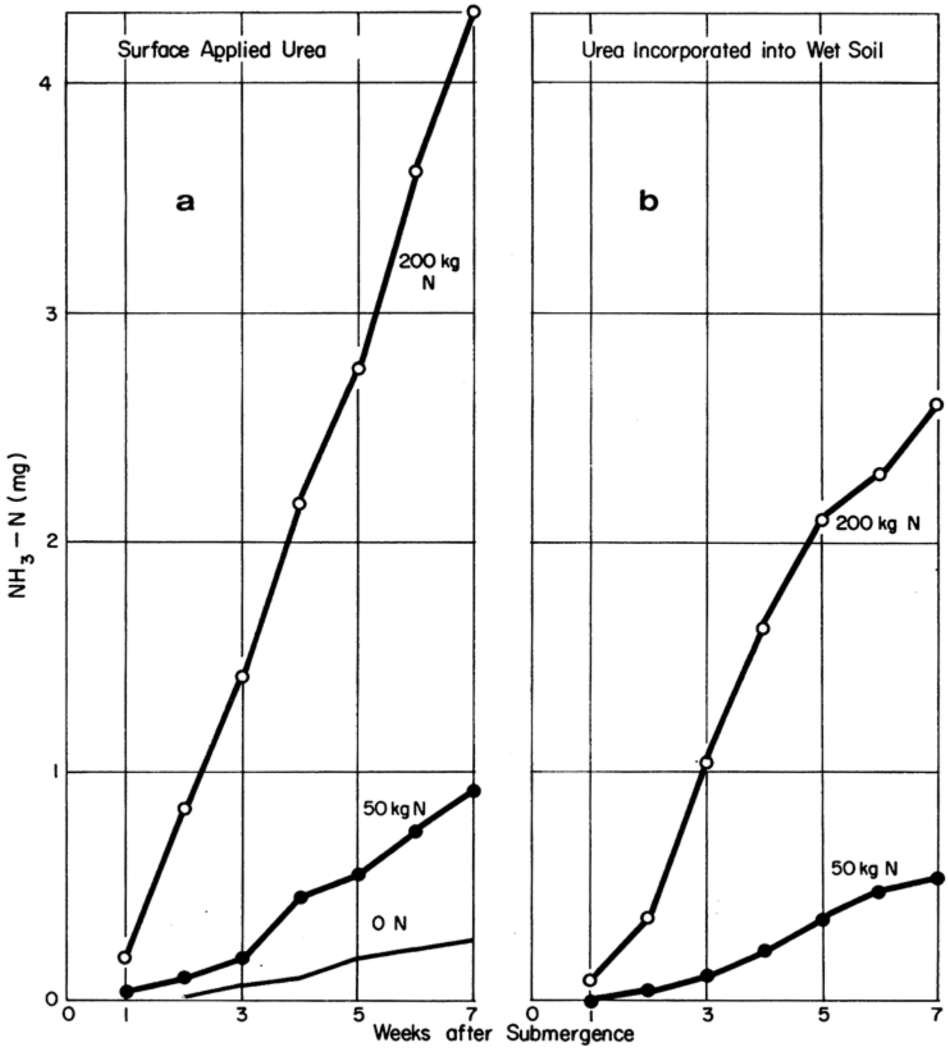

Fig. 4. Losses of ammonia by volatilization from Maahas clay treated with urea. Amounts of applied nitrogen were 7.3 mg and 29.2 mg at 50 and 200 kg/ha N, respectively.

Incorporation of urea into the wet soils significantly reduced the losses through ammonia volatilization (Fig. 4b).

The percentage losses of urea nitrogen at each level and for each method of urea application have been calculated (Table 7). The amount of ammonia evolved from each of the unamended soils was subtracted when these figures were calculated. Losses from the acid-sulfate soil due to ammonia volatilization were negligible regardless of level or method of application. However, nothing is known of the extent of urea hydrolysis in this soil. The extreme

Table 7. Percentage losses of urea nitrogen from submerged soils through ammonia volatilization.

Soil	% loss of applied urea N			
	Rate of urea application (kg N/ha)			
	50		200	
	Methods of application			
	Surface	Incorporated	Surface	Incorporated
Maahas clay	8.2	3.5	11.0	7.2
Luisiana clay	3.1	5.3	11.5	4.5
Silo silt loam	19.0	5.9	16.3	5.5
Acid-sulfate soil	0.1	0.03	0.03	0.02

acidity of this soil may retard urea hydrolysis or lead to losses of nitrogen by a process other than ammonia volatilization.

Extremely large losses of urea nitrogen were detected when the urea was applied to the surface of the Silo silt loam, and the alkaline aerobic pH of this soil may have contributed largely to these losses. The incorporation of the urea into this soil dramatically reduced losses. However, it remains to be seen whether the 5-percent level of loss found when the urea was incorporated into this soil can be tolerated from an economic point of view. Apart from one figure obtained for Luisiana clay (Table 7), the incorporation of the urea into a Maahas clay and Luisiana clay similarly reduced losses.

A comparison of the percentage losses of applied nitrogen in the present study with those obtained in the previous study using ammonium sulfate (Annual Report, 1966) indicates that losses are greater when urea is used as the source of nitrogen. For example, losses of ammonia after 7 weeks from Maahas clay amended with ammonium sulfate were for the incorporated treatment, at the 50- and 200-kg levels, 1.9 and 2.5 percent, respectively.

Urea hydrolysis in soil

Before the rice plant can utilize the nitrogen of urea, the urea molecule must be hydrolyzed to release the nitrogen in the form of ammonia. Losses of some of this ammonia can occur through volatilization, as mentioned earlier. In addition, some of the urea may be utilized by the soil microflora (immobilization) and therefore rendered unavailable to the rice plant.

To measure the efficiency with which urea is converted to ammonia (which is presumably the available nitrogen form as far as the rice plant is concerned), experiments were performed in which a known amount of urea was added to soils and the soils flooded. Periodically, soil samples were taken and the amount of urea remaining in the soils, plus the level of extractable ammonium (using N KCl), was determined.

Three levels of urea were applied to the soils (equivalent to application rates of 50, 100 and 200 kg/ha urea nitrogen), and three soils having the following characteristics were used: Maahas clay, pH 6.6, O.M. 2.0 %; Luisiana clay, pH 4.7, O.M. 3.2 %; and a clay loam from Pila, Luzon, pH 7.7, O.M. 1.5 %.

The results for Maahas clay are illustrated in Figs. 5, 6 and 7. They represent the levels of both urea nitrogen and extractable ammonium nitrogen, in excess of the levels found in the unamended soil controls. When computing these results, it was assumed that any extractable ammonium in excess of the level found in the unamended soils was derived from the hydrolysis of urea and that the mineralization rate of native soil nitrogen in both the amended and unamended soils proceeded at equal rates. These

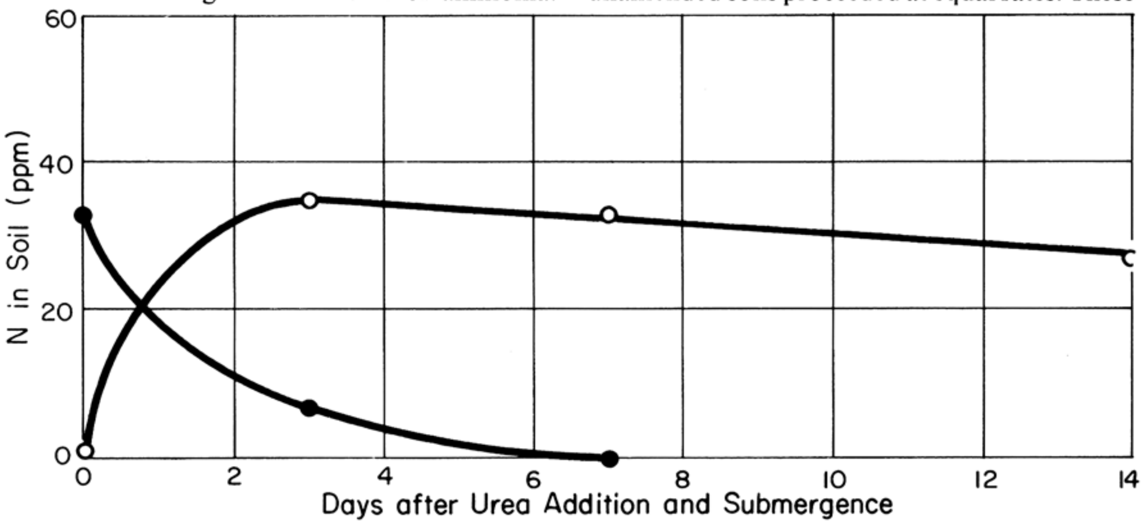

Fig 5. Conversion of urea nitrogen (●——●) to extractable ammonium nitrogen (0——0) in flooded Maahas clay treated with urea at a rate equivalent to 50 kg/ha N.

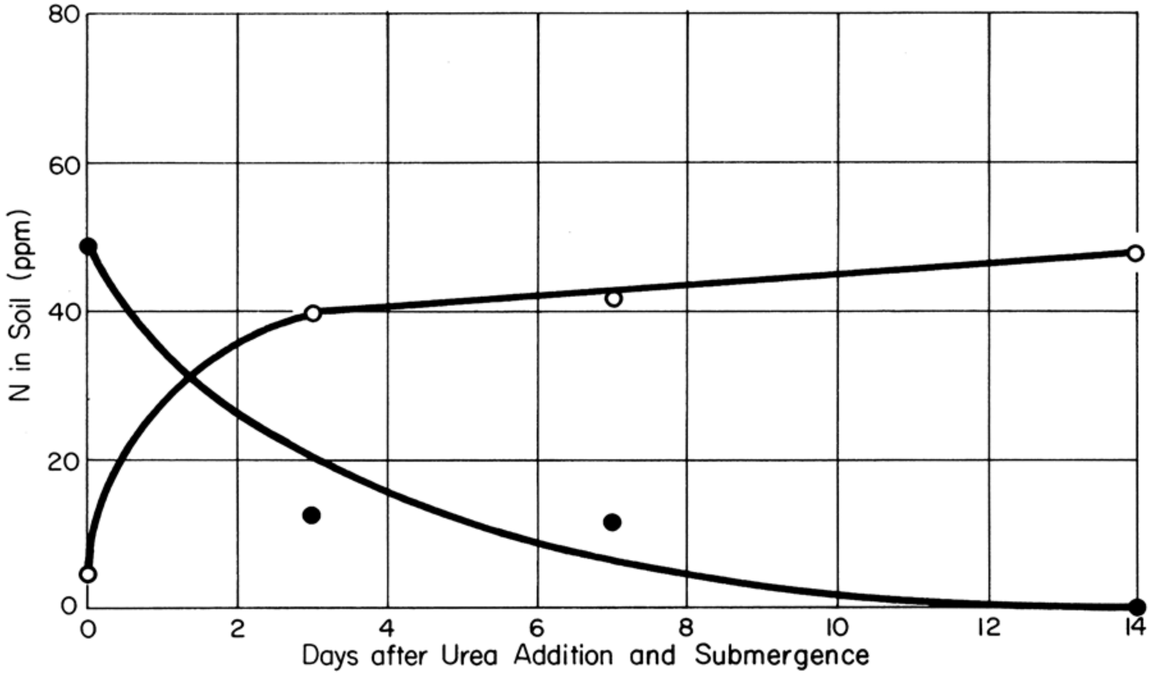

Fig. 6. Conversion of urea nitrogen (●——●) to extractable ammonium nitrogen (0——0) in flooded Maahas clay treated with urea at a rate equivalent to 100 kg/ha N.

assumptions may of course be subject to certain reservations.

The persistence of urea in all three soils was very brief, as no urea could be detected 7 or 14 days after application. This was not surprising as the hydrolysis of urea is known to proceed rapidly in non-flooded soils.

An interesting finding was that considerable levels of substances in the unamended soils gave a positive test in the urea analysis. The concentration of these substances declined rapidly, following a pattern similar to the disappearance of urea in the treated soils.

The recovery of urea nitrogen in the form of extractable ammonia was close to 100 percent at the 50- and 100-kg levels of application to Maahas clay. At the 200-kg application rate, the recovery was only about 70 percent. Prolonging the experiment to 28 days did not improve this figure.

The results obtained for the approximate percent recovery of urea nitrogen as extractable ammonium for the other two soils were as follows: Luisiana clay: 50 kg N 90 %, 100 kg N 85 %, and 200 kg N 70 %; clay loam (Pila): 50 kg N 50 %, 100 kg N 60 %, and 200 kg N 50 %.

The results indicate that recovery of urea nitrogen in an available form for the two clay soils at the 50-kg level of application was good, and that loss through volatilization was small. However, recovery in the clay loam soil at all

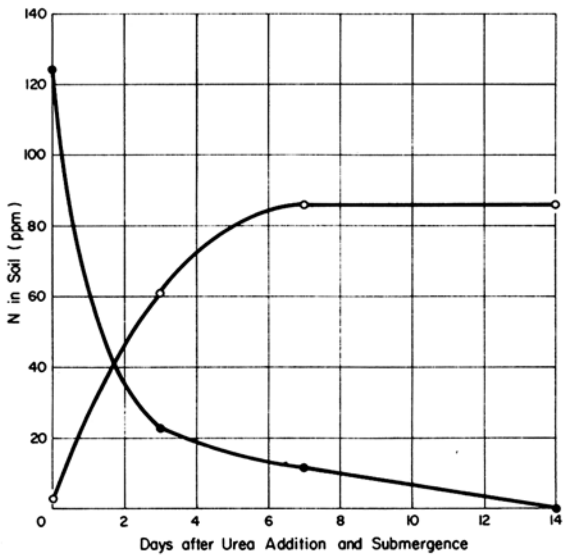

Fig. 7. Conversion of urea nitrogen (●——●) to extractable ammonium nitrogen (0——0) in flooded Maahas clay treated with urea at a rate equivalent to 200 kg/ha N.

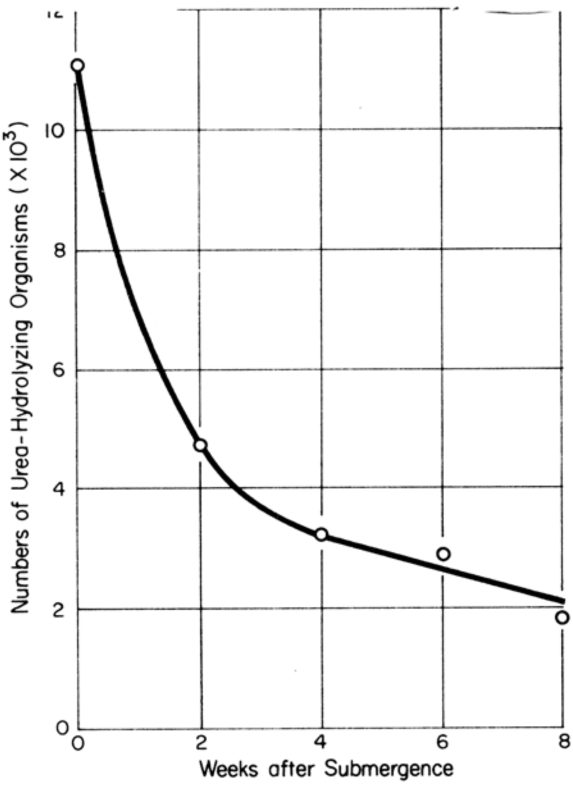

Fig. 8. Effect of flooding upon the numbers of urea-hydrolyzing microorganisms in Maahas clay.

levels of application was poor. Presumably, the higher aerobic pH of this soil may have been responsible for large losses of urea nitrogen through volatilization. The recovery of urea nitrogen at the highest level of application to all three soils was poor. Volatilization probably accounted for the major part of these losses. However, immobilization cannot be excluded as a means by which the urea nitrogen is rendered unavailable to the rice plant.

To obtain information on the numbers of urea-hydrolyzing microorganisms in flooded soils, and to determine the effect of flooding upon these organisms, samples of Maahas clay were flooded, sampled every 2 weeks for 8 weeks, and the numbers of urea-hydrolyzing organisms determined. Figure 8 shows the results obtained in this study. Numbers of urea-hydrolyzing microorganisms were never great but the population declined rapidly after submergence. No anaerobic bacteria capable of hydrolyzing urea were detected.

Nitrification in flooded soils

The conversion of ammonia to nitrite and nitrate (nitrification) is an aerobic process carried out by members of the bacterial genera *Nitrosomonas* and *Nitrobacter*. Bacteria of these two genera are strict aerobes. While nitrification is quite active in so-called "aerobic" soils, it is assumed that flooding a soil and the consequent production of anaerobic conditions in the flooded soil inhibits nitrification. However, the thin surface layer of a flooded soil, plus the standing water, could provide an environment suited to the aerobic nitrifying bacteria. Nitrate generated in these locations could move into the anaerobic regions of the soil profile and undergo denitrification, resulting in a loss of nitrogen from the soil.

Experiments were performed to obtain information on the extent of nitrification in flooded soils and a measure of losses which may occur in such soils from subsequent denitrification of the nitrate generated. The method employed in these experiments attempted to inhibit nitrification, using inhibitors specific for the first step in this process, viz., the oxidation of ammonium to nitrite, and to determine the increase in extractable ammonium was considered a measure of the extent of nitrification.

The two soils used in this greenhouse study were Maahas clay (pH 6.6, O.M. 2.0%) and a clay loam from Pila, Luzon (pH 7.7, O.M. 1.5%). One set of soil samples was treated with two commercial inhibitors of nitrification at two different levels (2 and 4 ppm) and another set with ammonium sulfate (100 ppm N) plus the two levels of inhibitors. Controls were represented by unamended soils and soils plus ammonium sulfate alone. The inhibitors used were 2-amino-4-chloro-6-methyl pyrimidine (TOYO KOATSU "Am") and 2-chloro-6- (trichloromethyl) pyridine (N-Serve) both received as gifts from the appropriate manufacturers.

Triplicate samples of soil from each treatment were removed periodically over a period of 8 weeks and the extractable ammonium in each sample was determined.

The results obtained for Maahas clay are shown in Figs. 9 and 10. Neither of the inhibitors appeared to have any effect at the 2-ppm level

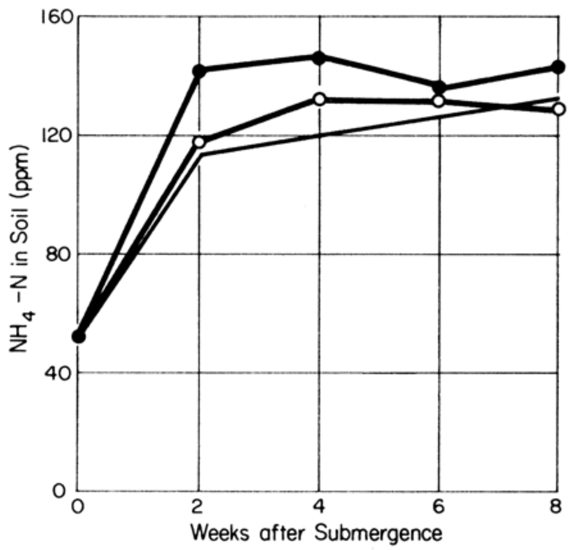

Fig. 9. Effect of two inhibitors of nitrification upon the level of extractable ammonium in flooded Maahas clay. Both inhibitors were applied to give a level of 4 ppm in soil. TOYO KOATSU "AM" (●——●), N-Serve (○——○), and the untreated soil (——).

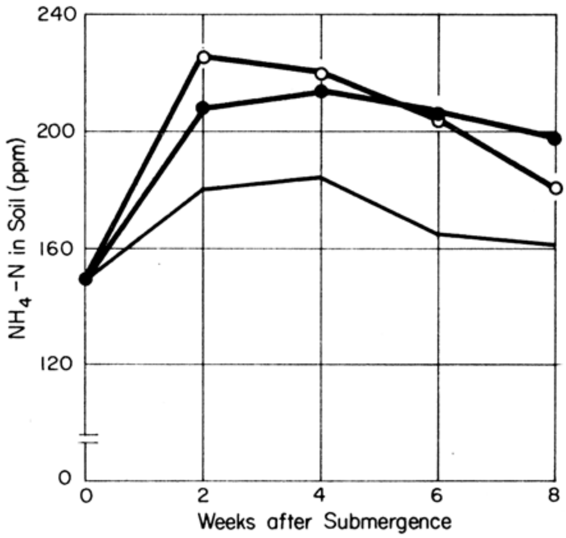

Fig. 10. Effect of two inhibitors of nitrification upon the level of extractable ammonium in flooded Maahas clay treated with ammonium sulfate. Both inhibitors were applied to give a level of 4 ppm in soil. TOYO KOATSU "AM" (●——●), N-Serve (○——○) and the uninhibited soil (——).

in the soils not receiving ammonium sulfate, and these results have not been shown in Fig. 9. However, at the 4-ppm level in the unamended soil, a significant increase ($p < 0.01$) in the amount of extractable ammonium was found with the fourth-week sample. After 4 weeks the differences between the control soil samples and those receiving inhibitors were not significant. It was assumed that after 4 weeks, the activity of the inhibitors declined because of loss through volatilization or other factors. The differences in extractable ammonium between the soil plus inhibitor and the control soil indicate that: a) nitrification in the control soil may account for a conversion of up to 20 ppm of ammonium —N to nitrate—N; and b) large losses due to denitrification of nitrate generated by nitrification in the aerobic portion of a flooded soil profile can occur.

The effect of the inhibitors applied at the 4-ppm level was greater in the soil samples receiving ammonium sulfate (Fig. 10). Soil samples receiving the inhibitors contained up to 40 ppm more extractable ammonium than the soil samples treated with ammonium sulfate alone. These results indicate that nitrification of fertilizer nitrogen in flooded soils may be considerable.

Fig. 10. Results of inoculation of internode of variety Tjeremas with stem rot fungi and related forms. Top: wounded by needle, bottom: unwounded; II, III, IV, V, VI are groups of fungi referred to in the text.

Agronomy

Agronomic investigations during 1967 were continued in the broad area of rice cultural practices with major emphasis on those which have immediate application. Additional research effort was devoted to the development of information on the fundamental principles concerning the growth and management practices of rice.

New production records for flooded rice were established at the Institute during the year when in replicated experiments IR8 produced 10,341 kg/ha in a single crop and 16,693 kg/ha in two crops. These new record yields were obtained with direct-seeded (broadcast) rice, whereas previous yield records were obtained with transplanted rice.

Experiments with upland rice reflected the potential yields possible when environmental factors, especially rainfall distribution, are highly favorable during the reproductive growth stage. A new yield record of 6,191 kg/ha was obtained from replicated upland experiments with IR5. The performance of IR8 under upland conditions was similar to that of IR5. In upland experiments IR8 and IR5 consistently outyielded the "standard" upland variety, Palawan, by 1,000 to 2,000 kg/ha.

Solar radiation during the period of 30 to 45 days before grain harvest of three indica varieties differing in plant type was highly correlated with grain yield in date-of-planting experiments.

In weed control research, increased emphasis was placed on the selective grass herbicides used alone and in combination with phenoxy herbicides. Pyriclor, molinate, and EPTC-2,4-D looked promising for both direct-seeded and transplanted rice. A new herbicide, CP 29037, appeared very promising without supplemental spray of phenoxy materials. A proprietary material, propachlor or "ramrod", and split applications of pyriclor gave good weed control and resulted in yields comparable to those obtained from handweeded, direct-seeded rice.

Experiments were also continued on the sources and rates of fertilizer phosphorus, herbicide screening, water management, continuous cropping and the economic and agronomic aspects of production resource management.

Continuous-Cropping Experiment

A continuous-cropping experiment started in 1962 was continued during the year. Some changes were made in variety but the four levels of fertilizer nitrogen and three methods of planting were continued in a manner similar to that in previous years. The nitrogen levels used in the rainy season were lower than those in the dry season, but relative differences between treatments were maintained.

Selected grain yields from the 13 successive crops grown since February 1963 are presented in Fig. 1. The yield data represent the means of four replications from the best treatment in each crop. Variety, fertilizer rate, and planting method are identified for these treatments. The total for the last three crops (crops 11 to 13, Fig. 1) was extremely low. It was similar to those obtained during 1963-64 (crops 2 to 4) and lower than the record for 2-crop totals of either 1966 (Annual Report, 1966) or 1967 (Annual Report, 1967). This low yield was partly due to damage caused by maleic hydrazide spray on the 11th crop, and also to the severe typhoon which occurred during the reproductive stage of the 13th crop. When the typhoon struck, IR8 and C_4-63 were in the soft dough stage, and Chianung 242 and Taichung (Native) 1 were approaching the soft and the hard dough stage, respectively. The mean grain yield for the four varieties harvested after the typhoon were: IR8, 3,242 kg/ha; C_4-63, 3,088 kg/ha; Taichung (Native) 1, 2,888 kg/ha; and Chianung 242, 817 kg/ha. Under the severe climatic conditions in 1967 the relatively weak-strawed variety, Chianung 242, did not perform well. Direct-seeded treatments continued to look promising during the year.

Date-of-Planting Experiments

Three varieties of different plant type were planted on the 20th of each month at three spacings (15 x 15 cm, 25 x 25 cm, 35 x 35 cm) and three nitrogen levels (0, 30 and 90 kg/ha). Phosphorus was applied uniformly (30 kg/ha P_2O_5) to all plots. The varieties used during the crop year were IR8, Milfor-6(2) and H-4. They are roughly characterized as: short with lodging resistance, intermediate height with relative lodging resistance, and tall with lodging susceptibility, respectively. The highest grain yield obtained was from IR8 harvested in May,

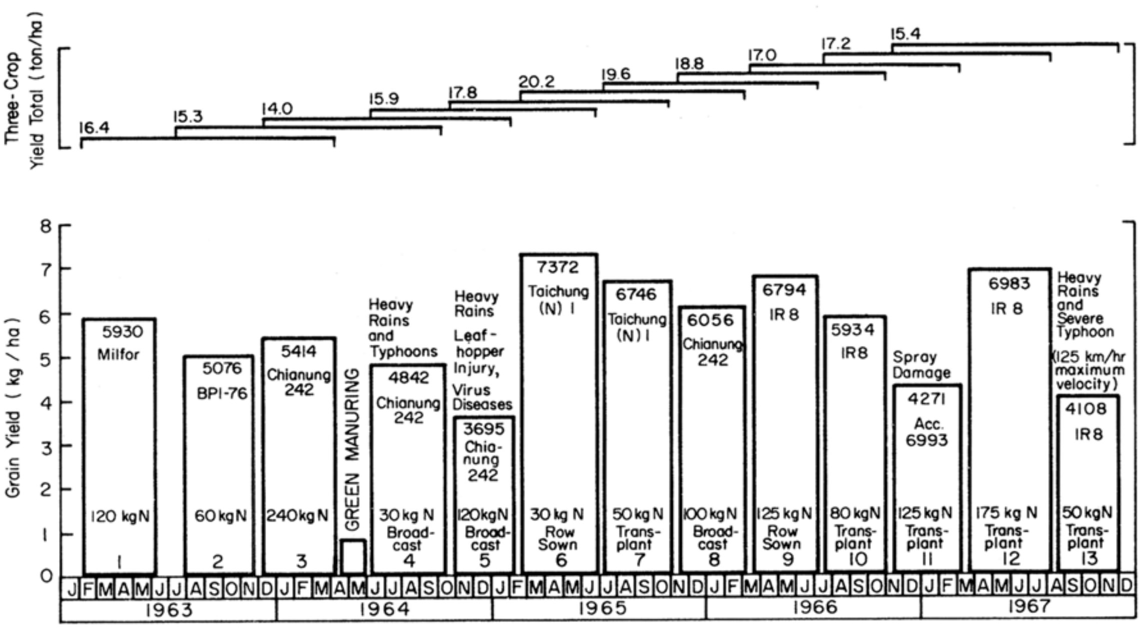

Fig. 1. A chart showing the grain yield of rice of the best treatment combination in a continuous-cropping experiment. IRRI. 1963 thru 1967 crop season.

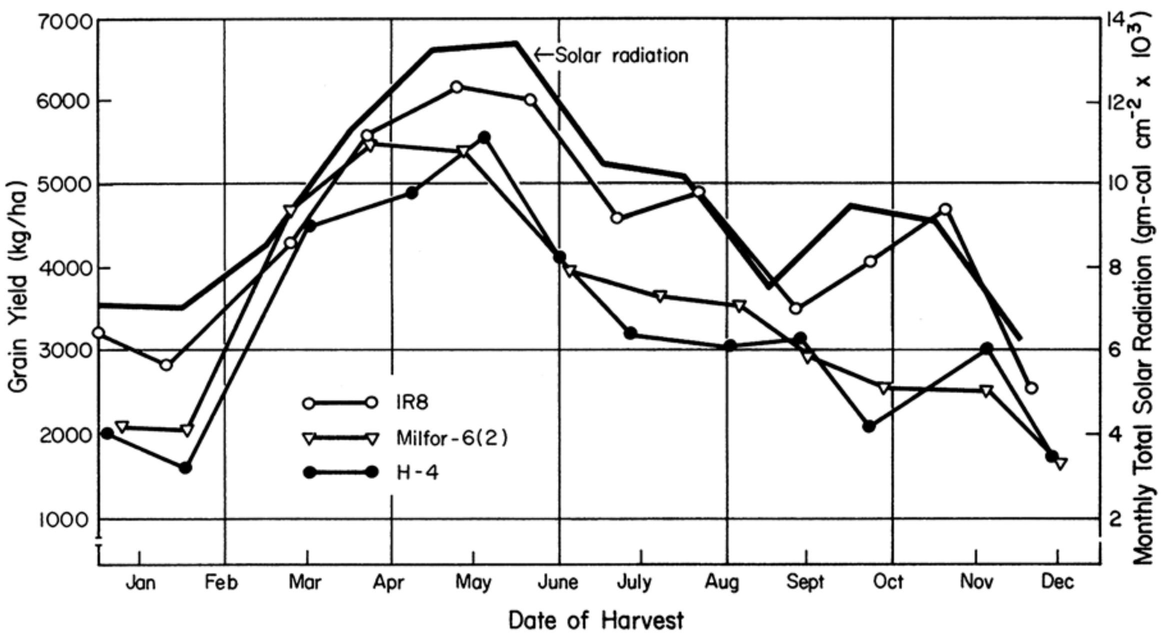

Fig. 2. Yields of IR8, Milfor-6(2), and H-4 from three spacings and three nitrogen levels plotted by dates of harvest. Monthly total solar energy values are also plotted with grain yields from 1967 harvests. IRRI.

followed by Milfor-6(2) and H-4 which were harvested in May and April (a period of high solar radiation), respectively (Fig. 2).

The 1966 and 1967 crops, particularly Milfor-6(2) and H-4, were severely attacked by rats, birds and virus diseases. The October harvest of H-4 was also attacked by leafhoppers, and Milfor-6(2) suffered from stem borers in the same month. These crop hazards tended to mask any yield differences between the two varieties.

For the cloudy wet season, IR8 and Milfor-6(2) harvested in late October or early November gave higher yields than those harvested at other periods of the same general season. With the variety H-4, no consistent trend was discerned during the wet season. A relatively mild typhoon ("Trining") occurred 1 month before the November harvest and caused H-4 to lodge severely, hence this crop could not take advantage of the high solar energy during October and November.

Differences in spacing did not affect significantly the grain yield of the three varieties tested except that the 35 x 35 cm spacing gave lower grain yield than the 15 x 15 cm or 25 x 25 cm spacing. Yield data (average for three varieties) showing the effect of spacing on yield are presented in Fig. 3.

Relationships between solar radiation and grain yield

Regression and correlation analyses of the solar radiation data for each month and grain yield values for the corresponding month show that, with one exception, solar radiation received during the last 30 and 45 days before harvest was highly correlated with grain yield. Solar radiation values for 30 days before the harvest of Milfor-6(2), measured by a net radiometer, were significant at the 5-percent level (Table 1). The solar radiation data were collected by the Institute using a net radiometer installed in its

Table 1. Correlation between solar radiation 30 and 45 days before harvest and grain yields of three rice varieties.

Variety	Solar radiation (g-cal/cm²/30 and 45 days): Pyrheliometer-UPCA, Days before harvest 30	Pyrheliometer-UPCA 45	Net radiometer-IRRI 30	Net radiometer-IRRI 45
IR8	0.92**	0.93**	0.77**	0.82**
Milfor-6(2)	0.81**	0.85**	0.66*	0.78**
H-4	0.85**	0.86**	0.84**	0.91**
Pooled for 3 varieties	0.86**	0.88**	0.76**	0.84**

experimental farm, and by the U.P. College of Agriculture by means of a pyrheliometer installed 1 kilometer away from the Institute farm.

High correlation values were also obtained when the data for the three varieties were pooled. Correlation coefficients obtained at 30 and 45 days were not significant although numerically different. There tended to be an increased correlation when data for 45 days before harvest were used (Table 1). The recent "r" values were higher than reported earlier (Annual Report, 1965), primarily because a greater degree of crop protection was obtained. Correlation values were higher with the pyrheliometer than with the net radiometer.

Association between environmental factors and the rice yield components

Correlation, multiple regression, and path coefficient analyses of 11 variables affecting grain yield were made for Peta, Milfor-6(2) and Taichung (Native) 1 from the date-of-planting experiments conducted from November 1963 to December 1965. From the correlation matrix, all variables recorded in Fig. 4, except for the 100-grain weight, were correlated with grain yield at the 1-percent level. One hundred grain weight was correlated with grain yield at the 5-percent level of significance.

Plant height and number of unfilled grains per five panicles gave the highest negative correlation with grain yield. Among the 11 variables studied, a very high correlation was obtained between tillers at harvest/sq m and panicle number/sq m with $r = 0.945$. The result from the multiple regression analysis showed that rainfall (mm) and maturity days did not contribute significantly to grain yield. The combined effect of the 11 variables accounted for 58 percent of the total variation in grain yield.

The path coefficient analysis indicates that among the 11 variables, number of panicles/sq m was the predominant component affecting grain yield. The direct effect of number of panicles/sq m on grain yield in the positive direction (P = 0.9468) produced the largest estimate of the 11 variables measured. The number of panicles/sq m was positively correlated with

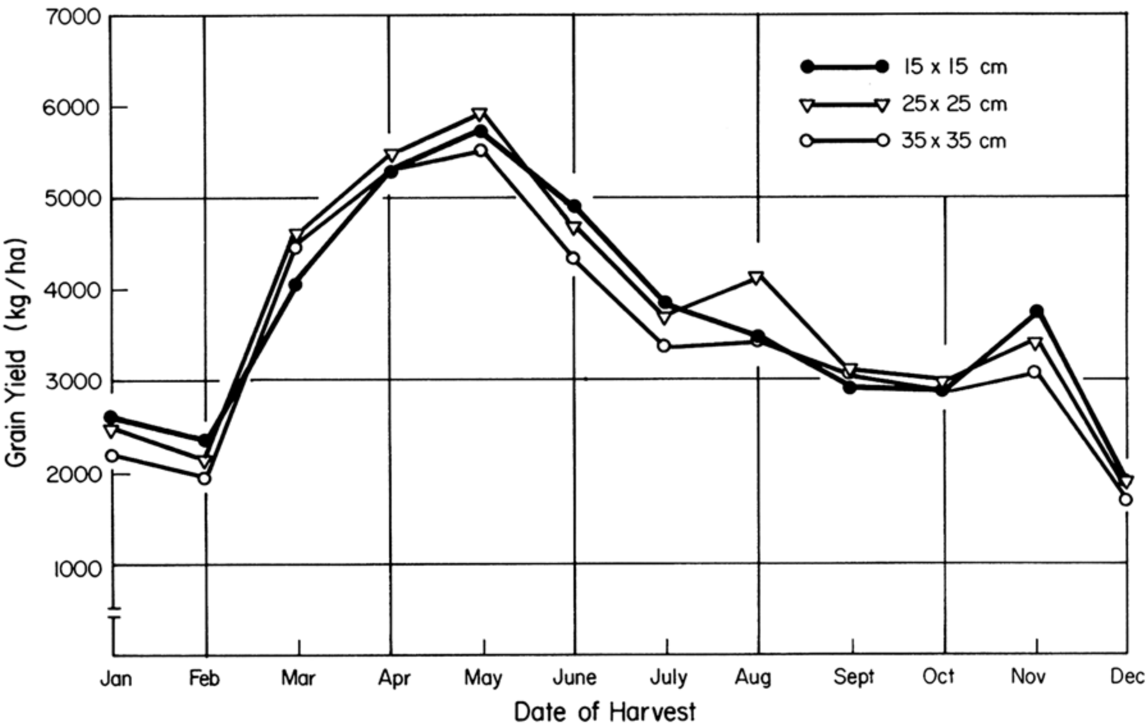

Fig. 3. Grain yields from three spacings (average of rice varieties: IR8, Milfor-6(2) and H-4) and three nitrogen levels (0, 30 and 90 kg/ha) plotted by dates of harvest. Date of planting experiment, IRRI, 1967 crop harvest.

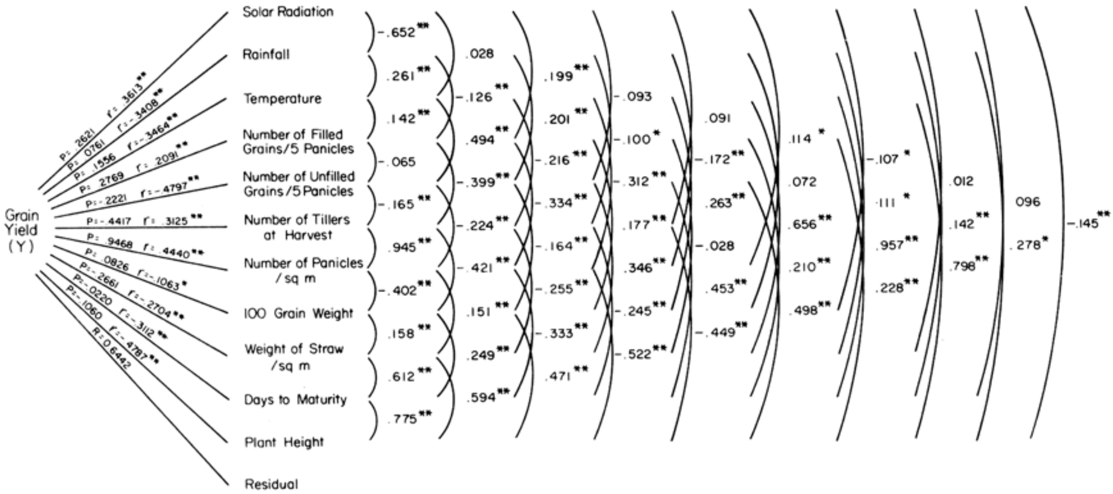

Fig. 4. Path diagram and association of three environmental factors and eight yield components to the grain yield of rice. Combined data of November 1963 thru December 1965. Date-of-planning experiment, IRRI.

grain yield ($r = 0.444$). The number of filled grains/5 panicles gave the second largest estimate of direct positive effect on grain yield. The total number of tillers at harvest gave the largest estimate of direct negative effect on grain yield. The number of tillers at harvest and number of panicles were positively correlated ($r = 0.945$).

High positive correlation was obtained between straw yield and maturity days and between plant height and maturity days. Increased rainfall was associated with cloudiness and low energy, hence the correlation between rainfall and solar radiation was significant but negative.

Soil Fertility and Fertilizer Management

During 1967, the major emphasis in soil fertility research was on various aspects of fertilizing flooded and upland rice with nitrogen. Studies were made on the effect of plant type, season of growth, soil, and method of planting on the nitrogen response of indica rice. Investigations were continued using a revised model of the 1966 experiments to take into account a wider range in level of management inputs. The effect of water management and split application of nitrogen in flooded rice was also studied in greater detail using N^{15}-labelled fertilizer nitrogen. Another area of research concerned sources and rates of fertilizer phosphorus.

Effect of plant type and nitrogen level on the growth characteristics and grain yield of indica rice

Experiments were continued in 1967 to study the nitrogen response and growth characteristics of indica varieties (mostly of improved plant type) bred at the Institute or elsewhere and of a traditional leafy tropical indica variety.

The response to nitrogen of nine varieties during the 1967 dry season are summarized in Fig. 5. The nitrogen rate applied varied from 0 to 120 kg/ha at 30-kg increments during the dry season and 0 to 80 kg/ha at 20-kg increments during the wet season. The full nitrogen application was made for each season and harrowed-in during land preparation. A split-plot experimental design was used, with nitrogen levels as the main plots and varieties or selections as the subplots. The treatments were replicated thrice. The seedlings were transplanted at 25 x 20 cm spacing.

Dry season. Peta and BPI-76-1 showed leaf lodging in mid-March and culm lodging at the end of April, while IR8, IR400-28-4-5 and IR154-61-1 did not lodge at any stage of plant growth. The differences in nitrogen response between two widely different plant types were well illustrated in comparisons between Peta and IR8. Figure 6 shows how Peta lodged without added nitrogen while IR8 remained erect and gave increased yields up to 9,339 kg/ha

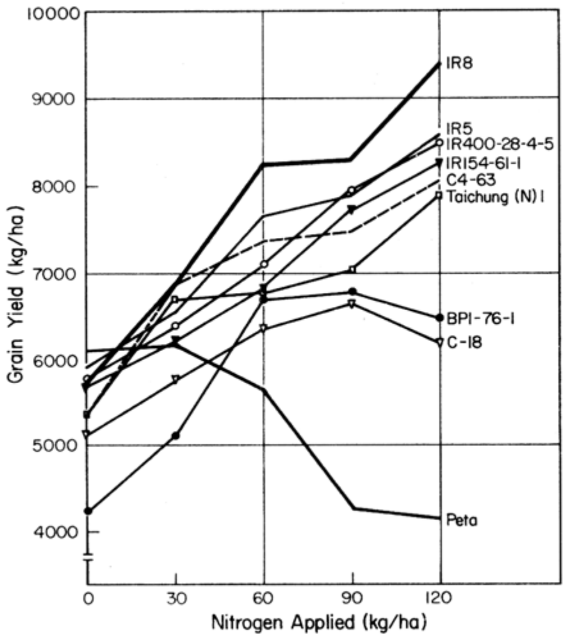

Fig. 5. Effect of levels of nitrogen on the grain yield of indica rice varieties. IRRI, 1967 dry season.

with 120 kg/ha N. IR5 lodged at the hard dough stage of grain formation but only with 90 and 120 kg/ha N. IR5 and IR400-28-4-5 produced yields of 8,500 kg/ha each with 120 kg/ha N. IR8 yielded significantly more than all varieties and selections. The light transmission ratios (LTR) determined at five physiological growth stages of the rice crop (measured 10 cm above the crop and 10 cm above the water surface) showed that IR154-61-1 had the highest LTR at heading and onwards because the selection had narrow, erect leaves and did not cover as much ground space as the other varieties and selections tested.

The medium- to high-tillering dwarfs such as IR8, Taichung (Native) 1 and IR400-28-4-5 had somewhat higher LTR values than the high-tillering varieties of intermediate height such as IR5 and C_4-63, and considerably higher values than the tall, leafy, high-tillering Peta (data not presented here).

Yield component data (Table 2) show that IR8 had the highest 100-grain weight among all the varieties and selections tested, including such high-yielding varieties as Taichung (Native) 1 and IR5. IR8 was also among those with the lowest percentage of sterility. These factors may partly explain the generally higher yields obtained with IR8 under most conditions compared with those obtained with other varieties and selections of similar plant type.

Wet season. The experiment was repeated during the cloudy wet season using the same varieties and selections. The highest yield, 5,695 kg/ha, was obtained with IR400-28-4-5 (Peta/4 x T(N)1). This was significantly higher than the yield of IR8 (Table 3). The 2-crop grain yield totals of the two dwarfs were similar: 14,616 kg/ha for IR8 and 14,263 kg/ha for IR400-28-4-5.

Based on two-season data, IR400-28-4-5 was similar to IR8 in several yield-influencing characteristics (Table 2). It was also similar in growth duration (122-124 and 119 days for the dry and wet seasons, respectively), and slightly shorter particularly during the sunny dry season (Table 2). This selection merited further testing under a wide range of cultural and environmental conditions.

Unlike IR8, IR5 and C_4-63 lodged when they neared maturity, particularly at the 80 kg/ha N level (Fig. 7).

Fig. 6. While a tall, weak-strawed indica variety, Peta, lodged heavily and produced most without fertilizer, a stiff-strawed indica variety, IR8, was erect and standing even at 120 kg/ha N and produced the highest grain yield, 9,339 kg/ha. Nitrogen response experiment, IRRI, 1967 dry season.

Table 2. Yield components of nine indica varieties or selections (average of five levels of nitrogen). IRRI, 1967 dry and wet seasons.

Variety or selection	Plant height (cm)		No. panicles/ hill		100-grain weight (g)		Sterility (%)		Grain: straw ratio	
	D*	W†	D*	W†	D*	W†	D*	W†	D*	W†
IR8	80	89	16	10	3.0	2.9	5	15	1.0	0.9
IR400-28-4-5	72	86	17	11	2.6	2.8	13	23	1.2	1.0
Taichung (Native) 1	84	89	16	11	2.5	2.6	8	13	1.2	1.0
IR154-61-1	78	82	17	10	2.0	2.1	7	12	1.2	0.9
IR5	107	114	15	10	2.0	2.5	11	21	0.8	0.9
C_4-63	95	108	16	9	2.2	2.5	12	24	0.9	0.9
BPI-76-1	105	118	15	8	2.2	2.2	19	24	0.8	0.8
C-18	118	130	14	9	2.5	2.5	25	28	0.8	0.8
Peta	150	155	14	8	2.8	2.8	31	42	0.6	0.4

*Dry season.
†Wet season.

Table 3. Effect of nitrogen levels on the grain yield of different rice varieties, IRRI, 1967 wet season.

Nitrogen applied (kg/ha)	Grain yield (kg/ha) at 14% moisture* IR 154-61-1	T (N) 1	IR8	IR 400-28-4-5	C-18	C_4-63	BPI-76-1	IR5	Peta	Mean (N level)
0	2456	2507	3389	3861	3579	3803	3071	3947	2594	3245
20	2894	3234	4011	3939	3969	4299	3561	4414	2201	3614
40	3006	3540	4324	4575	4202	4439	3933	4700	2244	3885
60	3314	3777	4470	5089	4106	4818	3635	5172	1508	3988
80	3668	4388	5277	5695	3284	5128	4154	4982	1540	4235
Mean (variety)	3068	3489	4294	4632	3828	4497	3671	4643	2017	3793
Duration (days)	104	108	119	119	125	125	125	132	137	

Analysis of variance:	s.e.	LSD (5%)	CV (X) %
N-level (N)**	64	209	10.6
Variety (V)**	108	299	10.8
V X N**	242	671	

*Average, three replications.

The total dry matter produced by two crops (dry and wet seasons, 1967) of IR8, IR5 and Peta reached the maximum 15 days following heading (Fig. 8). At maturity, IR5 had higher total dry matter than IR8, while Peta produced the least amount.

Nitrogen response experiments on farmers' fields
Studies on the nitrogen response of different varieties were continued on farmers' fields during the 1967 crop seasons. These experiments were conducted in cooperation with the Institute's Experimental Farm Department. The measures used to control pests were less elaborate than those followed at the Institute farm and were within the management capabilities of local farmers. Insect pest attacks found under farm conditions being less serious, good insect control was generally achieved with these procedures.

Dry season. An experiment using IR8, IR5,

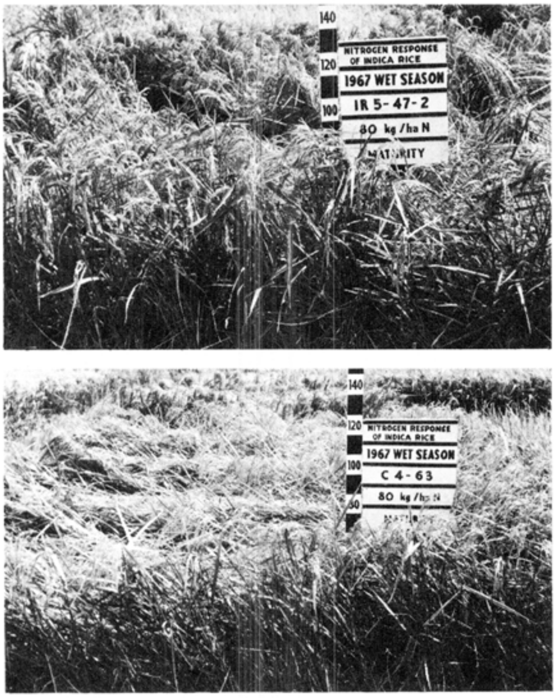

Fig. 7. Medium-statured varieties, IR5 and C_4-63, growing on fertile Maahas clay with 80 kg/ha N, lodged prior to maturity but nevertheless produced yields comparable to IR8 in the wet season. Nitrogen response experiment, IRRI, 1967 wet season.

C-18, BPI-76-1, and Milbuen Str. 20 was conducted in Calamba, Laguna, on a typical rice soil with nitrogen applications ranging from 0 to 130 kg/ha applied basally, plus 20 kg/ha applied as top-dressing at panicle initiation. A split-block design was used.

The application of 150 kg/ha N on IR8 resulted in a grain yield of 8,892 kg/ha, double that obtained at the 0 N level. This was the highest yield recorded from any replicated experiment conducted in this series of farmers' field experiments (Table 4). IR8 yielded significantly more than any other variety with each additional amount of nitrogen up to 150 kg/ha. C-18 and IR5 gave significantly higher grain yields than BPI-76-1 and Milbuen Str. 20.

Wet season. The nitrogen applied varied from 0 to 80 kg/ha, all harrowed-in during land preparation. The varieties used were similar to those used for the dry season except for C_4-63, a newly developed selection from the U.P. College of Agriculture, which replaced Milbuen Str. 20. The damage caused by the typhoon on November 3 and 4 reduced the grain yields as all the varieties were harvested after the typhoon. Differences in yields due to nitrogen or to variety were not significant but the nitrogen x variety interaction was highly significant (Table 5).

Similar to the dry season results, the grain yield increase of IR8 at 80 kg/ha N was double that of the check. All other varieties yielded significantly higher only up to 20 kg/ha N.

Table 4. Effect of nitrogen levels on the grain yield of indica rice. Nitrogen response experiment in farmer's field, Calamba, Laguna, 1967 dry season.

Nitrogen applied (kg/ha) (basal + panicle initiation)	Yield (kg/ha) at 14% moisture					Mean (N rate)
	IR8	C-18	IR5	BPI-76-1	Milbuen Str. 20	
0	4409	3967	4230	3094	3294	3799
30 +20	5509	5266	5442	4407	4631	5051
80 +20	7547	6990	6661	6059	5081	6468
130 +20	8892	7722	7154	6942	5380	7218
			Mean (variety)			
	6589	5986	5872	5125	4596	
			Duration (days)			
	120	115	131	115	120	

Analysis of variance:

	s.e.	LSD (5%) (kg)	CV (X) %
N-level (N)**	293	1318	16
Variety (V)**	144	565	7
N X V**	223	687	6

Table 5. Effect of nitrogen levels on the grain yield of indica rice. Nitrogen response experiment in farmer's field, Calamba, Laguna, Philippines, 1967 wet season.

Nitrogen applied (kg/ha)	Grain yield (kg/ha) at 14% moisture					Mean (N level)
	IR8	C-18	C_4-63	BPI-76-1	IR5	
0	2756	3430	3021	2409	3029	2929
20	3720	4685	3602	3482	4026	3903
40	4187	4718	3888	3680	3206	3936
60	5070	3781	4303	3813	2944	3982
80	5539	3219	4405	3135	4002	4060
Mean (variety)	4254	3967	3843	3304	3441	
Duration (days)	121	121	121	121	130	

Analysis of variance:

	s.e.	LSD (5%)	CV (X) %
Nitrogen (N)$^{n.s.}$	203	—	17
Variety (V)$^{n.s.}$	222	—	19
N X V**	283	848	11

Effect of levels of management (fertilizer N x weeding x insect control) on the grain yield of two varietal types of rice

Experiments to determine the production resource inputs contributing to maximum yield and optimum economic return were conducted in 1967. Results reported in 1966 indicated that the inability to improve farm profits at high levels of management resulted from the high cost of insecticides required to achieve those yields. (Other Institute studies showed that lower rates of insecticides were profitable but higher rates of insecticides necessary to achieve very high yields were not.)

In experiments conducted during the 1967 crop seasons, a revised model of the 1966 experiments was adopted to take into account a wider range in level of management inputs and to test diazinon, a new systemic insecticide capable of controlling the leafhoppers and stem borers. A split-split-split plot design was used with four factors—fertilizer nitrogen, varietal type, insecticide, and weed control.

Dry season. The variables included nitrogen level, 0 to 140 kg/ha; diazinon (active ingredient), 0 to 12 kg/ha (3 kg/ha per application); weed control, 0 to 2 handweedings; and MCPA herbicide, 1 spraying. The yield response to weeding was not significant when IR8 and H-4 were analyzed together. The mean yields of weeding treatments, and the yield responses to fertilizer and diazinon treatments are shown in Table 6.

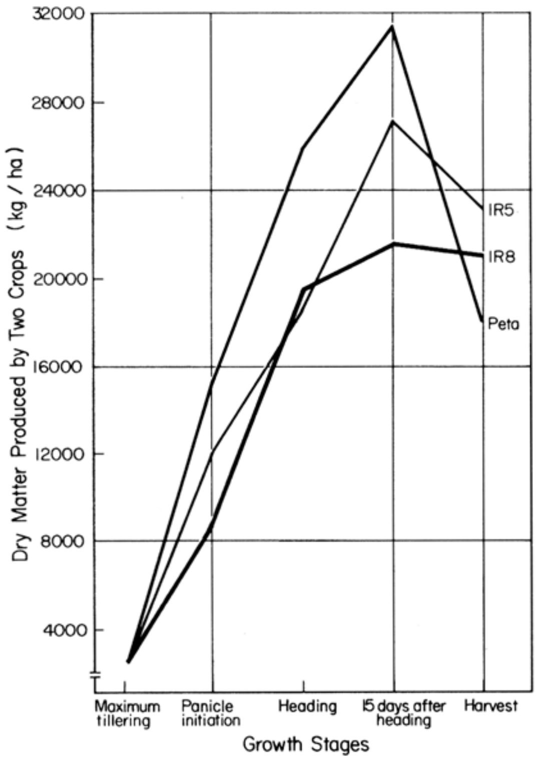

Fig. 8. Two-crop total dry matter produced by three varieties at five growth stages of rice crop. IRRI, 1967 dry and wet seasons.

A multiple regression analysis was made on

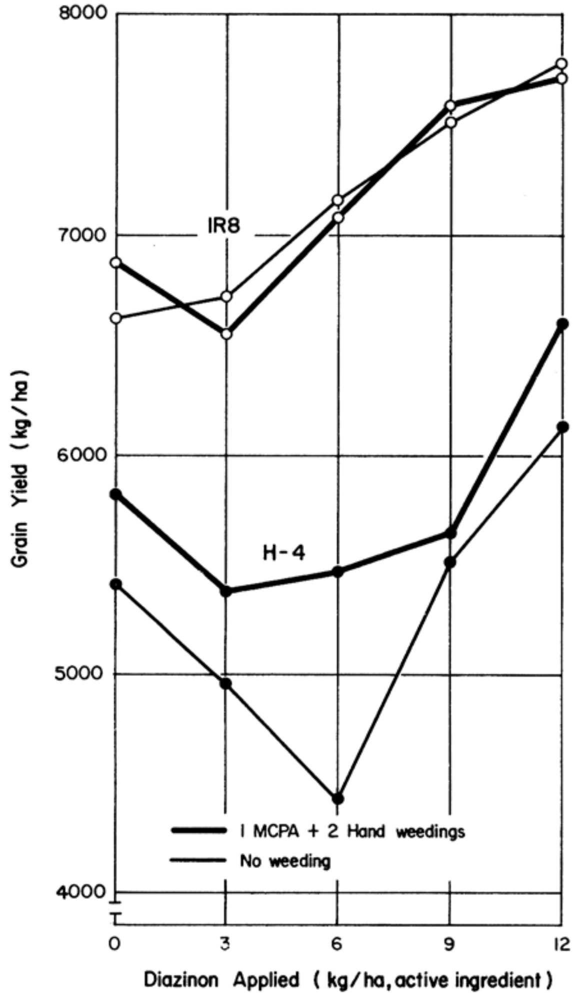

Fig. 9. Effect of level of diazinon with or without weed control on the grain yield of IR8 and H-4 (average of all nitrogen levels), IRRI, 1967 dry season.

grain yield ($\hat{Y}$) with nitrogen levels (X_1), weed control (X_2), and diazinon levels (X_3). Only weed control did not contribute to the variation in the grain yield ($\hat{Y} = 5{,}627 + 12.40X_1 + 259.10X_3$; $rX_1Y = 0.57^{**}$, $rX_2Y = -0.01_{n.s.}$; $rX_3Y = 0.35^{**}$) of IR8, while it was diazinon that did not contribute to the variation in the grain yield ($\hat{Y} = 5{,}746 - 7.82X_1 + 229.14X_2$, $rX_1Y = -0.26^{**}$, $rX_2Y = 0.17_{n.s.}$, $rX_3Y = 0.13_{n.s.}$) of H-4. These regression analyses indicated that the grain yield of IR8 increased with the increase in nitrogen and diazinon levels but it did not change with the variations in weed control level. The weed population was low as the land was thoroughly prepared. For H-4, weed control input caused some variations in grain yield, but this was not the case with the diazinon levels (Fig. 9). The grain yield of H-4 was negatively correlated with the nitrogen levels, indicating that even in the sunny dry season, this variety was not responsive to nitrogen under Los Baños conditions. Without insect and weed control, the grain yield of IR8 was higher than that of H-4, and the differences became greater with increased nitrogen levels (Fig. 10).

These results confirm earlier findings that any variety will respond to higher levels of management, and that those varieties of good plant type are more responsive to higher management levels than those of poor plant type.

Wet season. The nitrogen levels used, which varied from 0 to 100 kg/ha at 25-kg increments, and the diazinon level, which was 2 kg/ha a.i. per application, were lower in the wet season than in the dry season experiment. Only the weed control level and timing were similar to those used in the dry season experiment. F-test values in the analysis of variance showed that the differences due to variety, variety x nitrogen,

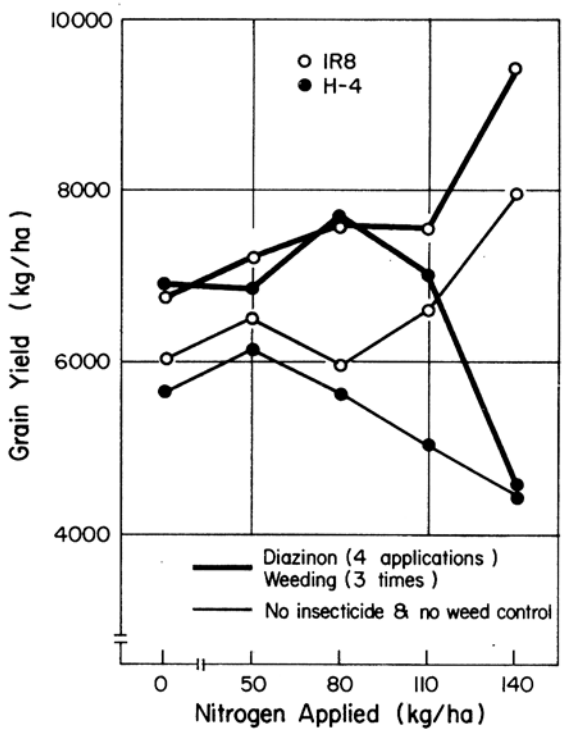

Fig. 10. Effect of two levels of insect and weed control on the nitrogen response of two varietal types of rice, IRRI, 1967 dry season.

Table 6. Yields of IR8 and H-4 rice at five levels of nitrogen and diazinon, IRRI, 1967 dry season*.

Diazinon level (kg/ha, a. i.†)	IR8						H-4					
	Nitrogen applied (kg/ha)											
	0	50	80	110	140	Mean	0	50	80	110	140	Mean
0	5953	6767	6609	6388	7638	6671	5219	6413	5974	4887	5447	5588
3	5729	6986	6652	6976	7432	6755	5439	6272	6170	4392	4155	5268
6	6066	6715	7254	7104	7696	6967	5258	5200	6292	4220	3772	4948
9	6305	6809	7443	7321	8796	7335	5449	6094	6662	4442	5189	5567
12	6880	6923	7542	8056	8969	7674	6280	6524	6971	6039	4682	6099
Mean	6187	6840	7100	7169	8106	7080	5511	6101	6414	4796	4649	5494

*Mean of four weed control treatments and two replications.
†Active ingredient.

Table 7. Yields of IR8 and H-4 rice at five levels of nitrogen and diazinon, IRRI, 1967 wet season*.

Diazinon level (kg/ha, a. i.†)	IR8						H-4					
	Nitrogen applied (kg/ha)											
	0	25	50	75	100	Mean	0	25	50	75	100	Mean
0	1900	2208	2715	3554	2839	2643	2015	2195	1180	827	1293	1502
2	2414	3173	3329	3209	2893	3004	2001	1946	1735	1213	1089	1597
4	2471	3107	3553	3707	3114	3190	2056	1851	1549	743	1012	1442
6	2492	2659	3714	3740	3700	3261	2291	2282	1893	1090	992	1710
8	3007	3165	4072	4175	4408	3765	2733	2394	1835	1711	1114	1957
Mean	2457	2862	3477	3677	3391	3173	2219	2134	1638	1117	1100	1642

*Mean of four weed control treatments and two replications.
†Active ingredient.

diazinon, and weed control were highly significant and that the diazinon x variety interaction was significant at the 5-percent level. The relationship between nitrogen level and grain yield was significant ($r = 0.98^*$) but not linear for IR8 and the quadratic relationship can be expressed as $\hat{Y} = 2{,}384.74 + 30.70X - 0.20X_2$. For H-4, the relationship with nitrogen was linear but negative and highly significant ($r = -0.96^{**}$, $\hat{Y} = 2{,}292.10 - 13.01X$). The relationship between weed control and grain yield was not significant for either variety. For IR8, the relationship between insect control with diazinon and grain yield was highly significant ($r = 0.97^{**}$, $\hat{Y} = 2{,}664.96 + 252.39X$). For H-4, the relationship between insect control with diazinon and grain yield was not significant. Without added diazinon, the grain yield of IR8 increased by 1,500 kg/ha at the 75 kg/ha N level. Without added nitrogen, it increased by 1,000 kg/ha at 8 kg/ha diazinon (four applications). For H-4, without added nitrogen, the highest grain yield was obtained with 8 kg/ha diazinon (Table 7). IR8 yielded about twice as much as H-4 (average of all treatments) and the difference was highly significant.

Fertilizing flooded rice with anhydrous ammonia under three methods of planting

Previous experiments at the Institute have demonstrated that anhydrous ammonia is as efficient as any other ammonium-containing or ammonium-producing commercial fertilizer. They have also shown that direct-seeded rice produces grain yields similar to and occasionally better than transplanted rice. During the 1967 dry and wet seasons, experiments were conducted with IR8 to study the nitrogen fertilization of flooded rice grown by different methods, i.e., broadcast, band-sown, and in

Table 8. Effect of fertilizing IR8 rice with anhydrous ammonia under three methods of planting, IRRI, 1967 dry season.

Nitrogen applied (kg/ha)	Grain yield (kg/ha) at 14% moisture*			Mean (N level)
	Planting method			
	Broadcast	Row-sown†	Transplanted‡	
0	9647	7767	7595	8336
30	10312	7860	9096	9089
60	10341	8407	9168	9305
90	10088	8216	9186	9163
120	10242	9316	9304	9621
150	10312	8928	8837	9359
		Mean (method)		
	10157	8416	8864	
		Duration (days)		
	117	120	125	
		Seeding rate (kg/ha)		
	100	200		

Analysis of variance:

	s.e.	LSD (5%)	CV (X) %
Nitrogen level (N)§	261	787	9.9
Methods of planting (P)**	182	523	9.8
N X P$^{n.s.}$	447	—	—

*Average of four replications.
†10-cm band, 40-cm row space.
‡20-cm paired rows, 30-cm row space x 15-cm within rows.
§Approaching significance at 5% level.

transplanted paired rows. The seeding rates and row spacings used for the dry and wet seasons are given in Tables 8 and 9, respectively. A split-plot design was used with nitrogen level as the main plot and methods of planting as the sub-plot.

Dry season. Nitrogen was applied as anhydrous ammonia at rates varying from 0 to 150 kg/ha at 30-kg increments. It was applied at a 15-cm depth using a portable anhydrous ammonia applicator 2 and 3 weeks after transplanting for the transplanted and row-sown treatments, respectively. For the broadcast treatment, anhydrous ammonia was applied at a 15-cm depth before seeding. The difference in grain yields due to nitrogen level fell just below the 5-percent significance level. The native fertility of the experimental field was very high as reflected by the 8,336 kg/ha average yield without added nitrogen (Table 8). The broadcast treatments gave significantly higher yields than either the transplanted or row-sown treatment (average of all levels of nitrogen). There was, however, no significant difference between the latter treatments.

In the broadcast method, all levels of added nitrogen yielded over 10,000 kg/ha. The grain yield of 10,341 kg/ha rough rice is the highest recorded yield to date at the Institute from any replicated experiment. The number of total and productive tillers produced in the broadcast treatment was considerably higher than that produced in the row-sown or transplanted treatment (Table 10). These results demonstrate that to obtain grain yields of 10,000 kg/ha or higher, a large number of total tillers per unit area is necessary. In this experiment, about 560 tillers/sq m were produced, most of which were productive (about 500 panicles/sq m). The sterility grain : straw ratio and the 100-grain weight were similar for the three planting methods (Table 10).

Wet season. The nitrogen levels varied from 0 to 75 kg/ha. Applications were made before seeding in the broadcast and row-sown treat-

Table 9. **Effect of levels of nitrogen as anhydrous ammonia* and methods of planting on the grain yield of IR8 rice, IRRI, 1967 wet season.**

Nitrogen applied (kg/ha)	Grain yield (kg/ha) at 14% moisture			
	Planting method			Mean (N level)
	Broad-cast†	Row-sown†	Trans-planted‡	
0	5329	4398	4908	4878
15	5774	5230	5273	5426
30	5579	5642	5682	5634
45	6352	5731	5925	6003
60	6303	5813	5791	5969
75	6018	5641	6060	5906
Mean (planting method)	5892	5409	5606	

Analysis of variance:	s.e.	LSD (5%)	CV(X) %
Nitrogen level (N)**	140	422	9.5
Methods of planting (M)**	109	313	
N X M^n.s.	268	—	

*Applied at 15 cm depth.
†Seeding rate = 100 kg/ha; duration = 113 days.
‡Duration = 120 days.

ments, and 13 days after planting in the transplanted rice. The seeding rate for the row-sown plots was 100 kg/ha which was half that used during the dry season. Compared to the unfertilized check, there was a significant response to each increment of added nitrogen up to 60 kg/ha (Table 9). The difference in grain yields between the transplanted and row-sown treatments was highly significant but not between the transplanted and the broadcast treatments. The trend in grain yield of the three methods of planting was similar to that obtained in the dry season. The number of total and productive tillers per unit area, however, was considerably lower than that in the dry season crop (Table 10). The differences in yield components among the planting methods did not account for the difference in grain yields between the two direct-seeded treatments. The high yield for the wet season, and that for the dry season, totalled 16,693 kg/ha. Figure 11 shows the excellent stand of broadcast IR8 in the dry and wet season crops from the two high yielding treatments.

A significant feature of these results is that the new 1- and 2-crop yield records were obtained from broadcast rice, whereas the previous high yield records were obtained from transplanted rice. These results demonstrate that high yields may be obtained from broadcast plantings when adequate management levels are maintained, i.e., using herbicides to minimize early grassy weed competition, proper water management, and adequate snail and algal control. The insect control procedures followed were essentially the same for direct-seeded and transplanted rice.

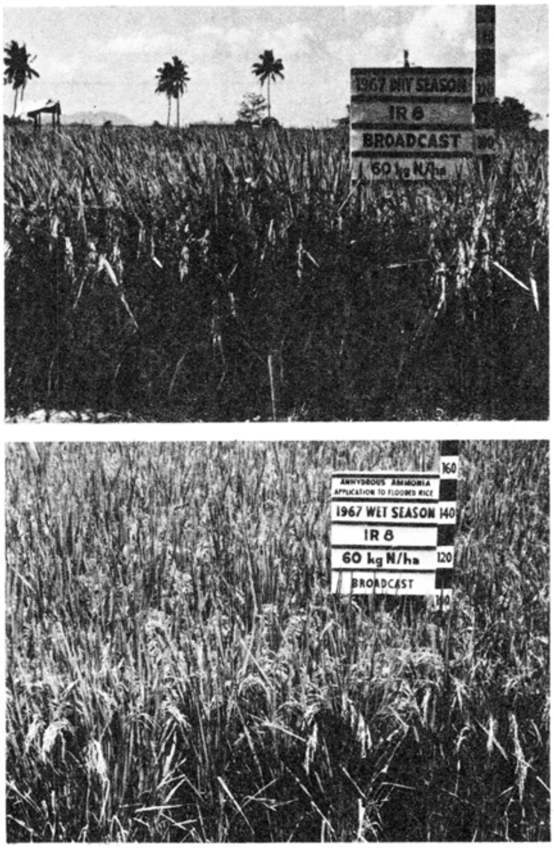

Fig. 11. IR8 produced record yields of 10,341 kg/ha in a single crop and 16,693 kg/ha in two direct-seeded (broadcast) crops. Results were obtained from an experiment on fertilizing flooded rice with anhydrous ammonia under three methods of planting. IRRI, 1967 dry and wet seasons.

Water management and split application of nitrogen in flooded rice (N^{15} study)

Water management may directly affect the efficiency of nitrogen fertilizer for lowland rice.

Experiments were conducted during the 1967 crop seasons to measure the time response of nitrogen application with two water manage-

Table 10. Effect of methods of planting on some yield components of IR8, IRRI, 1967 dry and wet seasons.

Yield component*	Broadcast		Row-sown		Transplanted	
	Dry Season	Wet Season	Dry Season	Wet Season	Dry Season	Wet Season
Tiller number/sq m	564	392	232	396	389	257
Panicle number/sq m	507	377	217	377	359	247
Sterility (%)	14	18	17	13	13	12
Grain/straw	1.0	1.0	1.0	1.1	1.1	1.2
Weight of 100 grains (g)	2.9	2.9	2.7	3.0	2.8	2.9

*Average, all nitrogen levels.

Table 11. Effect of two treatments of water management and time of nitrogen application on the grain yield and utilization of added nitrogen in flooded H-4 rice (N^{15}-study), IRRI, 1967 dry season.

Treatment no.	Nitrogen applied (kg/ha) at					Grain yield (kg/ha) at 14% moisture: Water management			Utilization of N^{15} - nitrogen by grain + straw (%)
	1*	2†	3‡	4§	5‖	Continuously flooded (5 cm)	Drained before fertilizer application then immediately reflooded	Mean (treatment and variety)	
								(Treatment)	
1	0	0	0	0	0	5159	—	—	—
2	60	0	0	0	0	3411	—	—	—
3	0	30▸	30	0	0	5041	4455	4748	33
4	0	0	30▸	30	0	5943	6333	6138	48
5	0	0	0	30▸	30	5859	6003	5931	45
6	0	20	20	20	0	5344	6093	5719	—
7	0	0	20	20	20	5972	5911	5941	—
8	0	20	20	0	20	5979	6025	6002	—
9	45	0	0	0	15▸	5163	4695	4929	60
10	45	0	15▸	0	0	4628	4887	4757	48
						Mean (water management)			
						5491	5550		
								(Variety)	
								5521	

Analysis of variance:

		s.e.	LSD (5%)	CV (X) %
A[1]	Water management (W)$^{n.s.}$	236	—	21
	Treatment mean (T)*	320	971	14
	T X W mean$^{n.s.}$	296	—	9
B[2]	Water management (W)$^{n.s.}$	236	—	21
	Treatment mean (T)**	335	995	14
	T_1 vs T_2*	—	—	—
	T X W mean	296	—	9

* Last harrowing.
†Maximum tillering.
‡Panicle initiation.
§Booting.
‖Heading.
▸N^{15}-labelled ammonium sulfate.
[1] Analyses exclude treatments 1 and 2.
[2] Analyses include treatments 1 and 2.

Table 12. Effect of two treatments of water management and time of nitrogen application on the grain yield of IR8 and H-4 (N^{15}-study), IRRI, 1967 wet season.

Treatment no.	Nitrogen applied* (kg/ha) at					Grain yield (kg/ha) at 14% moisture				Mean (treatment and variety)	
						Water management					
	1†	2‡	3§	4‖	5▶	Continuously flooded (5 cm)		Drained before fertilizer application then immediately reflooded			
						IR8	H-4	IR8	H-4	IR8	H-4
										(Treatment)	
1	0	0	0	0	0	2199	2531	—	—	—	—
2	60	0	0	0	0	5180	1983	—	—	—	—
3	0	30**	30	0	0	5090	1979	5013	2277	5052	2128
4	0	0	30**	30	0	4681	2483	4820	2395	4750	2439
5	0	0	0	30**	30	4298	2888	4038	3000	4168	2944
6	0	20	20	20	0	4991	1491	5155	2169	5073	1830
7	0	0	20	20	20	4470	2620	4389	2738	4430	2679
8	0	20	20	0	20	5073	2765	4880	2515	4976	2640
9	45	0	0	0	15**	4923	2295	5257	2303	5090	2299
10	45	0	15**	0	0	4964	1915	5443	2181	5204	2048
						Mean (water management)					
						4999	2304	4811	2447		
										(Variety)	
										4905	2375

Analysis of variance:

	s.e.	LSD (5%)	CV (X) %
Variety IR8—Treatment mean (T)**	227	674	11
Treatment x water management n.s.	146	—	5
Variety H-4—Treatment (T) n.s.	306	—	13
Treatment x water management	316	—	23

Duration (days): IR8 = 118
H-4 = 130

*Half the rate for H-4 (total 30 kg/ha N).
†Last harrowing.
‡Maximum tillering.
§Panicle initiation.
‖Booting.
▶Heading.
**N^{15}-labelled ammonium sulfate.

ment systems (Tables 11 and 12). Five treatments received N^{15} (1.2% atom excess)-labelled nitrogen. Sixty kg/ha N was applied at different stages of plant growth in single and multiple applications. The variety tested in the dry season was H-4, while IR8 and H-4 were used in the wet season.

Dry season. Grain yields under the two water management systems were not significantly different. Compared with the 0 N control, the grain yield of H-4, which severely lodged, was significantly reduced when 60 kg/ha N was applied before the last harrowing. The highest grain yield of H-4 of 6,333 kg/ha was obtained when 60 kg/ha N was applied in split doses at the time of panicle initiation and at booting. H-4 lodged irrespective of nitrogen level (Fig. 12); however, the earlier nitrogen applications resulted in earlier lodging and a higher percentage of sterility. N^{15} analyses showed that the utilization of N^{15}-labelled nitrogen by grain + straw was about 12 to 15 percent higher in later treatments than in early ones (treatments 3 to 5, Table 11). The percentage of utilization of

Table 13. Chlorophyll content of leaves of two varietal types as affected by time of nitrogen application, IRRI, 1967 wet season.

Treatment no.	Nitrogen applied (kg/ha) at					Variety	Chlorophyll in leaves* (%, oven-dry basis) Growth stage				
	1†	2‡	3§	4‖	5▸		Maximum tillering	Panicle initiation	Booting	Heading	Harvest
1	0	0	0	0	0	IR8	0.48	0.38	0.26	0.32	0.19
	0	0	0	0	0	H-4	0.55	0.40	0.34	0.34	—
2	60	0	0	0	0	IR8	0.61	0.54	0.53	0.44	0.15
	30	0	0	0	0	H-4	0.57	0.45	0.34	0.32	—
3	0	30**	30	0	0	IR8	—	0.51	0.47	0.62	0.20
	0	15**	15	0	0	H-4	—	0.51	0.41	0.29	—
4	0	0	30**	30	0	IR8	—	—	0.50	0.88	0.24
	0	0	15**	15	0	H-4	—	—	0.35	0.35	—
5	0	0	0	30**	30	IR8	—	—	—	0.70	0.33
	0	0	0	15**	15	H-4	—	—	—	0.32	—
6	0	20	20	20	0	IR8	—	0.55	0.48	0.72	0.23
	0	10	10	10	0	H-4	—	0.45	0.37	0.29	—
7	0	0	20	20	20	IR8	—	—	0.41	0.68	0.27
	0	0	10	10	10	H-4	—	—	0.30	0.34	—
8	0	20	20	0	20	IR8	—	—	—	0.53	0.24
	0	10	10	0	10	H-4	—	—	—	0.29	—
9	40	0	0	0	20**	IR8	—	—	0.37	0.51	0.21
	20	0	0	0	10**	H-4	—	—	0.28	0.26	—
10	40	0	20**	0	0	IR8	0.63	0.47	0.45	0.53	0.17
	20	0	10**	0	0	H-4	0.57	0.44	0.36	0.28	—

*Leaves no. 2 and 3 from the top until harvest flagleaf at harvest.
†Last harrowing.
‡Maximum tillering.
§Panicle initiation.
‖Booting.
▸Heading.
**N^{15}-labelled ammonium sulfate.

N^{15}-labelled nitrogen was high at the panicle initiation stage. Both 30 and 15 kg/ha N^{15}-labelled nitrogen gave similar values, indicating that the later the application, the higher the percentage of nitrogen recovery.

Wet season. The nitrogen applied to IR8 and H-4 were 60 and 30 kg/ha, respectively. IR8 yielded significantly more grain with added nitrogen irrespective of time of application than did the no-nitrogen check. For H-4, the grain yields under different nitrogen treatments did not differ significantly. The mean grain yields for IR8 and H-4 were not affected by the two water management systems. For IR8, nitrogen when applied early, either in single or split doses, resulted in higher yields than when applied late, particularly at the booting or heading stage. The grain yield difference between time of nitrogen application treatment and water management was not significant. H-4 lodged severely and the differences in grain yield between treatments (1 and 2 included) were not significant (Table 12).

Leaves (no. 3 and 4 from the top) of IR8 and H-4, sampled at various growth stages of the crop up to the heading stage and IR8 flagleaves collected at harvest were analyzed for chlorophyll content. The values are presented in Table 13. For IR8, nitrogen topdressing at later growth stages gave higher chlorophyll contents of leaves at heading than did the same amount all applied at planting. This difference was not found for H-4 (Table 13). The chlorophyll content of the flag leaf at maturity was also higher when nitrogen was applied later than when applied early. A modest application of nitrogen to IR8 following heading is necessary to maintain the dark-green color of the flagleaf until maturity (Table 13). In this experiment, however, keeping the flagleaf dark-green by nitrogen topdressing at later stages of crop growth did not result in a higher grain yield.

Data for two-crop seasons demonstrate that if the water depth of the field is maintained at 5 cm, temporary drainage for nitrogen topdressing offers no advantage in terms of grain yield and, therefore, is not recommended in areas where the water needed for reflooding is not assured.

Effect of varietal types and time of nitrogen application on the grain yield of upland rice

Studies on the time of nitrogen application in flooded rice have received more attention from rice agronomists than perhaps any other study, but information is meager on the best time for nitrogen application in upland rice. An experiment was conducted during the wet season (May 23 to October 24) using an upland variety, Palawan, and two fertilizer-responsive indicas, IR8 and IR5. Seeds were drilled in dry soil at 100 kg/ha, 1 to 2 cm in depth and at 15-cm row spacing with an Australian linkage seeder. Nitrogen was applied at 0, 60 and 120 kg/ha, each rate at various splits (Table 14). Palawan and IR8 matured between 134 and 139 days, and IR5 in 151 days. IR5 yielded significantly higher than IR8 and Palawan by 610 and 1,888 kg/ha (average of all treatments), respectively. The highest grain yield yet achieved in a replicated experiment with upland rice at the Institute farm, 6,191 kg/ha, was obtained with IR5 when 60 kg/ha N was applied between panicle initiation and booting stage. This treatment gave a significantly higher yield than that

Table 14. Effect of varietal types and time of nitrogen application on the grain yield of upland rice, IRRI, 1967 wet season.

Treatment no.	Nitrogen applied (kg/ha) at					Grain yield (kg/ha) at 14% moisture			Mean (treatment)
	1*	2†	3‡	4§	5‖	IR8	Palawan	IR5	
1	0 —	0 —	0 —	0 —	0	3352	2562	3907	3274
2	60 —	0 —	0 —	0 —	0	4202	2924	5349	4158
3	0 —	30 —	30 —	0 —	0	5064	3603	5546	4738
4	0 —	0 —	30 —	30 —	0	4796	3644	6191	4877
5	0 —	0 —	0 —	30 —	30	3866	3002	4400	3756
6	0 —	20 —	20 —	20 —	0	4798	4571	5079	4816
7	0 —	0 —	20 —	20 —	20	4785	4018	5785	4863
8	0 —	20 —	20 —	0 —	20	5002	2966	5752	4573
9	0 —	15 —	15 —	15 —	15	4565	3369	5593	4509
10	12 —	12 —	12 —	12 —	12	4890	3768	5107	4588
11	120 —	0 —	0 —	0 —	0	4048	2468	4213	3576
12	0 —	60 —	60 —	0 —	0	5174	2077	3794	3682
13	0 —	0 —	60 —	60 —	0	4514	4520	5903	4979
14	0 —	0 —	0 —	60 —	60	3426	2889	4669	3661
15	0 —	40 —	40 —	40 —	0	4580	2973	5059	4204
16	0 —	0 —	40 —	40 —	40	4733	3873	5749	4785
17	0 —	40 —	40 —	0 —	40	4733	3091	5270	4365
18	0 —	30 —	30 —	30 —	30	5678	3233	6050	4987
19	24 —	24 —	24 —	24 —	24	4870	3229	5254	4451
							Mean (variety)		
						4583	3305	5193	—

	IR8	Palawan	IR5
Seeded:	May 23	May 23	May 23
	(100 kg/ha seeding rate, 15-cm row spacing)		
Harvested:	Oct. 9	Oct. 4	Oct. 21
Duration (days):	139	134	151

Analysis of variance:

	s.e.	LSD (5%)	CV (X) %
Time of N application (T)**	290	833	
Variety (V)**	117	459	12
V X T**	298	843	

* Planting.
†Maximum tillering.
‡Panicle initiation.
§Booting.
‖Heading.

Fig. 12. A tall and weak-strawed Ceylonese variety, H-4, lodged heavily prior to maturity on fertile Maahas clay. Lodging occurred with 60 kg/ha N, applied either alone or in split doses, and without fertilizer nitrogen. IRRI, 1967 dry season.

in which the same amount of nitrogen was applied all at planting, and, over 2,000 kg/ha more yield than the 0 N control. Even when properly timed, nitrogen rates higher than 60 kg/ha did not increase the grain yield of IR5. IR5 lodged seriously at the 120 kg/ha N level, particularly when the nitrogen was applied earlier. IR8 did not lodge even with 120 kg/ha N applied at any growth stage. The difference between IR8 yields at 60 kg/ha N applied in two splits (treatment 3), and at 120 kg/ha N applied in four splits (treatment 18) was not significant although higher yield was obtained in the latter treatment.

For Palawan, the highest yield was obtained at 60 kg/ha N, applied in three splits. Its lodging was relatively low at 60 kg/ha N but at 120 kg/ha N applied at the early growth stages 50 percent of the crop lodged.

These results indicate that the higher yields of IR5 cannot be explained by the differences in lodging resistance, particularly at the 60 kg/ha N level. Analysis of weather data during the reproductive stages of the three varieties showed that compared with IR8 or Palawan, IR5 received higher solar energy and rainfall during the period between panicle initiation and heading but lower solar energy and rainfall after heading (Table 15). The total amounts received by the three varieties from panicle initiation to maturity (42 days) were similar although that received by IR5 (559 to 653 g-cal-cm^{-2}) was slightly higher. This probably explains the relatively higher yields of IR5.

IR5 and IR8 received similar amounts of total rainfall during the reproductive stage but Palawan received about 100 mm more rain than the other two.

These varieties matured in 19 to 21 days following heading (Table 15), compared to about 30 days required under flooded conditions. Lower moisture content probably accounted for the more rapid maturity of the upland varieties. These results suggest that the period from panicle initiation to harvest may be particularly important in determining the yield potential of upland rice.

These findings indicate further that under favorable environmental conditions, good levels of nutrition, and adequate weed and insect control, the inherent yield potential of a variety can be realized under upland conditions.

Long-term fertility experiment

The results reported here are those for the sixth and seventh crops of an experiment started during the 1964 wet season. The treatments used were the same as in previous years but two of the varieties were changed. Those used in 1967 were IR8, IR262-43-8-11 (early-short Peta) and IR262-43-8-1 (early-tall Peta). The latter two selections were from a cross between Peta/3 and Taichung (Native) 1.

Dry season. Early-short Peta and early-tall Peta matured in 109 to 111 days while IR8 matured in 124 days. The yield differences between IR8 and early-short Peta were not significant, but

Table 15. The amount of rainfall and solar energy received during the reproductive stage of upland rice, IRRI, 1967 wet season.

Variety	Panicle initiation to heading (22-23 days)		Heading to harvest (19-21 days)		Total (42-43 days)	
	Rainfall (mm)	Solar radiation (g-cal-cm^{-2})	Rainfall (mm)	Solar radiation (g-cal-cm^{-2})	Rainfall (mm)	Solar radiation (g-cal-cm^{-2})
Palawan	238	7,802	242	10,398	480	18,200
IR8	190	7,710	198	10,584	388	18,294
IR5	249	10,591	117	8,262	366	18,853

Table 16. Effect of NPK fertilization on the grain yield of IR8, IR262-43-8-11 (early short Peta), and IR262-43-8-1 (early tall Peta). Long-term fertility experiment, sixth crop, IRRI, 1967 dry season.

Treatment no.	Fertilizer treatment (kg/ha)			Grain yield (kg/ha) at 14% moisture*			Mean (treatment)
	N	P_2O_5	K_2O	IR8	IR262-43-8-11 (Early short Peta)	IR262-43-8-1 (Early tall Peta)	
1	0	0	0	4390	4383	4880	4551
2	100 +40	0	0	7249	7211	6312	6924
3	0	30	0	4430	4712	4790	4644
4	0	0	30	4442	4115	5043	4533
5	100 +40	30	0	7860	7192	6215	7089
6	100 +40	0	30	8402	7687	6587	7559
7	100 +40	30	30	7356	7476	5273	6702
8	100 +40	30	30	7674	7872	6560	7369
					Mean (variety)		
				6475	6331	5707	
					Duration (days)		
				124	112	109	

Analysis of variance:

	s.e.	LSD (5%)	CV (X) %
Treatment combinations**	330	933	10.7
Variety (V)**	116	329	
Treatment (T)**	190	538	

*Average, four replications.
†Compost +inorganic.

Table 17. Effect of NPK fertilization on the grain yield of IR262-43-8-11 (early short Peta), IR262-43-8-1 (early tall Peta) and IR8. Long-term fertility experiment, seventh crop, IRRI, 1967 wet season.

Treatment no.	Fertilizer treatment			Grain yield (kg/ha) at 14% moisture*			Mean (treatment)
	N	P_2O_5	K_2O	Early short Peta	Early tall Peta	IR8	
1	0 —	0 —	0	3208	3428	3427	3354
2	60 —	0 —	0	5087	4427	4214	4576
3	0 —	30 —	0	3462	3532	3742	3578
4	0 —	0 —	30	2964	3606	3686	3418
5	60 —	0 —	30	4942	3897	4614	4484
6	60 —	30 —	0	5101	4308	4754	4721
7	60 —	30 —	30	5172	3791	4512	4491
8	60 —	30 —	30†	4473	4389	4210	4374
					Mean (variety)		
				4301	3922	4145	
					Duration (days)		
				109	112	120	

Analysis of variance:

	s.e.	LSD (5%)	CV (X) %
Treatment combinations**	165	467	8
Variety**	58	164	
Treatment**	95	209	

*Average, four replications.
†Compost +inorganic (24.6 kg N + 35.4 kg N).

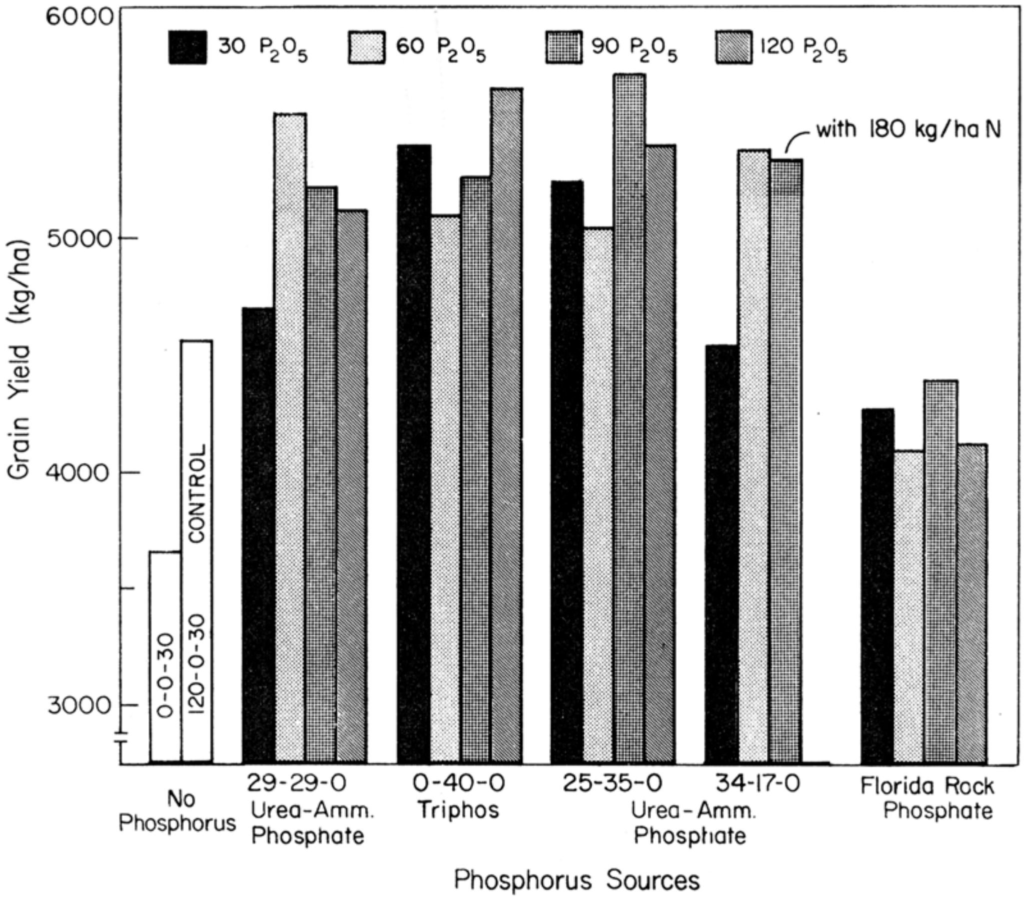

Fig. 13. Effect of sources and rates of fertilizer phosphorus on the grain yield of flooded IR8. Soil, Buenavista clay, Bulacan, Philippines, 1967, wet season.

both yielded significantly more than early-tall Peta (Table 16). Early-tall Peta lodged severely, particularly where nitrogen was applied.

Wet season. All three varieties or selections yielded significantly better with 60 kg/ha N than without N (Table 17). None of the treatments receiving phosphorus and/or potassium showed any significant increase in grain yield over the treatment receiving only nitrogen.

Sources and rates of fertilizer phosphorus for flooded rice

Studies on sources of fertilizer phosphorus for flooded rice were continued during 1967. During the wet season, three combinations of urea-ammonium phosphate fertilizers were compared with super-phosphate and Florida ground rock phosphate (33.6% P_2O_5, particle size 10 mesh). The experiment was conducted on Buenavista clay which is known to be low in phosphorus (Annual Report, 1966).

Rock phosphate gave significantly lower grain yield but there were no significant yield differences among the other sources. Most of the phosphorus-treated plots yielded significantly more than the no-phosphorus control (Fig. 13). This tends to confirm the results obtained in 1966. Higher tillering and darker green color were observed in plots receiving nitrogen and phosphorus (Fig. 14).

These results indicate that the urea-ammonium phosphate was just as effective a phosphorus source as superphosphate. In this experiment, Florida rock phosphate did not show promise as a fertilizer source.

IRRI-BPI cooperative fertility experiments

During 1967, experiments on nitrogen fertilization were continued in collaboration with the Maligaya Rice Research and Training Center

Table 18. Effect of nitrogen levels on the grain yield of different rice varieties. IRRI-BPI cooperative fertility experiment, Maligaya Rice Research and Training Center, Philippines, 1967 dry season.

Nitrogen applied (kg/ha)	Grain yield (kg/ha) at 14% moisture*									Mean (N level)
	IR8	MIFB-322-1	IR11-452-1-1	C-18	BPI-76-1	C_4-63	IR4-93-2	IR5	Peta	
0	3925	2588	3220	3047	2951	3851	3686	3997	4263	3503
30 +30	5338	4289	6249	4417	3706	3641	4721	5159	4671	4688
60 +30	7635	5109	6058	4141	4169	4773	6189	6866	5273	5579
90 +30	7261	5674	6864	4054	4830	5379	6649	6478	4284	5719
120 +30	7499	5722	7055	4810	5852	5438	6549	7263	3430	5958
150 +30	7961	5817	7316	4534	5570	5051	6366	7265	3007	5876
	Mean (variety)									
	6603	4866	6127	4167	4513	4689	5693	6171	4154	
	Duration (days)									
	138	138	138	125	125	125	144	144	155	

Analysis of variance:

	s.e.	LSD (5%)	CV (X) %
N-levels (N)**	171	539	
Variety (V)**	128	355	
Variety mean at same N level	313	867	10
N-mean at the same or at different V	343	983	

*Average, three replications.

of the Philippine Bureau of Plant Industry.

Dry season. The nitrogen rates ranged from 0 to 180 kg/ha. Except for 30 kg/ha applied as topdressing during panicle initiation, all nitrogen was harrowed-in just before transplanting. Without added nitrogen, the mean grain yield for 10 varieties or selections was 3,503 kg/ha compared to 5,958 kg/ha with 150 kg/ha of added nitrogen (Table 18). The responses varied widely among varieties but all gave the same yield response to applied nitrogen. The strongest response and highest yields were obtained with IR8, although the yield difference between this variety and IR5 was not significant. Yield responses were significant only up to 90 kg/ha N. Typical results are shown in Fig. 15.

BPI-76-1, MIFB322-1, C-18 and C_4-63 yielded significantly less than IR8, IR5 and IR11-452-1-1, but higher than Peta. Most varieties and selections took more time to mature than when grown at the Institute farm.

Wet season. During the wet season, IR39-14 was dropped and IR11-288-3-1-2 and IR95-42-11-2-2 were included in the experiment. Several varieties and selections were severely attacked by bacterial leaf blight (*Xanthomonas oryzae*), particularly at higher levels of added nitrogen.

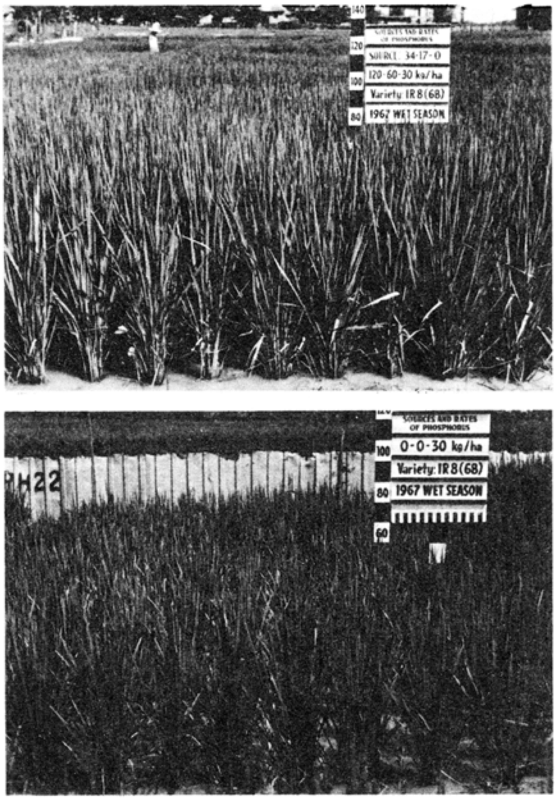

Fig. 14. IR8 plants (grown on Buenavista clay in Bulacan) treated with phosphorus and nitrogen were higher tillering and darker-green in color than the untreated ones. 1967 wet season.

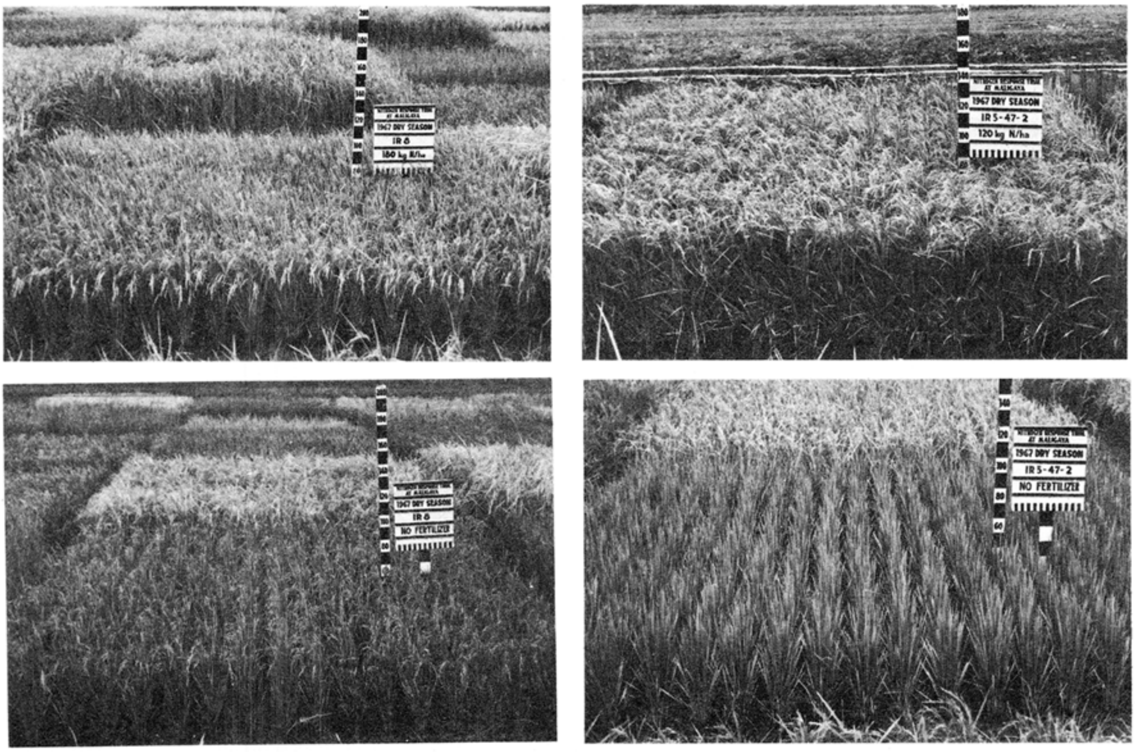

Fig. 15. IR8 and IR5 responded remarkably well to high levels of applied nitrogen (top). Without added nitrogen, yields were lower even with adequate crop protection (bottom). IRRI-BPI cooperative fertility experiment, 1967 dry season.

Table 19. Effect of levels of nitrogen on the grain yield of different rice varieties, IRRI-BPI cooperative fertility experiment. Maligaya Rice Research and Training Center, Philippines, 1967 wet season.

Nitrogen applied (kg/ha)	Grain yield (kg/ha) at 14% moisture												Mean (N level)
	IR95-42-11-2-2	Peta	IR5	IR4-93-2	IR11-288-3-1-2	MIFB-322-1	IR11-452	C-18	BPI-76-1	IR8	C_4-63	IR39-14	
0	4067	2797	4293	4021	2249	4380	2981	2129	3077	3258	3273	3195	3310
10 +20	4198	2651	4057	4111	2379	4289	3175	2179	3233	2902	3609	3487	3356
40 +20	4595	2373	4070	4241	2403	4681	2928	2201	3358	3399	3402	3703	3446
70 +20	4502	2399	4105	3968	2535	4828	3075	2118	3408	3180	3434	3591	3428
100 +20	4327	1934	4010	3839	2649	4757	2391	1882	3210	3062	3688	3607	3279
130 +20	3211	2178	3727	3411	2458	3640	2953	2281	2601	2545	3219	3157	2948
	Mean (variety)												
	4150	2389	4044	3930	2445	4429	2917	2132	3149	3058	3437	3457	
	Duration (days)												
	141	141	141	141	127	127	127	127	124	124	124	113	
	Bacterial leaf blight index*												
	1.2	1.1	1.2	2.2	3.1	1.2	3.3	2.5	2.9	2.8	2.6	3.1	

*1 — resistant; 5 — very susceptible.

Table 20. Effect of varietal type on the grain yield of upland rice, IRRI, 1967 wet season.

Grain yield (kg/ha) at 14% moisture*					
Palawan	Milfor-6(2)	IR400-28-4-5	IR8	IR5	C_4-63
2330	2765	4129	3770	4102	3324

Seeded: May 23, 1967.
Seeding rate: 100 kg/ha.
Harvested:

Palawan	Milfor-6(2)	IR400-28-4-5	IR8	IR5	C_4-63
Oct. 13	Oct. 14	Oct. 20	Oct. 20	Nov. 6	Oct. 23

Duncan's multiple range test:

Variety or selection	Palawan	Milfor-6(2)	C_4-63	IR8	IR5	IR400-28-4-5
Mean†	2330	2765	3324	3770	4120	4129

*Average, five replications.
†Any two means underscored by the same line are not significantly different at the 5% level.

Observations on bacterial leaf blight taken 94 days after seeding and based on a visual score showed that the most resistant varieties or selections were IR5, IR95-42-11-2-2, Peta, IR4-93-2, and MIFB322-1 (Table 19). Except for Peta, these varieties also yielded more than the less resistant ones, suggesting that high yield cannot be obtained if a variety is severely affected by bacterial leaf blight. Even a highly responsive variety such as IR8 may fail to perform well. Under such a situation a more resistant variety such as IR5 may have an advantage over IR8.

Upland Rice Experiments

Upland rice (nonflooded, rain-fed) yields in tropical Asia are generally very low. These low yields are a result primarily of lack of suitable varieties, uneven rainfall distribution, poor weed control, insufficient application of fertilizer, and inadequate control of pests and diseases. During the 1967 wet season, several experiments were initiated and a few were continued based on previous years' findings. An experiment on the time of nitrogen application on upland rice is discussed in the soil fertility section of this report while the other experiments are discussed below.

Varietal trial in upland rice

Most upland rice varieties are tall, leafy, lodging susceptible, and have a poor plant type. To evaluate potential upland varieties, an experiment was conducted using the "standard" upland variety, Palawan, and Milfor-6(2) which is used under both upland and lowland conditions in the Philippines. Also included were C_4-63, an improved selection from the University of the Philippines College of Agriculture, IR8, IR5, and IR400-28-4-5 (Peta/4 x T(N)1). Seeds were drilled at 100 kg/ha at 25 cm row spacing on May 22, 1967.

The results showed that the varieties or selections developed for planting under flooded conditions (IR8, IR5, and IR400-28-4-5) outyielded the upland varieties, Palawan and Milfor-6(2), which had the highest upland yield record at the Institute until this year (Table 20). IR400-28-4-5 and IR8 had total tillers of 515 and 454/sq m, respectively, which were very high compared to 190 and 252/sq m for Palawan and Milfor-6(2), respectively. IR400-28-4-5 also had the highest number of panicles (473/sq m) followed by IR8 (397/sq m) and IR5 (351/sq m). Palawan and Milfor-6(2) produced 174 and 227 panicles/sq m, respectively. High tillering capacity may partly explain the differences in yield between the varieties.

Rainfall distribution and solar energy during the reproductive stage (from panicle initiation to maturity) were equally favorable for all varieties (Fig. 16). Most of the varieties matured during the period of high solar energy (Fig. 16), and differences in grain yield were primarily due to the inherent productivity of each variety. These results indicate that high tillering indicas

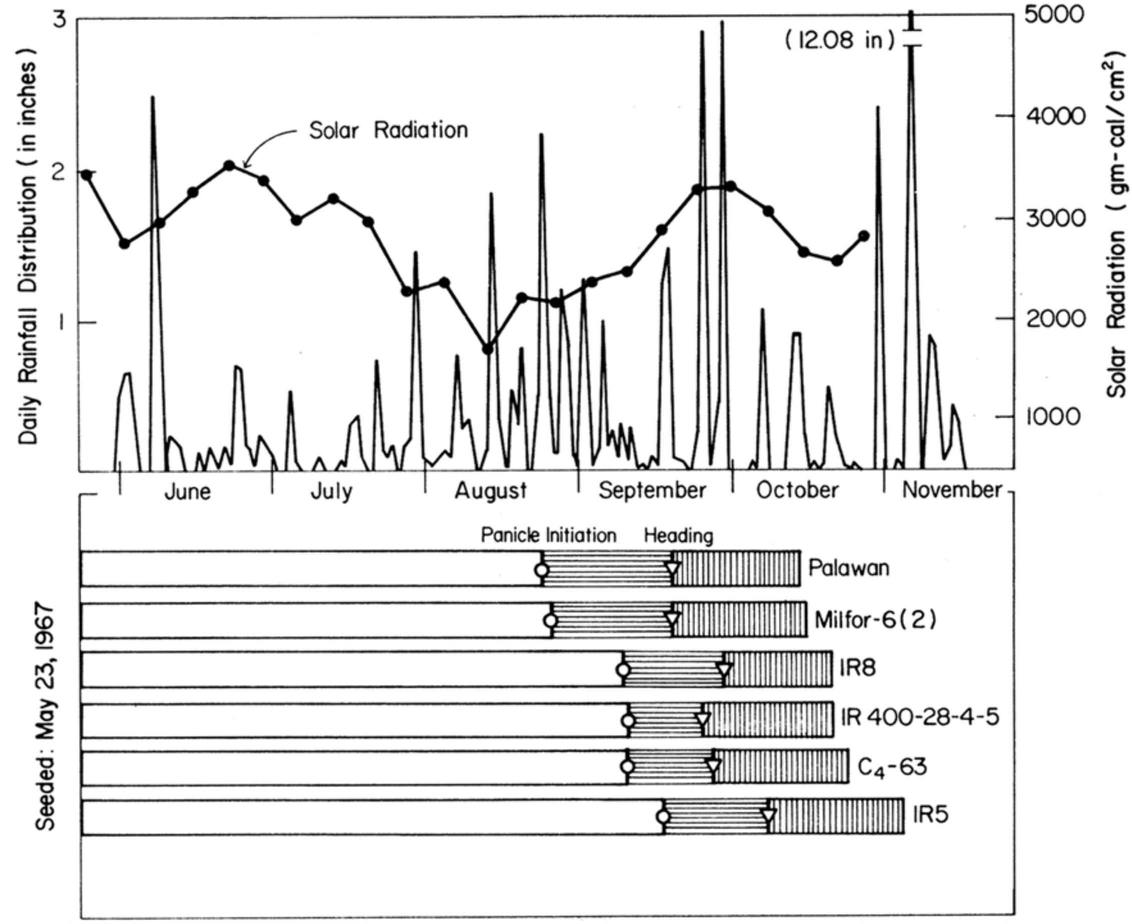

Fig. 16. Solar radiation and rainfall elements during the growth stages of upland rice. IRRI, 1967 wet season.

with high yield potential and good plant type normally grown under flooded conditions may outyield the so-called upland varieties. However, in order to obtain high yields, the varieties must be lodging resistant, must receive adequate rainfall and high solar energy during the ripening period, and in addition, must have adequate fertilization and weed, insect, and disease control.

Rate of seeding in upland rice

The seeding rates of upland rice may be expected to vary depending upon the capacity of a variety to produce tillers. For a high-tillering variety such as IR8, the normal seeding rate of about 100 kg/ha, usually used for planting low to medium tillering upland varieties (such as Palawan) in the Philippines, may not be necessary. An experiment was conducted at the Institute to determine the effect of seeding rate on the yield of IR8.

IR8 seeds were drilled with a tractor-mounted linkage seeder at 15-cm row spacing at seeding rates that varied from 25 to 150 kg/ha at 25-kg increments. A total of 90 kg/ha N was applied in equal doses during planting, maximum tillering and panicle initiation. The plants were protected from insect pests, and weeds were controlled by a combination of chemical treatments and handweeding. The highest grain yield, 5,304 kg/ha, was obtained with a 75 kg/ha seeding rate (Table 21). Duncan's multiple range test showed that seeding rates of 125 and 150 kg/ha gave significantly lower grain yields than seeding rates of 25 and 75 kg/ha. These results clearly indicate that for a high-tillering variety such as IR8, the seeding rate can vary from 25 to 75 kg/ha

Table 21. Effect of seeding rate on the grain yield of IR8 rice, IRRI, 1967 wet season.

Treatment number	Seeding rate (kg/ha)	Grain yield (kg/ha) at 14% moisture*
1	25	5124
2	50	5070
3	75	5304
4	100	4848
5	125	4708
6	150	4703

Duration (days): 141-144
Duncan's multiple range test.

Treatment	6	5	4	2	1	3
Mean†	4703	4708	4848	5070	5124	5304

*Average, four replications of two cuts per replication.
†Any two means underscored by the same line are not significantly different at the 5% level.

and still give yields of over 5,000 kg/ha under upland conditions, provided the plants are adequately fertilized and the seeds have a high germination percentage (80-85%).

Row spacing, seeding rate and methods of planting upland rice

Under a specific environmental condition, the grain yield of upland rice may vary with seeding rate, method of planting and row spacing. All of these agronomic factors affect the competition among plants for light, water, nutrients and space and ultimately influence the yields. Using a high-yielding variety (IR8), a factorial experiment was conducted during the 1967 (June 8 to October 26) wet season using two seeding rates, three methods of seeding, and three row spacings. The broadcast method of planting gave signifi-

Table 22. Effect of seeding rate. row spacing, and planting method on the grain yield of IR8 rice, IRRI, 1967 wet season.

Spacing (cm)	Grain yield (kg/ha) at 14% moisture*				
	Seeding rate (kg/ha)		Mean		
	80	160	Row spacing	Seeding method	Treatment
15 single row	5817	5376	5596		
30 single row	5644	5226	5435		
45 single row	4152	4456	4304	5112	
30-15 double row†	4991	5072	5032		
45-15 double row	4428	4423	4426		
60-15 double row	3952	4112	4032	4497	4693
20-10 band‡	5684	4909	5296		
35-10 band	4874	4014	4444		
50-10 band	3378	3964	3671	4470	
Broadcast (control)					
	5539	5508	5524	5524	
Mean (seeding rate)					
	4846	4706	4776		

Duration (days): 124-130.

Analysis of variance:

	s.e.	LSD (5%)	CV (X) %
Treatment combinations**	234	662	
Treated vs. control**	74	209	
Seeding rate (R)$^{n.s.}$	78	—	10
Methods of planting (M)**	95	269	
Spacing w/in (R and M)**	234	662	

*Average, four replications.
†Also called paired row, with fixed 15-cm distance between pairs of rows.
‡Width of band was maintained at 10 cm.

Fig. 17. A tall, weak-strawed upland variety, Palawan, lodged and yielded 3,380 kg/ha while a stiff-strawed variety, IR8, grown as upland rice, was erect and standing, and yielded 6,433 kg/ha. IRRI, 1967 wet season.

cantly higher grain yield than the treatment mean of all other methods of planting (average of three methods of seeding and three-row spacings in each method) (Table 22). The highest grain yield, 5,817 kg/ha, was obtained at the 80 kg/ha seeding rate in single rows at 15-cm row spacing, although this did not differ significantly from the 30-cm row spacing. At 45-cm row spacing, single-row seeding yielded significantly less than either the 15- or 30-cm row spacing. In the double-row and band-sown treatments, widest spacing produced significantly lower grain yield than did two narrower spacings. Double-row planting had no particular advantage over either single-row or bandsown planting. The 10-cm band-sown method compared favorably with the single-row and broadcast methods when seeded at close spacing (20 cm). These results clearly demonstrate that if weeds and insects are adequately controlled, the differences among broadcast, single-row, and band-sown methods are not significant provided row

Table 23. Mechanized upland variety trial. Production plot of one-fourth hectare per variety, IRRI, 1967 wet season.

Variety	Grain yield (kg/ha) at 14% moisture†	Duration (days)
Palawan	3380	123
IR8	6433	129
IR5	4221	143

Statistical analysis:
IR8 vs. (Palawan, IR5)**
Palawan vs. IR5*

†Average, six samples.

seeding is done at close spacing. If a low-cost weed control technique is developed for upland rice, the broadcast method of planting upland rice may be just as good as the row- or band-sown procedure.

Mechanized upland rice production

Two Institute varieties, IR8 and IR5, and a standard upland variety, Palawan, were planted in non-replicated quarter-hectare plots with a tractor-mounted Australian linkage seeder at an 80 kg/ha seeding rate and 30-cm row spacing. Weeds were controlled with herbicides and by hand. The plots were protected against insect pests mostly with broadcast diazinon granules. Six 5-sq m samples were harvested per plot. Each sample was considered as one replicate for statistical analysis. A high grain yield of 6,433 kg/ha was obtained with IR8; this was significantly higher than the yields of IR5 and Palawan (Table 23). Palawan lodged severely before harvest and yielded about half as much as IR8 (Fig. 17). IR5 was harvested following a typhoon which caused severe grain shattering but it nevertheless yielded significantly higher than the recommended upland variety, Palawan.

Effect of rice plant type and time of weed emergence on the competition between rice and weeds

Echinochloa crusgalli is the most troublesome grassy weed in flooded rice in many rice-growing areas of the world. A greenhouse experiment was conducted during 1967 (January thru May) to determine the effect of time of emergence and density of *E. crusgalli* on the competitive ability of two varieties, H-4, a tall leafy tropical variety,

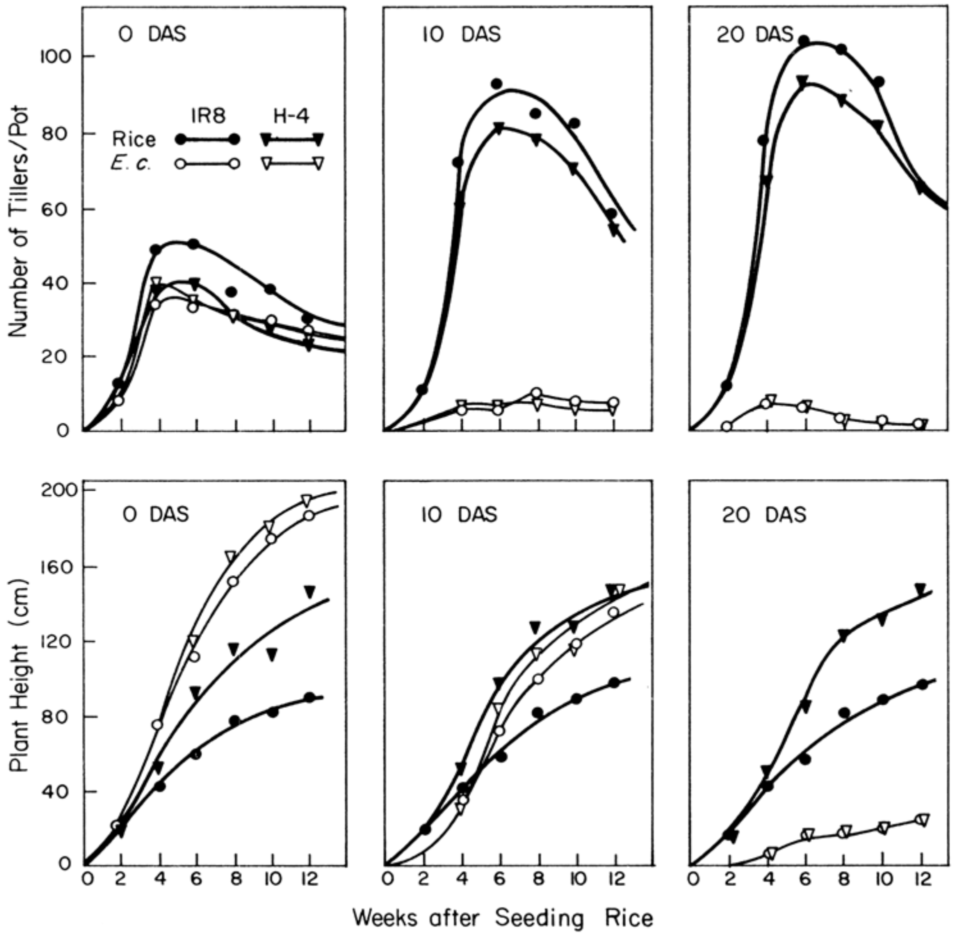

Fig. 18. Relative height and tiller production of *E. crusgalli* when seeded at different times in relation to two different rice variety types.

and IR8. Seeds of these varieties were planted in four replications with *E. crusgalli* seeds planted at 0, 10, and 20 days after seeding (DAS) the rice. Both rice and weed seeds were pre-germinated before planting. The density of rice was kept constant at 9 plant/pot, while the weed density was varied at 2, 4, 8 and 12 plant/pot. Volunteer weeds were removed as they appeared. At the maximum tillering stage, IR8 produced 50 tiller/pot while H-4 produced 39 tillers when *E. crusgalli* seeds were planted at seeding of rice. A total of 34 and 39 *E. crusgalli* tillers were produced in the IR8 and H-4 pots, respectively (Fig. 18). The numbers of rice and *E. crusgalli* tillers produced were about equal when both weed and rice emerged at the same time, particularly with the variety H-4.

When the emergence of *E. crusgalli* was delayed by 10 days, the number of *E. crusgalli* tillers was considerably reduced while that of rice was increased. When delayed by 20 days, the emergence of *E. crusgalli* did not affect the tillering of rice plants which had outgrown those of *E. crusgalli*. These results indicate that early grassy weed competition with rice greatly affects the tiller number of rice.

IR8 produced tillers more rapidly than H-4, particularly at the early growth stages (4 weeks after planting). However, at 12 weeks after planting the tiller number of IR8 and H-4 did not differ since the density of the rice plants per pot was extremely high. Generally, the time of weed emergence did not affect the height of the rice plant (Fig. 18).

The dry matter produced by rice with *E. crusgalli* seeded at planting even at low weed density was significantly reduced, but no reduction was observed with competition starting at 10 and 20

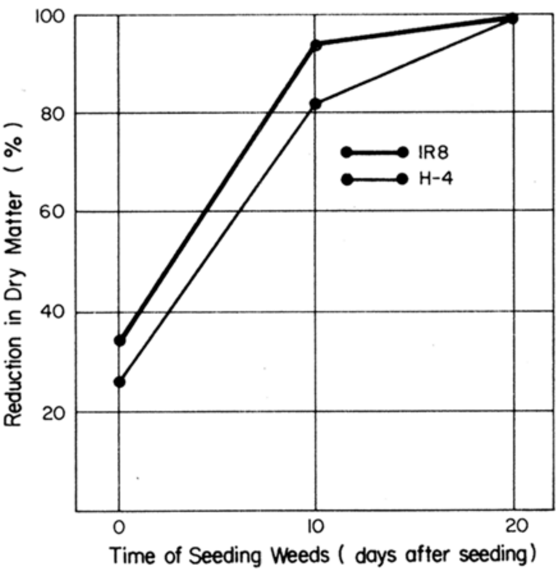

Fig. 19. Effect of time of seeding weeds on the reduction of dry matter production by IR8 and H-4. IRRI, 1967 dry season.

days after planting. There was an inverse relationship between weed and dry matter production. The reduction in dry matter at the heading stage was more severe for H-4 than for IR8, particularly with early weed emergence, indicating that as far as weed competition is concerned, tiller number is more important than plant height (Fig. 19).

Competition between rice plants and weeds

The weed species predominantly present at the Institute farm can be grouped in two broad categories: (1) those more or less similar to or shorter than the rice plant such as the broadleaves and sedges, and (2) those taller than the rice plant such as the grassy weeds, particularly *E. crusgalli*. The degree of competition between rice plants and weeds depends on the growth characteristics, time of emergence, and density of the weeds.

The ability of each group of weeds to compete with the rice plant was studied during the 1967 wet season. The treatments were: (1) rice + *M. vaginalis* (representing category 1 above) (200 plant/sq m), (2) rice + *E. crusgalli* (representing category 2) (128 tiller/sq m), and (3) rice alone. Three-week-old seedlings were transplanted at 25 x 25 cm spacing. At the booting stage of the crop, the light transmission ratios (LTR) were taken 10 cm above the rice or weed plants, whichever was taller, and 10 cm above the water surface and upwards at 10-cm intervals.

Compared with the pure stand of rice, the plots with rice + *E. crusgalli* had 40 percent lower LTR, while there was no difference in LTR in plots with rice + *M. vaginalis*. On the other hand, the nitrogen content of *M. vaginalis* was higher than that of *E. crusgalli* (Table 24). These results suggest that *E. crusgalli* competes highly with rice for solar energy and *M. vaginalis* competes more for nitrogen from the soil and from fertilizer.

The reduction in grain yields by different weed species was studied during the 1967 dry season. Compared with a weed-free crop, *M. vaginalis* did not reduce the grain yield of rice while *E. crusgalli* reduced it by 90 percent (Table 25). These experiments emphasize the well-known fact that grassy weed control is of major importance for flooded rice.

Screening of herbicides

The screening of herbicides for flooded, transplanted rice was continued under four test conditions. These included two times of application (4 days after transplanting and 16 days after transplanting), and two water management systems (temporary drainage for 48 hours to permit chemical application and continuous flooding). The water depth was 3 to 5 cm in all cases. Early application of herbicides corresponds to pre-emergence and late application to post-emergence (2- to 3-leaf stage) of grassy weeds. Seventy-two chemicals and chemical combinations were tested, and the 20 best treatments are listed in this report (Table 26). Chemical entries whose control rating was

Table 24. Percentage of total nitrogen in different plants, 1967 wet season.

Plant	Growth stage	Position	Total N* (%)
Rice	Booting	Leaf	2.74
		Stem	0.92
M. vaginalis	Flowering	Leaf	3.93
		Stem	1.47
E. crusgalli	Heading	Leaf	1.96
		Stem	0.72

*Rice sample was taken from pure stand and weed samples from plots mixed with rice plants.

Table 25. Effect of different weed species on rice grain yield, IRRI, 1967 dry season.

Treatment	Rate (kg/ha)	Weed count 3 weeks after spray (no./sq m)		Weed weight at heading (g/sq m)		Grain yield (kg/ha)
		M. vaginalis	*E. crusgalli*	*M. vaginalis*	*E. crusgalli*	
Molinate 4 DAT	3.0	302	0	129	0	7578
Molinate ff 2, 4-D 4 +25 DAT	3.0	312	7	0	13	8535
No weeding	—	380	124	37	1206	1094
Handweeding 25 +40 DAT	—	—	—	7	15	7745

LSD (5%): 1,502 kg/ha.

Table 26. Twenty best herbicides in a screening test evaluating weed control under four conditions of testing, IRRI, 1967 wet season.

Herbicide treatment (Common chemical or trade name)	Herbicide applied (kg/ha a.i.)	Weed weight*(g/sq m)					
		Early application (4 DAT)			Late application (16 DAT)		
		Drained temporarily for herbicide application	Flooded (3-5 cm)	Mean (water manage-ment)	Drained temporarily for herbicide application	Flooded (3-5 cm)	Mean (water manage-ment)
CP 29037	4.0	2	0	1	35	15	25
CP 50144	3.0	0	20	10	175	—	—
CP 29037	2.0	17	5	11	175	60	118
2, 4-D oil soluble amine salt	0.8	7	15	11	—	—	—
CP 54040	1.5	20	2	11	—	—	—
CP 54040	3.0	3	25	14	—	—	—
Amiben	5.0	13	15	14	—	—	—
EPTC/MCPA	1.5 +0.3	28	8	18	—	—	—
EPTC/MCPA	3.0 +0.6	8	28	18	45	40	43
2, 4-D Isooctyl ester	0.8	33	5	19	—	—	—
Planavin	1.5	35	3	19	—	—	—
Sindone/MCPA	2.5 +0.2	25	15	20	—	—	—
Pyriclor/2, 4-D (M3234)	0.2 +0.5	35	7	21	160	52	106
2, 4-D Isobutyl ester	0.8	40	5	23	290	27	158
EPTC/MCPA	2.0 +0.6	43	5	24	47	52	50
EPTC/MCPA	1.0 +0.3	20	30	25	40	50	45
ICAA (ramrod 65)	3.0	50	2	26	—	—	—
Pyriclor/2, 4-D (M3236)	0.4 +0.5	28	28	28	25	87	56
Pyriclor/2, 4-D (M3233)	0.2 +0.1	38	18	28	—	—	—
ICAA (CP 31393) G	3.0	0	60	30	—	—	—
Control:							
Pyriclor ff MCPA	0.2 +0.8	2	0	1	82	100	91
Molinate ff MCPA	3.0 +0.8	15	0	8	5	0	3
MCPA ff HW	0.8	5	7	6	20	5	13
No weeding		330	152	241	195	260	259

* Evaluation is based on: Toxicity rating—below 3; control rating—below 2.5 (Rating scale: 1—best control or non-toxic; 5—no control or highly toxic) *Paspalum* sp. weed weight not included.

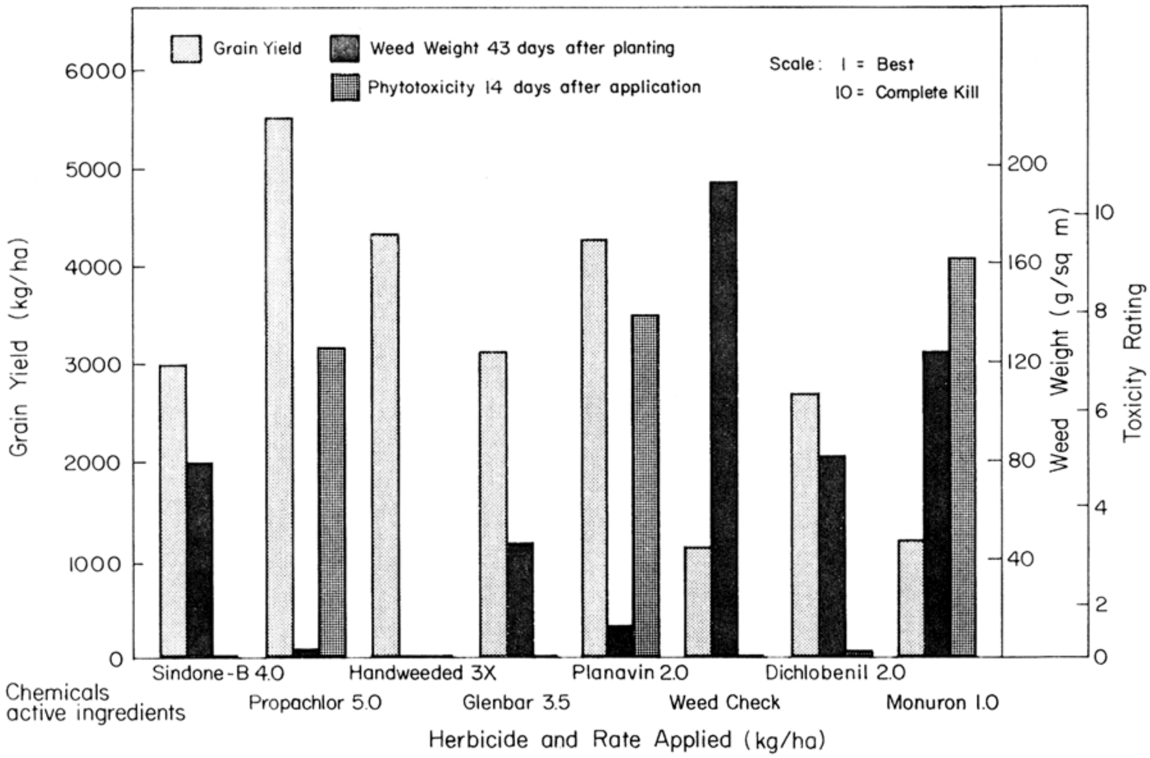

Fig. 20. Effect of different herbicides on the grain yield, weed weight and phytotoxicity of direct-seeded IR8. IRRI. 1967 wet season.

satisfactory with respect to both water management systems and which were of low or no toxicity to the rice crop are also shown in the list. The data on grain yield are not reported since the crop was badly damaged by a severe typhoon (maximum wind velocity = 125 km/hr) when the crop was nearing maturity. Noteworthy among the herbicides tested was CP 29037 (by Monsanto Company), a new chemical which, when applied at either 2 or 4 kg/ha, has given outstanding results in weed control. In a single application without a follow-up of MCPA spray, CP 29037 gave better results than either pyriclor or molinate, both of which need to be followed by MCPA spray.

Weed control in direct-seeded flooded rice

Chemical weed control is more difficult in direct-seeded rice than in transplanted rice because the similarities in the age and morphological characteristics of grassy weeds and rice often affect the selectivity of the chemicals. Weed competition is also higher for direct-seeded rice since rice and weed seeds germinate at the same time. During the 1967 wet season, two field experiments were initiated to test some of the promising chemicals for direct-seeded rice. IR8 was seeded with the Connor-Shea linkage seeder at 100 kg/ha at 15-cm row spacing. The field was flushed with water a day after seeding to initiate the germination of the seeds. A randomized complete block design was used and various chemicals were applied, as indicated in Fig. 20 and Table 27. The treatments in Experiment 1 were sprayed 1 day after seed emergence. Three weeks later, water was introduced and the field was kept flooded until maturity. Several chemicals gave significantly increased grain yields compared to the weed check. Propachlor (2-chloro-N-isopropyl acetanilide) and nitralin (planavin) gave high yields (Fig. 20). Propachlor (ramrod) gave weed control similar to that of the thrice-handweeded control (Fig. 21), but significantly higher grain yield (Fig. 20) probably because of the injury to rice during handweeding. Both of these chemicals showed some phytotoxicity to rice, but this was greatly reduced by the introduction of water. The high-tillering capacity of IR8 also helped make up for the loss of tillers due to chemical injury.

The herbicides included in Experiment 2 were applied either alone, split, or in combination with other chemicals (Table 27). The treatments were sprayed at three different dates to evaluate the effect of time of application on the effectiveness of the herbicides. Slight or no phytotoxicity was observed with the pre-emergence application of herbicide while moderate to extreme toxicity was apparent in the post-emergence spray of propanil, EPTC-2, 4-D, and pyriclor. Applying propanil following pyriclor was highly toxic to the rice crop. Pyriclor at 200 g/ha active ingredient, applied in two split doses 4 and 11 days after flushing with water, provided excellent weed control (Fig. 22) and gave the highest grain yield (Table 27). Pyriclor at 100 to 200 g/ha and molinate made a compatible combination, and there was no additional injury from molinate. Chemicals such as pyriclor applied alone or at two splits, pyriclor plus EPTC-2, 4-D, and pyriclor plus molinate gave grain yields similar to those obtained with thrice-handweeded treatments and 3 to 4 times higher than the non-weeded control (Table 27).

Chemical weed control in transplanted rice

Some of the herbicides that showed promise in screening tests were carefully evaluated to determine their suitability for transplanted rice. The ideal chemical for transplanted rice should be of at least equal cost to one MCPA spray plus one handweeding. It should be relatively easy to apply, effective under a wide range of uncontrolled variations in water management, and have a safe margin of phytotoxicity. During the 1967 dry season, an experiment was conducted using several promising chemicals. Table 28 summarizes the treatments used and the yield data obtained. A randomized complete block design was used with three replications. Weed seeds, primarily *E. crusgalli,* were broadcast at 2 kg/ha 2 days before IR8 was transplanted. Several species of broadleaved weeds were naturally present. With a few exceptions, higher grain yields were obtained when the chemicals were followed by MCPA spray, indicating that

Table 27. Effect of herbicides on the weed control, weed weight and grain yield of direct-seeded, flooded IR8 rice, IRRI, 1967 wet season.

Treatment	Rate (kg/ha a.i.)	Time of application (days after flushing)	Toxicity rating†	Weed control rating†	Weed weight (g/sq m)		Grain yield (kg/ha)
					Grasses‡	Sedges‡	
1. Pyriclor ff pyriclor	0.1 ff 0.1	4-11	3.5	2.0	74	66	4561
2. Pyriclor +molinate	0.1 +3.0	4	2.0	2.8	55	35	4244
3. Pyriclor ff knoxweed	0.1 ff 2.5	4-11	3.2	2.2	48	18	4163
4. Propanil	3.5	11	2.0	1.5	61	13	4033
5. Pyriclor	0.2	4	2.0	3.2	97	8	4032
6. Pyriclor ff propanil	0.15 ff 3.5	4-11	6.0	2.0	64	10	3847
7. Pyriclor ff propanil	0.1 ff 3.5	4-11	6.0	1.5	36	26	3527
8. Knoxweed	2.5	11	1.2	4.8	112	76	3018
9. Pyriclor +molinate	0.15 +3.0	4	2.5	2.8	94	12	2804
10. Trifluralin	1.0	4	1.0	7.2	72	78	2792
11. Trifluralin ff 2,4-D	1.0 ff 0.8	4-40	1.0	6.0	78	52	2549
12. Molinate	3.0	4	1.0	8.0	82	66	1774
13. MCPA	0.8	40	1.0	8.0	222	96	1470
14. PCP/333 1. diesel oil	4.0	4	1.0	7.8	151	95	1232
15. Handweeded 3X		27-43-64§	1.0	2.0	12	18	4344
16. Weedy check (control)			1.0	9.5	327	182	1140
LSD (5%)				1.6	140	69	1082

*Toxicity rating: 1 — best; 10 — complete kill.
†Weed control rating: 1 — best; 10 — no control.
‡70 days after flushing.
§883 man-hr/ha.

Fig. 21. Propachlor (Ramrod) (2-chloro-N-isopropylacetanilide) gave adequate weed control and higher grain yield than the control (three times handweeding) in a direct-seeded experiment with variety IR8. IRRI, 1967 wet season.

broadleaves and sedges in addition to the grassy weeds were prevalent in the experimental field (Table 28). Chemicals such as DBN, molinate, CDAA, ICAA (propachlor) pyriclor, and EPTC 2, 4-D, applied either alone or in combination with MCPA spray, gave grain yields similar to those obtained from combinations of two handweedings. The effectiveness of pyriclor applied at an extremely low rate and MCPA applied alone twice, 1 day before transplanting and 20 days after transplanting, may prove to be highly competitive with the standard recommendation of one MCPA spray and one handweeding. Partial budgeting analysis showed that several chemicals give returns similar to two handweedings (Table 28).

Weed control with 2, 4-D and other selected herbicides in transplanted rice

Phenoxy herbicides, primarily used for controlling broadleaves and sedges, are among the least expensive and most widely used herbicides in flooded rice. Early experiments at the Institute indicated that the application of phenoxy herbicides at the early stages of weed growth gives good control of both broadleaved and grassy weeds in transplanted rice.

During the 1967 dry season, an experiment was conducted to compare a split application of 2, 4-D isopropyl ester with pyriclor-2, 4-D combination and other commonly used herbicides in controlling annual grasses, sedges and broadleaves. On January 30, 1967, 21-day-old seedlings were transplanted 3 to 5 seedlings per hill at 25 x 25 cm spacing. Weed seeds, mainly *E. crusgalli,* were broadcast at the time of transplanting at the rate of 1.5 kg/ha. Thirty-nine treatments were used and except propanil, all the chemicals were applied in standing water 3 to 5 cm deep. Pyriclor was applied during the pre-emergence of grassy weeds, while 2,4-D IPE was applied during emergence. Late applications of pyriclor and 2,4-D IPE were made at the 2- to 4- and 4- to 6-leaf stages of grassy weeds, respectively. A randomized complete block design was used and treatments were replicated four times.

The results are summarized as follows:

(1) For the control of *E. crusgalli,* early (pre-

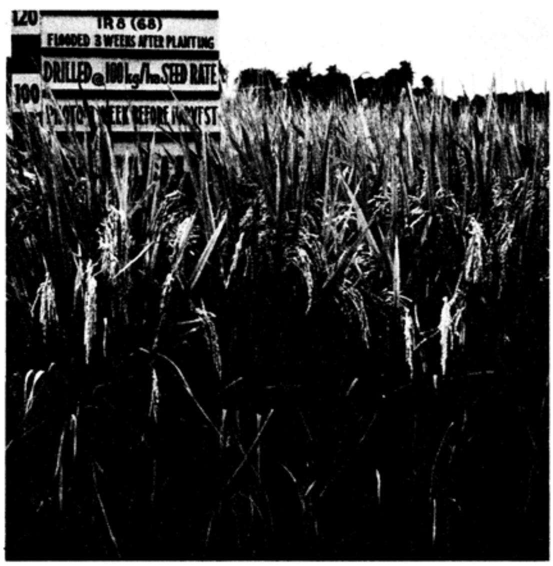

Fig. 22. Split applications of Pyriclor at 200 g/ha active ingredient at 4 and 11 days after flushing the field with irrigation water gave the highest yield in a weed control experiment on direct-seeded IR8 rice. IRRI, 1967 wet season.

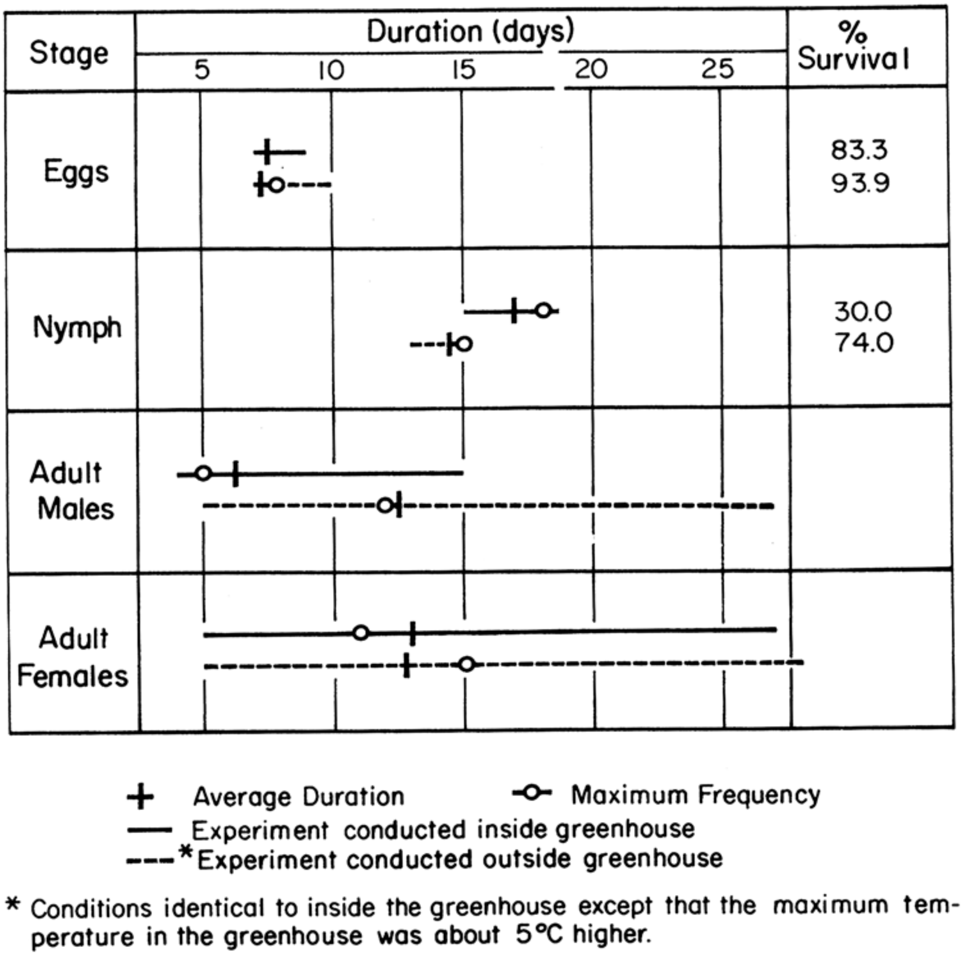

Fig. 1. Duration of the different life history stages of the brown planthoppers.

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

Table 29. Grain yield of transplanted IR8 rice treated with 2,4-D and other selected herbicides, IRRI, 1967 dry season.

Early-application treatment (4 DAT)	Rate (kg/ha)	Grain yield (kg/ha) at 14% moisture				Mean
		Late-application treatment				
		2, 4-D IPE (25 DAT)				
		0	0.2	0.4	0.8	
2, 4-D IPE	0.8	6721	—	—	—	6721
	0.2	—	5997*	6805	6126*	6309
	0.4	—	5798*	7005	7134	6646
	0.8	—	7439	7460	7196	7365
	Mean	—	6411	7090	6819	6773
Molinate (G)	3.0	7578	8212	7784	8535	8027
		Pyriclor (15 DAT)				Mean
		0	0.1	0.2	0.3	
Pyriclor	0.2	6613	—	—	—	6613
2, 4-D IPE	0.2	—	8187	6322	7402	7304
	0.4	—	6301	6961	6690	6651
	0.8	—	7979	6826	7561	7455
	Mean	—	7489	6703	7218	7137
Propanil 3.5 +MCPA	0.8	—	—	—	—	6343
2, 4-D +EPTC	3.0	—	—	—	—	7324
KN_3 (G)	4.0	—	—	—	—	5890*
MCPA +HW (1X)	0.8	—	—	—	—	7619
No weeding		—	—	—	—	1094*
Handweeding (3X)		—	—	—	—	7745

LSD (5%) =1486 kg.
*Yields were significantly lower than with standard MCPA +HW (1X).

emergence to 1-leaf stage) application of 2, 4-D IPE at 0.8 kg/ha and pyriclor at 0.2 kg/ha was effective under flooded condition when the infestation was heavy.

(2) A high rate of pyriclor (0.3 kg/ha active ingredient) was toxic to rice when applied early (2 DAT) but controlled grassy weeds effectively when applied about 15 DAT.

(3) With 21-day-old seedlings, 2, 4-D IPE was effective even at 0.8 kg/ha active ingredient, both at early (4 DAT) and late (25 DAT) growth stages.

(4) Despite high populations (0 to 250 g/sq m of dry weight) of *Paspalum scrobiculatum,* moderate rates (0.4 to 0.8 kg/ha) of 2, 4-D IPE and pyriclor (0.1 to 0.2 kg/ha) gave yields as high as those obtained with the other chemicals used in the experiment and were not significantly different from handweeding or the standard MCPA + handweeding treatment (Table 29).

(5) A single application of EPTC-2, 4-D at 3 kg/ha gave not only good weed control but also high yield. Molinate at 3 kg/ha did not control *M. vaginalis* but gave high yield (Table 29), indicating that these weeds do not compete much with rice under normal field conditions.

Time and frequency of handweeding in flooded rice

In tropical Asia, handweeding is by far the most common method of weed control in flooded rice, but the timing and frequency of handweeding to make for the most profitable returns needs careful evaluation. An experiment was conducted during the 1967 dry season with treatments receiving 1 to 3 handweedings at various times (Table 30). IR8 was used as the test variety in a randomized complete block design with four replications. Weed seeds, primarily *E. crusgalli,* were broadcast at 2 kg/ha after transplanting. When a single handweeding was done beyond 42 days after transplanting, the grain yields of IR8 decreased significantly and the man-hours needed for weeding were generally increased (Table 30). The differences in grain yields

Table 31. Effect of weed control and land preparation methods on the grain yield of IR8 rice, IRRI, 1967 dry season.

Weed control methods*	Herbicide applied (kg/ha a.i.)		Grain yield (kg/ha) Land preparation I†	II‡	III§	Mean (weed control methods)
Handweeding 2X—20 and 40 DAT	—	—	8273	8146	8162	8167
Rotary weeding 2X—20 and 40 DAT	—	—	8598	7969	8379	8315
Pyriclor 1 DBT +MCPA—20 DAT	0.2	1.0	8586	7988	8329	8301
Molinate 1—2 LSG +MCPA—20 DAT	3.0	1.0	7646	7715	8889	8083
Mean			8276	7955	8440	

Analysis of variance:

	s.e.	LSD (5%)	CV (X) %
Weed control methods	165	n.s.	7
Land preparation	265	n.s.	13
Weed control methods within land preparation	286	n.s.	

*X = Frequency
DAT = Days after transplanting
DBT = Days before transplanting
LSG = Leaf stage of grasses
†One plowing and one harrowing.
‡One plowing and two harrowings.
§One plowing and three harrowings.

rice had been harvested over 3 months earlier. Three days after spraying, pre-germinated seeds of IR8 were broadcast at 100 kg/ha in 2 to 3 cm water depth. Broadcast and transplanted control plots were prepared with normal tillage practices (plowed and harrowed) and sprayed with molinate at 3 kg/ha, active ingredient, 5 days after transplanting and handweeded 51 days after transplanting. All plots were uniformly sprayed with MCPA at 0.8 kg/ha at 41 days after planting. Ten days following planting, the water depth was raised and maintained at 5 cm until crop maturity.

Chemicals such as pyriclor, at 1 kg/ha, and PCP-oil applied before planting, gave grain yields similar to those of the broadcast control and gave good weed control as shown by the very low weed weight, indicating that weed control was comparable for these treatments (Table 32). The differences in grain yields between the lowest and the highest rates of paraquat, pyriclor, and PCP-oil were significant, suggesting that rates higher than those used might effect even better weed control and help maximize the yield. The highest yield obtained from the paraquat treatment, however, was significantly lower than the highest yield obtained from either pyriclor or PCP-oil herbicides. The significantly lower yields obtained from the transplanted control over the broadcast control may partly be explained by the higher incidence of bacterial leaf blight in the transplanted control. The tillers counted 22 days after planting showed no apparent toxicity due to the chemicals applied (Table 32).

These results demonstrated that under some field conditions high yields can be obtained from broadcast rice seeded in fields without land preparation using a suitable herbicide combination as pre-plant spray.

Weed control in upland rice

Grassy weeds in upland rice are more difficult to control than broadleaves and sedges. A herbicide rate and timing experiment was conducted during the 1967 wet season using several chemicals which showed promise in previous experiments. The successful treatments from the current test, plus handweeded and non-weeded treatments are listed in Table 33.

The experimental field was rotovated three times before IR5 seeds were drilled with the

Table 32. Results from a minimum tillage experiment with broadcast IR8 rice in which chemical weed control was substituted for land preparation, IRRI, 1967 dry season.

Treatment no.	Treatment*	Herbicide applied (kg/ha a.i.)	Grain yield at 14% H_2O (kg/ha)	Dry weed weight (g/sq m)	Time-to-weed (man-hr/ha)	Tiller count (no./sq m) (22 DAP)
1	Paraquat +MCPA	0.5 +0.8	4067	165	—	560
2	Paraquat +MCPA	1.0 +0.8	5180	168	—	414
3	Paraquat +MCPA	1.5 +0.8	5856	133	—	542
4	Pyriclor +MCPA	0.25 +0.8	6035	223	—	458
5	Pyriclor +MCPA	0.5 +0.8	6505	150	—	482
6	Pyriclor +MCPA	1.0 +0.8	7344	70	—	472
7	PCP—oil +MCPA	5.0 +0.8	7342	60	—	458
8	PHB +molinate +MCPA +HW (Broadcast control)	3.0 +0.8	7635	33	144	412
9	PHT +molinate +MCPA +HW (Transplanted control)	3.0 +0.8	5407	71	106	446
10	No tillage +MCPA	0.8	1210	447	—	318

LSD (5%):958
CV (X) %:12
*PHB =Plowed and harrowed, broadcast.
PHT =Plowed and harrowed, transplanted.
HW =Handweeded.

Table 33. Effect of some promising herbicides on the weed control and grain yield of IR5 rice. Weed control in upland rice, IRRI, 1967 wet season.

	Treatment*	Herbicide applied (kg/ha a.i.)	Time of herbicide application			
			Pre-emergence		Post-emergence	
			Grain yield (kg/ha)	Weed weight (g/sq m)	Grain yield (kg/ha)	Weed weight (g/sq m)
1	Pyriclor	0.1	2243	421	3183	141
2	Pyriclor	0.15	2937	298	2787	186
3	Pyriclor +molinate	0.1 +2.0	3302	156	3023	262
4	Pyriclor +molinate	0.1 +5.0	4160	96	3281	207
5	Pyriclor +molinate	0.15 +2.0	3427	225	2930	255
6	Pyriclor +molinate	0.15 +4.0	3467	114	2877	179
7	DCPA	8.0	3104	206	2918	215
8	Trifluralin	1.0	3253	105	2540	194
9	Handweeding	3X	2888	40	2772	66
10	Weedy check	—	1079	470	1742	524

Analysis of variance for grain yield:

	s.e.	LSD (5%)	CV (X) %
Time of application (T)$^{n.s.}$	206	n.s.	16
Herbicides (H)**	159	448	
T X H**	409	1154	

*2, 4-D spray at 0.6 kg/ha 33 days after seeding.

Table 34. Effects of irrigation treatments on grain and straw yields, grain : straw ratio, efficiency of water use and percentage of sterility for IR8, IRRI, 1967 dry season.

Irrigation treatment	Yield				Grain: straw ratio	Cumulative water use†		Efficiency (g/l)		Sterility (%)
	Grain (kg/ha)	Index*	Straw (kg/ha)	Index*		Total (mm)	Index*	Grain/ liter	Grain +straw	
Deep continuous (10 cm) flooding (DCF)	8430	100	8170	100	1.0	910	100	.93	1.82	16
Flowing irrigation (FI)	8280	98	8200	100	1.0	4581	503	.18	0.36	11
Mid-season drainage (MSD)	8470	101	8130	100	1.0	867	95	.98	1.94	19
Shallow continuous (2.5 cm) flooding (SCF)	8210	97	8460	104	1.0	804	88	1.02	2.07	21
Alternate irrigation (AI)	7150	85	5360	66	1.3	695	76	1.03	1.80	29
AI +flood at P.I.	7450	88	6180	76	1.2	832	91	.90	1.64	23
ID +DAMT +F	7680	91	5910	72	1.3	850	93	.90	1.60	15
Irrigation at moisture stress (IMS)	3170	38	1620	20	2.0	197	22	1.61	2,43	38

LSD (5%): 1489
CV (X) %: 17
*% of deep continuous flooding.
†Does not include irrigation for land preparation.

linkage seeder at a 100 kg/ha seeding rate at 15-cm row spacing. A split plot design was used with time of herbicide application as the main plot and herbicide treatment as the subplot. The two applications (pre-emergence and post-emergence) were made 3 and 10 days after seeding. The highest yield (4,160 kg/ha) was obtained when 100 g of pyriclor was sprayed at pre-emergence in combination with 5 kg/ha molinate. The weed weight, compared to that of the weedy check, was also reduced substantially with the pre-emergence spray application of a combination of herbicides (Treatment 4). Pyriclor applied alone as a post-emergence spray was most effective in reducing weed weight per plot. DCPA and trifluralin gave adequate weed control and grain yields comparable to three handweedings.

Studies on Other Cultural Practices

Water depth in direct-seeded rice

Studies to determine the effect of water depth on the establishment of direct-seeded rice and subsequent grain yield were continued. During the 1967 dry season, pre-germinated seeds of selected varieties were seeded in rows on the mud surface of a sloping bed. The slope of the bed was 2.3 cm per meter, allowing the water depth to vary from 3.5 cm above the water surface to 34 cm deep. The bed was kept flooded from seeding until harvest.

The trend in seedling survival at various water depths was similar to that in previous tests (Annual Report, 1965) and the stand was greatly reduced as the water depth was increased beyond 10 cm. Among the varieties tested, IR8, Taichung (Native) 1 and Kaoshiung 21 survived until maturity even at a 30-cm water depth. The highest yields for these varieties were obtained at depths below 10 cm. Observations made during the first weeding showed that the first

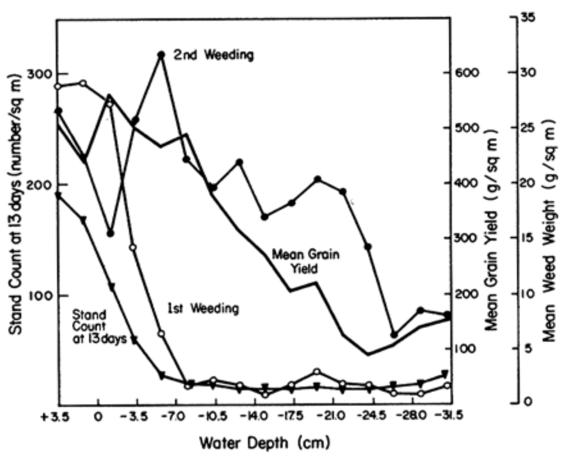

Fig. 23. Effect of water depth on stand establishment, weed weight and grain yield of 10 direct-seeded rice varieties. IRRI, 1967 dry season.

3.5 cm of water reduced the weed weight considerably, although complete weed control was obtained only at water depths greater than 8.5 cm (Fig. 23). The weeds that grew at depths shallower than 8 cm at first weeding were mostly broadleaves and sedges. The high weed weight at second weeding even at the 22-cm depth indicated weed regrowth, primarily aquatic weeds. Phenoxy acid applied to standing water did not control these aquatic weeds effectively.

These data show that direct-seeded rice varieties vary in their yielding ability at various depths of continuous flooding. The standard high-yielding semi-dwarfs such as IR8 and Taichung (Native) 1 can yield reasonably well in relatively deep water (30 cm). Early seedling establishment in deep water is important.

Water management

During the 1967 dry season an experiment on water management practices was conducted to determine consumptive water use and water use efficiency.

The eight irrigation treatments applied to IR8 were similar to those used in previous years except that a continuous-flow irrigation treatment was introduced. Water was maintained at a depth of 10 cm in these continuous-flow plots. The grain yield differences among the irrigation treatments in which 800 mm or more of water was used were not significant (Table 34). The yield of plants which were subjected to severe moisture stress dropped to 38 percent of either shallow continuous (2.5 cm) or deep continuous (10 cm) flooding. Water use in the treatment receiving irrigation at moisture stress amounted to 197 cm in 90 days. Shallow continuous flooding gave equally good grain yield and higher water use efficiency than either deep or continuous-flow irrigation (Table 34). An earlier study also indicated that 2.5 cm water depth also reduces weed weight drastically (Annual Report, 1966). These results indicate that high yields and high water use efficiency can be achieved with continuous shallow water (2.5 cm) in a typical rice soil like Maahas clay.

Table 35. Mean yield and growth performance of soybeans selected for high seed yields from 31 varieties and lines from the Philippines, United States, Taiwan and Indonesia, IRRI, 1965 dry and 1967 wet seasons.

Variety*	Seed yield (kg/ha) at 14% moisture	Plant height (cm)	Maturity (days)
1965 dry season (Feb.-June)†			
1. Black Manchurian	3078	68	100
2. Economic Garden I	2477	47	111
3. Improved Pelican	2430	49	100
4. C-11	2412	120	111
5. Head Green	2380	66	124
6. B-256	2250	90	111
1967 wet season (July-Nov.)‡			
1. Clark 63	3163	70	89
2. CS_1C_3	2231	92	106
3. LS_1C_6	2176	128	105
4. LS_1D_2	2115	110	105
5. TK No 5	2109	54	85
6. Economic Garden I	2028	111	105
7. LS_1A_1	1997	106	100
8. LS_6C_1	1987	118	105
9. Bragg	1973	40	93
10. UPCA No 486	1951	100	106
11. Taichung E-32	1828	46	87

*LS—Lincoln selection (from UPCA).
†Average, five replications.
‡Average, two replications.

Soybean as a rotation crop

Screening varieties of soybean for use as a possible rotation crop with rice was continued. Since 1965, more than 30 soybean varieties from the United States, the Philippines, Taiwan and Indonesia have been tested in replicated trials for yield and other agronomic characters. Plantings made during the dry season were irrigated in furrows while ridges were used to improve drainage during the wet season. Weeds were controlled by directed spray of pre- and post-emergence herbicides. Additional handweedings were made during the wet season when necessary. The yield data for selected high yielding varieties or lines are presented for the 1965 dry season and 1967 wet season experiments (Table 35). These data show that high seed yields can be obtained in either the dry or wet season provided that water is available through irrigation during the dry season and adequate drainage is provided during the wet season. To obtain high seed yields of soybean, adequate weed, insect and disease control must be provided. During the 1967 wet season experiment, a US variety, Clark 63, yielded 3,163 kg/ha soybean seeds, the highest yield recorded for any replicated trial reported

Entomology

The effective control of insect pests of rice is a major factor in increasing yields throughout Southeast Asia. Experiments conducted at the Institute and elsewhere have shown that plots receiving insect protection generally yield from 1 to 3 ton/ha more rice than the unprotected plots. Frequently this yield increase attributable to insect control amounts to 30 to 50 percent. The immediate control of insect pests, therefore, has received the major attention in the entomology program, although such long-lasting approaches as varietal resistance, biological control, and the use of sex attractants and sterilants have also been investigated.

Intensive investigations on γ-BHC and diazinon during the year further confirmed their high effectivity when applied to the paddy water. As diazinon controls the pink borer, the rice green leafhopper, and the brown planthopper, which γ-BHC does not, it has generally received wider acceptance than γ-BHC. Significantly, diazinon treatments in most cases effectively prevented the spread of grassy stunt virus.

Experimental data obtained both during the dry and wet season plantings have shown that highly effective insect control is possible when diazinon is used at the rate of 1 kg/ha every 20 days—which means that the cost of this insecticide may be reduced by 50 percent over previous practice.

The search for newer and more effective insecticides was continued with the intensive evaluation in laboratory, greenhouse and field experiments of 40 new compounds as seed treatment, foliar spray, and when applied to the paddy water. While the data needs further confirmation, they show that at least two compounds are highly effective.

Encouraging results have also been obtained on varietal resistance. The advanced progenies of some crosses between stem borer-resistant and high-yielding rice varieties have exhibited stem borer resistance, good plant types and other desirable features. An important finding is that brown planthoppers, which have been responsible for extensive losses in recent years, cannot multiply on the variety Mudgo. Similar host-plant interactions between green leafhoppers and the variety Pankhari-203 have also been recorded.

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Laboratory Rearing and Field Behavior of Striped Borer Larvae

Mass rearing of the rice stem borer

Since the availability of different instar striped borer larvae is a major limiting factor for most laboratory and greenhouse experiments on this insect, studies were undertaken to standardize a mass rearing technique for this species. When tested, several synthetic or semi-synthetic diets currently being used in some laboratories caused low larval survival, a slow rate of growth and bacterial and fungal contamination of the synthetic media. To overcome these problems, the diet has been modified to include rice bran which brings about better larval growth and sodium acetate which prevents contamination. The ingredients used and the procedure for preparing the diet appear below.

Components	Amount
Cellulose	10 g
Casein	10 g
Dry yeast	10 g
Agar	6 g
Glucose	5 g
Sucrose	5 g
Wesson's salt mixture	2 g
L-ascorbic acid	1 g
Sorbic acid	1 g
Choline chloride	0.5 g
Cholesterol	0.2 g
Sodium acetate	1-2 g
Distilled H_2O	300 ml
Rice bran	50 ml

The various ingredients are blended thoroughly for about 15 minutes and autoclaved at 250 F and a pressure of 17 lb/sq inch for another 15 minutes. The diet is then transferred to desired containers or first allowed to cool; when it solidifies it is cut into discs of the desired shape and weight for rearing individual larvae. Before being transferred to the diet, the stem borer eggs or larvae are rinsed with a .05 percent mercuric chloride solution to eliminate surface contamination.

In earlier experiments, rice stem pieces (¼-½ inch long), instead of rice bran, were mixed with the synthetic diet, but subsequent studies showed that the addition of rice bran made a more efficient diet (Table 1).

This diet is semi-aseptic and does not need to be kept in a sterilized condition. Although suitable for rearing striped stem borer larvae from hatching through pupation, generally the freshly hatched larvae exhibit low survival on it. Also, in simultaneous experiments, freshly hatched larvae had higher survival when reared on rice seedlings than on synthetic diets.

Table 1. Percentage of survival and pupation of *Chilo suppressalis* larvae on three different rearing media. IRRI, 1967.

Rearing medium	Larval age at caging (days)	Survival at 35 days from hatching (%)	Pupation at 35 days from hatching (%)
Diet+Cut stem	12	45.4	43.87
Diet+Rice bran	15	72.6	53.33*
Rice seedlings	Newly hatched	26.0	21.00
Rice seedlings	12	74.2	60.00

*Average of four replications, each consisting of 100 larvae per treatment.

The seedlings used are those grown from about 20 g seeds of the variety Peta previously disinfected for about 3 minutes in a solution of one Mel Tab* tablet dissolved in 500 ml distilled water. About 10 striped borer egg masses at the blackhead stage are caged on these seedlings at 5 to 7 days after germination in bottles with fine wire meshed lids which permit aeration but prevent larval escape. The larvae usually feed on basal parts and roots of the seedlings and as many as 300 larvae survived in each bottle for about 10 days. Thus, rearing them on seedlings is rather simple but it requires frequent changes, particularly from the third instar onwards, when the larvae feed excessively. For these latter instar larvae, the rice seedlings and the semi-synthetic diet are equally suitable.

The advantages of high survival of early instar larvae on rice seedlings and of their equally high survival at later instars on artificial diets have been combined in a procedure in which the larvae are reared on rice seedlings during the first 5 to 10 days after hatching and are then transferred to the artificial diet. In this method about 80 percent of the caged larvae survive compared to less than 10 percent in the case of 3-day-old or younger larvae caged on the artificial diet (Fig. 1).

*Supplied by Nihon Nohyaku, Japan. Active ingredient—1.87 ethyl mercuric phosphate.

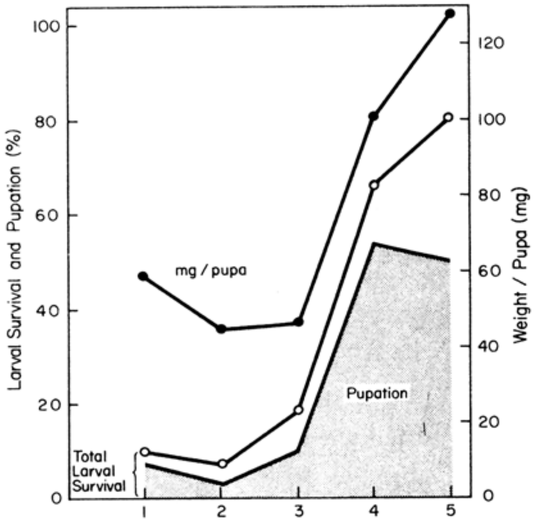


Fig. 1. Survival and development of *Chilo suppressalis* larvae on artificial insect diet. IRRI, 1967. (Data taken at 39 days after larval caging.)

Survival, migration and damage by freshly hatched striped borer larvae in field plots

No basic information is available on the survival of the striped borer larvae in field plots, their rate of growth, extent of migration to adjacent hills and the damage they cause. To obtain the information frequently needed for analyzing various field data, IR8 plants protected from insect infestation until the time of treatment were artificially implanted with laboratory incubated striped borer egg masses at 40 days after transplanting.

Twenty 2.25 x 2.25 m plots were prepared, each comprising 81 hills. All the hills were numbered and that most centrally located was infested with a striped borer egg mass with about 40 eggs at the blackhead stage. At 12, 20, 25 and 30 days after infestation all plants in five randomly selected plots were dissected to determine the number of striped borer larvae present on them and the dead heart tillers caused by their feeding. The results were expressed by grouping the plants in concentric squares, numbered in ascending sequence from the infested plant. Throughout the experiment, these plots were inspected and unintroduced egg masses and the recovered larvae which differed distinctly in age from those hatching from the implanted eggs were removed.

At 12 days after infestation, the larvae exhibited a survival rate of 55 percent which was relatively high, considering that all of the 40 eggs in the implanted egg mass hatched. Subsequent observations also revealed a low larval mortality. This generally agrees with the results obtained in greenhouse experiments where the larvae showed low mortality beyond the first 10 days after hatching. The habit of group feeding was demonstrated by the early instar larvae when even a larger population infested relatively lower number of hills than in later instars. This is shown by the increase in ratio of number of dead hearts produced to the larval number, from 1:3 at 12 days after infestation to 1:2 13 days later and onwards (Fig. 2).

At 12 days after infestation most larvae, now at about the second or third instar, were still on the same plant on which they were first implanted, but subsequently, their number declined on the originally infested hill and increased on those surrounding it (Fig. 3). In later observations, most of the larvae were recovered on the hills surrounding the plant on which they were originally placed although their distribution extended up to four hills around the originally infested plant.

Varietal Resistance to Rice Stem Borers

Feasibility of using rice seedlings in tests for stem borer resistance

The resistance to stem borers of varieties selected from field screening experiments is usually evaluated by artificially infesting the plants with freshly hatched stem borer larvae at 30 to 40 days after transplanting and dissecting them 20 to 30 days later to determine larval survival and growth. Although this technique provides highly consistent results, it is laborious and time-consuming. As an alternative, the larvae were caged on seedlings of different rice varieties. The details of such a procedure are similar to those of mass rearing borer larvae on rice seedlings.

The seedlings of 11 varieties were grown in $3\frac{1}{2}$ x 7-inch bottles and, 6 days after germination, infested with 100 freshly hatched striped borer larvae. Each variety was tested in four replications. The results, which were highly consistent between replications, generally agreed with the

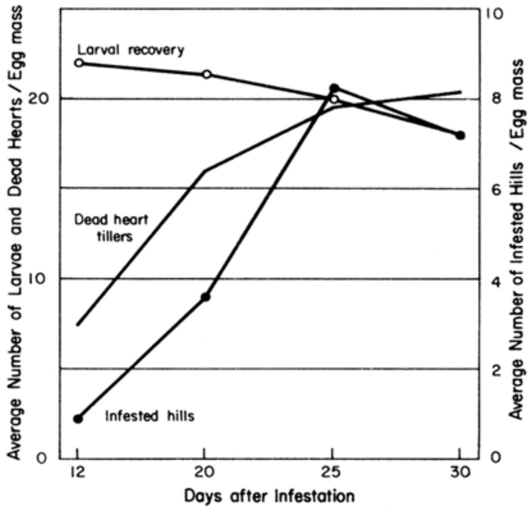


Fig. 2. Survival of and damage caused by striped borer larvae hatching on a rice plant artificially infested by implanting an egg mass on it. IRRI, 1967.

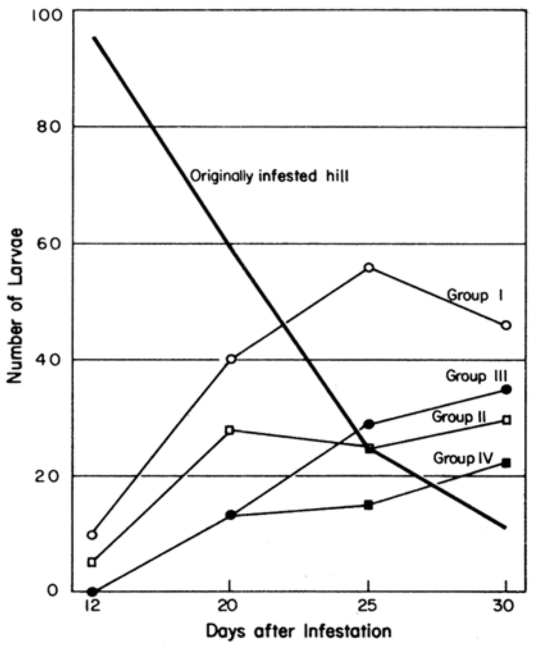


Fig. 3. Migration of larvae to hills around a plant artificially implanted with a striped borer egg mass. The different groups denote the hills in concentric squares in ascending order from the originally infested plant. IRRI, 1967.

performance of these varieties in previous greenhouse and field experiments. Larval survival on varieties TKM-6, Yabami Montakhab, and a few others was significantly lower than on such known susceptible varieties as Rexoro, Sapan Kwai and Milfor-6(2) (Fig. 4). However, larval survival was also high on varieties Taitung-16 and Chianan-2 which had generally shown lower field infestations and also low larval survival when artificially infested in greenhouse experiments. In earlier studies both these varieties had shown changes in stem borer susceptibility at different plant ages (Annual Report, 1966). Whether or not the differences obtained in this experiment are due to changes in the susceptibility of plants at different ages or to differences in the mechanism of resistance is being investigated further. The latter could also be a major factor as the borers remain external feeders when reared on rice seedlings. Furthermore, larvae reared on varieties showing low larval survival weighed three to four times less than those on varieties showing high larval survival.

Using the same procedure, the varietal resistance of Milfor-6(2) and TKM-6 were compared by rearing the larvae until pupation. The results showed that the larvae suffered high mortality on the variety TKM-6, on which also no pupation occurred until 52 days after hatching. During the same period, however, about 30 percent of the caged larvae on Milfor-6(2) pupated (Fig. 5). The available data so far indicate the high reliability of this technique. It is more convenient and less time-consuming than the greenhouse infestation of 30- to 40-day-old plants. Also, the larval recovery in this technique was higher than when the larvae were used for infesting uncaged whole plants. This procedure, however, does not account for such aspect of resistance as mechanical interference in larval boring in the stem because the larvae remain only as external feeders when reared on seedlings.

Breeding for stem borer resistance

In intensive field and greenhouse screenings of about 10,000 rice varieties collected at the Institute, such varieties as TKM-6, Taitung-16, Chianan-2, and Yabami Montakhab have been identified as highly resistant to the striped rice borers. Some of these varieties were less preferred or were avoided by ovipositing moths, while others presented the larvae with conditions unsuitable for growth. Correlations between various morphological and anatomical characters have also been recorded. Among these varieties, TKM-6 in most field experiments outperformed others in varietal resistance not only to stem borers but also to the tungro virus, the bacterial blight disease and the brown planthopper. However, being a tall, leafy, narrow-stemmed and lodging-susceptible variety, it represents a poor agronomic plant type and has low yield potential.

In a cooperative project with the Institute plant breeders, several varieties have been crossed to combine different kinds of resistance and to incorporate stem borer resistance into improved plant types capable of producing high yields. The tall and leafy plants representing poor agronomic types are rejected but other progenies are screened for insect resistance under natural infestations. Since these studies are directed toward obtaining stem borer-resistant lines of improved plant types which possess a general field tolerance to other common problems, plants susceptible to leafhoppers, planthoppers, the virus diseases, and bacterial blight are also rejected.

During the 1967 dry and wet season plantings, F_6 and F_7 progenies of the following crosses were studied.

No.	Cross	No. of pedigree lines studied F_6	No. of pedigree lines studied F_7	No. of lines selected for further study
IR-355	Chianan-2 x Sapan Kwai-3	30	46	—
IR-356	Taitung-16 x TKM-6	246	113	92
IR-357	Taitung-16 x Rexoro	56	38	8
IR-359	TKM-6 x Rexoro	7	2	—
IR-360	SEL No. 6 x BPI-76	23	5	—

All these selections were planted as pedigree lines in four row plots 5 meters long. The F_7 lines were grown in two replications—one without any insect control to evaluate the resistance and the other treated with diazinon to assess plant type and yield potential. Also, after selecting the best individual plants, the seeds of each of several promising F_6 lines were bulked for use in yield trials along with their parents and IR8(40) as the standard check. These were each

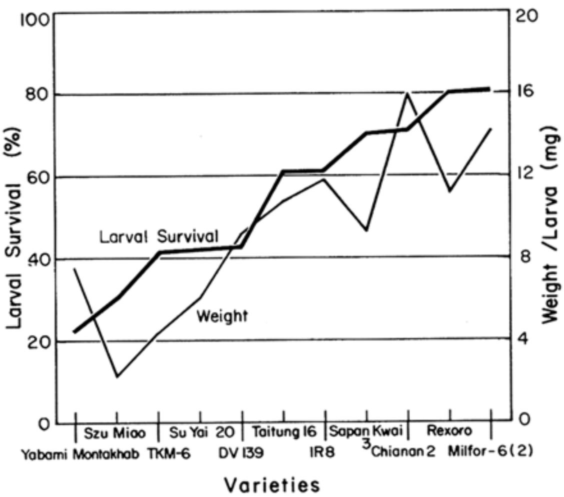


Fig. 4. Survival of newly hatched striped borer larvae and their weights when caged for 10 days on seedlings of different rice varieties. IRRI, 1967.

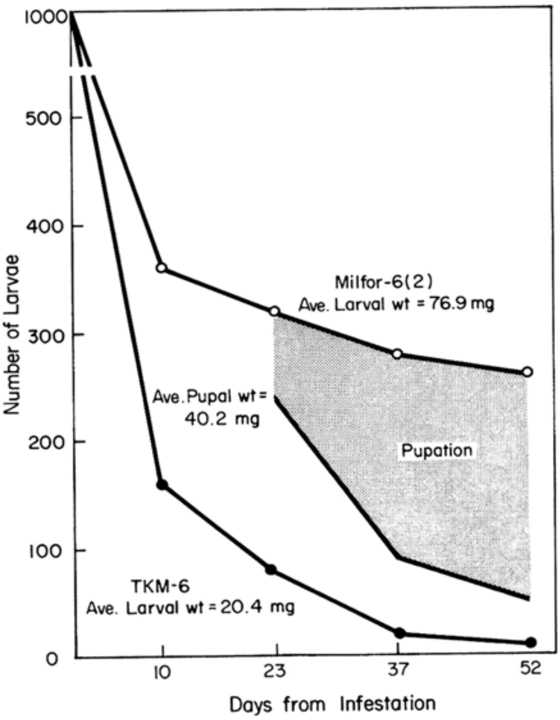


Fig. 5. Survival and pupation of first instar *Chilo suppressalis* larvae on Milfor-6(2) and TKM-6 seedlings. IRRI, 1967.

planted in four replications of 2 x 5 meter plots in a randomized complete block design. Two of these blocks representing two replications were treated with insecticide while the other two were exposed to natural insect infestation. The results showed that several of these crosses had

Table 2. Insect infestation and grain yields of several F_7 (bulk) progeny of stem borer resistant and susceptible rice varieties and of standard checks. IRRI, July to September, 1967.

Variety or selection	Untreated plots					Plots* treated with diazinon	
	†Grade of maggot damage	Dead hearts (%)	White heads (%)	Virus-infected hills (%)	Hopper-burn hills (%)	50% flowering (days from seeding)	Grain yield (kg/ha)
IR 356-81	2.5	1.58	0.88	26.35	55.0	69	4445
IR 356-79	3.5	1.31	0.88	32.77	75.0	69	4371
IR 356-76	2.5	0.59	0.66	24.43	5.0	71	4348
IR 357-307	3.0	2.55	2.85	14.36	0.0	71	4245
IR 356-84	2.5	0.75	0.32	30.88	87.5	69	4163
IR 357-231	3.0	7.06	4.82	23.44	7.5	79	4084
IR 357-232	3.0	3.02	2.78	19.44	2.5	71	4081
IR 356-98	3.0	1.82	0.42	32.88	45.0	71	4080
IR 356-86	2.5	1.29	0.93	45.14	75.0	69	3944
TKM-6	2.5	2.96	1.93	1.89	0.0	74	1832
IR8 (40)	3.0	0.93	0.49	27.35	7.5	82	5036
Rexoro	3.0	11.82	7.63	6.17	60.0	87	2601

*Average of two replications.
†Damage by rice whorl maggot on a scale of 1-4. Lower number indicates less damage.

lower stem borer incidence and also produced moderately high yields (Table 2). While these lines have the advantage of early maturity, the same advantage may be a factor limiting their higher yields. Two major drawbacks of these crosses appear to be their susceptibility to lodging and their lower tolerance to 'hopper-burn' caused by brown planthopper feeding.

Among these different crosses the progenies of TKM-6 x Taitung-16 had higher stem borer resistance and were of better plant types. In field experiments TKM-6 was consistently resistant to the borers, Taitung-16 and Chianan-2 were resistant during the early stages of plant growth but became susceptible at the white head stage, while Rexoro and Sapan Kwai were highly susceptible at all growth stages. These trends were evident in high dead heart and white head incidence in crosses of Taitung-16 or Chianan-2 with a susceptible variety but not with the resistant variety TKM-6 (Figs. 6 and 7). Also, several selections in each of these crosses had high resistance to stem borers and many of them produced moderately high yields (Table 3).

Combining stem borer resistance with high yielding ability

The various crosses described above had high stem borer resistance but their yielding ability, while much better than that of the resistant parent TKM-6 and other susceptible checks, was generally lower than that of newer high

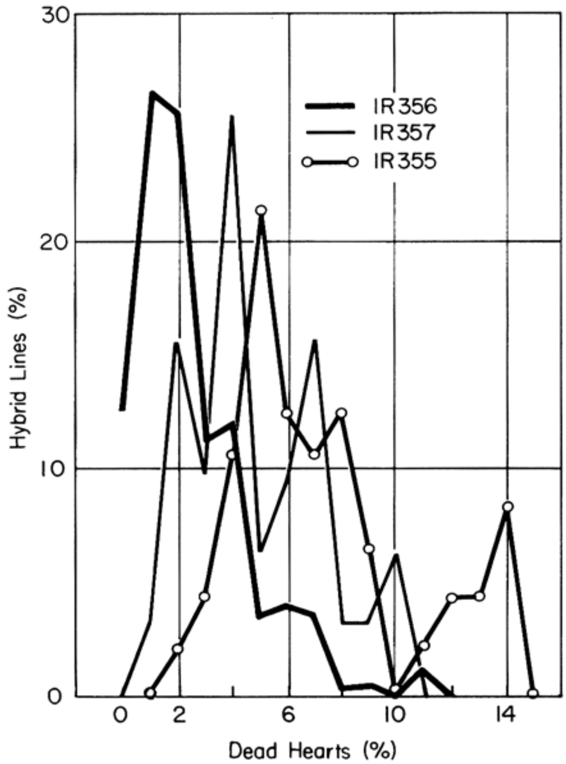


Fig. 6. Dead heart distribution in F_7 hybrid lines of different crosses. IRRI, 1967.

yielding varieties. To incorporate the borer resistance of TKM-6 into plants of high yield potential, various crosses with varieties of improved plant types have been made. Table 3 shows the performance of a few lines from one such cross (IR8 x TKM-6). Significantly, one of these lines produced a high yield of 5,200 kg/ha in 105 days from seeding in a wet season planting. However, the table presents only partial data as several other equally good or even more promising lines, but of somewhat later maturity, were damaged by a severe typhoon.

Another promising cross tested at the F_4 and F_5 generations was [$Peta_3$ x Taichung (Native) 1] x TKM-6. The F_4 seeds, obtained from an F_3 bulk population consisting only of dwarf plants, were grouped into 24 different categories based primarily on maturity and plant height. From these seeds, about 26,000 plants (F_4) were grown in a field from March to August and exposed to natural insect infestation. Besides the two parents, Taitung-16 and Rexoro were used as the standard checks. During the experiment the stem borer incidence was so severe that it almost completely killed the susceptible check variety Rexoro. The attack by the grassy stunt virus and the bacterial blight disease were equally severe and heavily damaged several other check varieties. While a large number of these F_4 plants were also heavily damaged, many remained comparatively insect- and disease-free. From these, 795 different plants, also of good plant type, were tested further.

These were grown as F_5 pedigree lines in two replications each consisting of four 5-meter rows. In one replication they were exposed

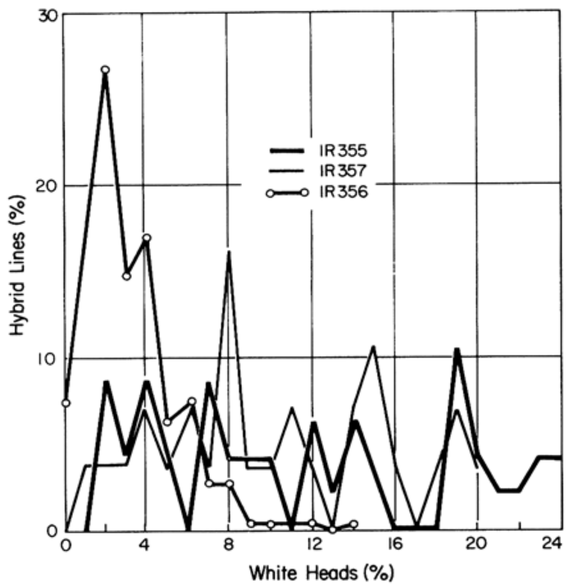


Fig. 7. White head distribution in F_7 hybrid lines of different crosses. IRRI, 1967.

Table 3. Insect infestation and yields of some pedigree lines from crosses of stem borer resistant and susceptible rice varieties. IRRI, July to October, 1967.

Selection*	Generation	Untreated plots			Plots treated with diazinon	
		Dead hearts (%)	White heads (%)	Hopper-burn hills (%)	50% flowering (days from seeding)	Grain yield† (kg/ha)
IR 580-385-20	F_4	1.20	2.10	0	82	5292
IR 580-385-18	F_4	2.50	3.20	0	76	4809
IR 580-385-25	F_4	4.50	2.80	0	76	4412
IR 580-386-9	F_4	1.80	3.78	0	82	4392
IR 356-85-11	F_7	2.94	3.66	100	69	4323
IR 580-385-5	F_4	1.35	0.75	0	82	4216
IR 580-385-3	F_4	1.20	3.50	0	82	4169
IR 356-83-1	F_7	3.71	1.12	25	72	3834
IR 356-81-7	F_7	1.75	1.16	10	67	3790
IR 356-81-6	F_7	0.75	2.64	50	69	3651
IR 356-173-3	F_7	5.00	2.80	0	72	3619
IR 357-239-1	F_7	5.40	19.50	0	76	1707

*IR 580 — IR8 x TKM-6
IR 356 — TKM-6 x Taitung-16
IR 357 — Taitung-16 x Rexoro
†Yield data on standard checks and several late selections could not be obtained as the crop was damaged by a typhoon.

Table 4. Stem borer and virus incidence on F_5 lines of IR532 (Peta$_3$ x Taichung (Native) 1 x TKM-6). IRRI, September, 1967 to January, 1968.

Hybrid line or variety	Untreated plots			Grain yield* (kg/ha)
	Dead hearts (%)	White heads (%)	Grassy stunt hills (%)	
IR 532-451	0.50	5.00	17.8	4320
IR 532-262	3.78	9.10	5.9	4017
IR 532-275	10.08	3.63	47.6	4027
IR 532-317	3.78	2.56	28.6	3960
IR 532-485	0.40	2.08	25.0	3953
IR 532-492	0.30	1.75	61.9	3883
IR 532-62	4.10	0.50	49.2	3892
IR 532-105	3.50	2.00	20.0	3822
IR 532-63	5.50	0.96	40.0	3820
IR 532-452	0.75	2.64	55.9	3830
IR 532-57	4.05	0.57	40.5	3780
IR 532-280	2.70	4.80	38.1	3628
IR 532-273	14.04	2.00	63.1	3664
IR 532-71	3.60	5.80	38.1	3593
IR 532-491	0.70	0.40	30.0	3577
IR 532-76	3.52	1.28	40.0	3524
IR 532-257	6.10	5.12	30.0	3523
IR 532-496	1.25	0.28	35.0	3515
TKM-6	3.00	3.50	15.0	1118
Peta$_3$ x T(N)1	15.00	2.00	25.0	2596
IR8	12.92	3.40	70.2	2371
Rexoro		All plants killed by borers		

* Plots were partially protected from insect pests by diazinon applied to the paddy water at 5 and 40 days after transplanting. Also, several lines were severely affected by bacterial blight and bacterial streak following a severe typhoon and had high incidence of grassy stunt.

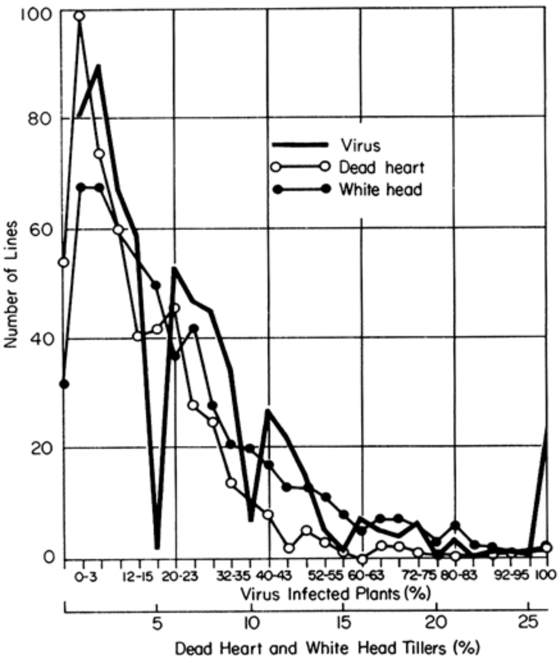


Fig. 8. Dead heart, white head and virus distribution in F_5 hybrid lines of the cross Peta x Taichung (Native) 1 x TKM-6. IRRI, 1967.

to natural insect infestation while in the other they were protected with diazinon applied to the paddy water at 5 and 40 days after transplanting to evaluate their yield potentials under partial insect control conditions. Besides the intense stem borer and grassy stunt virus incidence (Fig. 8) on this crop, a severe typhoon followed by a prolonged cloudy and drizzling weather during the late booting to flowering stages of most test lines caused heavy bacterial leaf streak and bacterial blight damage to the crop. The combined effect of these problems is evident in the low yield (2,371 kg/ha) of IR8 in partially protected plots. In the unprotected plot this and several other checks were almost completely killed. However, it is significant that several test lines which had low incidence of stem borers and grassy stunt virus also produced high yields (Table 4). Many of them had better grain type, high seedling vigor and also resistance to the brown planthopper. All these characters combined with high yielding ability under favorable environmental and comparatively insect-free conditions can give these lines greater practical significance.

Varietal Resistance to the Brown Planthoppers and Rice Green Leafhoppers

Screening for brown planthopper resistance

Following a technique standardized in 1967, a large number of varieties were tested for their resistance to the brown planthopper *Nilaparvata lugens* Stal. The test varieties were sown in rows 5 inches apart in 24 x 10 x 4-inch wooden flats several of which were placed in a galvanized iron tray containing one inch of standing water. At about 2 weeks after sowing they were exposed to a high population of brown planthoppers. The number of insects on each variety and the extent of plant damage were recorded at 5-day intervals until 80-90 percent of the test varieties were killed. At this stage another group of varieties, also grown in wooden flats, was placed with the previous batch and the planthoppers from the old batch migrated to the new batch. With this technique, the same insect population can be used to screen several batches of test varieties. The standing water in the tray provides the high humidity suitable for survival of the planthoppers and also eliminates the need for frequent watering which may dislodge the insects feeding near the base of the plants. Since these experiments were aimed at mass rejection of susceptible lines, each variety was tested in only two replications. Those showing promise were caged with a uniform number of brown planthoppers in a further study of the insect's survival and growth rate. In mass-screening experiments, the level of adult population on different varieties indicated their degree of preference while the number of eggs and nymphs reflected the insect's ability to multiply on these varieties. The eggs were counted only on a few selected varieties by examining 10 randomly selected plants under a binocular microscope. The egg masses appeared as brown spots with the egg operculum protruding on the surface of the leaf sheaths or midribs.

About 200 varieties showing varying susceptibility to the stem borers and 60 highly resistant and highly susceptible hybrid lines were screened for brown planthopper resistance. Several of

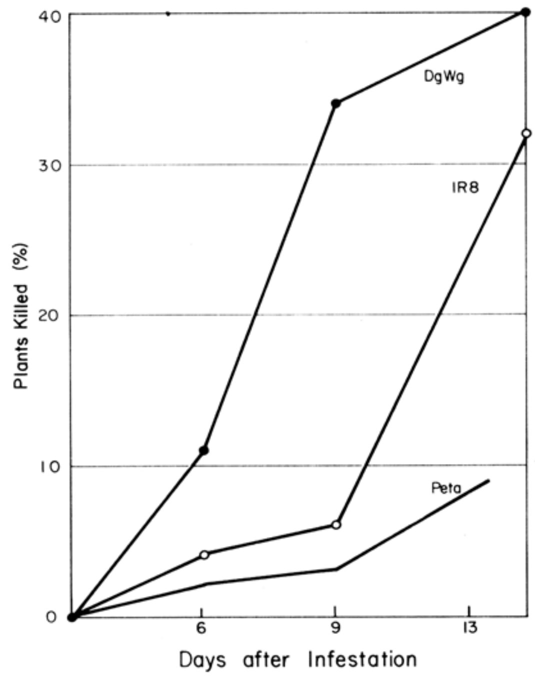


Fig. 9. Effect of infestation with a heavy population of brown planthoppers on IR8 and its parents, Dee-geo-woo-gen and Peta. IRRI, 1967. (Average of 4 replications. The varieties planted in rows in wooden flats were exposed to several thousand brown planthoppers.)

these varieties, including Mudgo on which the brown planthopper can barely survive, were studied further.

Also, as reported earlier, IR8 in repeated greenhouse experiments exhibited a high resistance to the brown planthopper. However, it did not adversely affect the survival or population build-up of the brown planthoppers. Further experiments to compare the susceptibility of this variety to the brown planthopper with those of its parents, Dee-geo-woo-gen and Peta, showed that IR8 had an insect tolerance intermediate to those of its parents (Fig. 9). Dee-geo-woo-gen was the most susceptible while IR8 exhibited resistance almost equivalent to that of Peta until 9 days after infestation from which time it suffered increasingly heavy damage.

In a similar experiment, the F_4 plants of IR-356 ($Peta_3$ x Taichung (Native) 1 x TKM-6) were found to be much more resistant than TKM-6 and Taichung (Native) 1. At 13 days after transplanting when 25.73 and 78.57 percent of the plants of the two check varieties, TKM-6 and Taichung (Native) 1, respectively, had been killed, only 6.58 percent of the hybrid

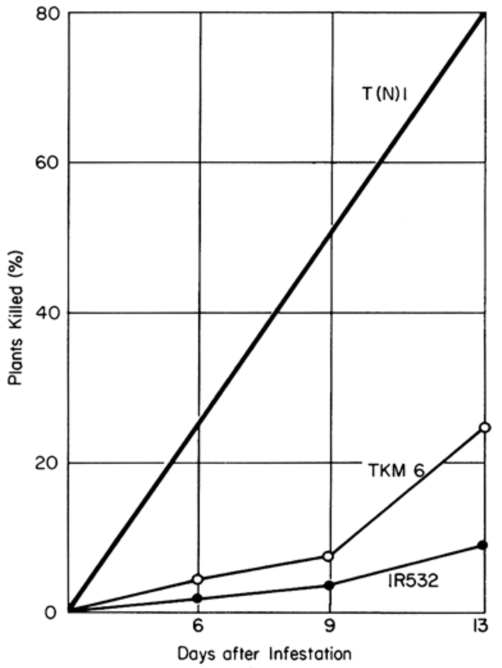


Fig. 10. Effect of infestation with a heavy population of brown planthoppers on F_4 progenies of IR5-32 [$Peta_3$ x Taichung (Native) 1 x TKM-6] and the varieties Taichung (Native) 1 and TKM-6. IRRI, 1967. (Average of 4 replications. The varieties planted in rows in wooden flats were exposed to several thousands brown planthoppers.)

plants were dead (Fig. 10). The progenies tested in this experiment were obtained from a program aimed at combining the high stem borer resistance of TKM-6 with the better plant type of $Peta_3$ x Taichung (Native) 1. The high resistance of these progenies to the brown planthoppers, therefore, has special significance. In subsequent field experiments several selections from these hybrids were not only of good plant types but also were highly resistant to the striped borer.

Survival and population build-up of the brown planthopper on selected rice varieties

Fourteen varieties of varying brown planthopper susceptibility were intensely evaluated for their resistance to the brown planthopper. In separate experiments individual potted plants enclosed in cages at 2 to 3 weeks after sowing were infested with a uniform number of either nymphs or adult brown planthopper.

In experiments where 10 newly hatched nymphs were caged on individual plants, more than 70 percent of the caged nymphs were still alive on most test varieties 6 days after infestation while only 6.6 percent survived on the variety Mudgo (Table 5). Six days later, when more than 40 percent of the nymphs had already reached the adult stage on such other varieties as IR5, IR8, Peta, Ratnachudi Bam-6 and 81B-25, no adult planthopper was found on Mudgo. On other varieties, the nymphs showed moderately low survival. At 32 days after infestation

Table 5. Survival* and development of freshly hatched brown planthopper nymphs on different rice varieties.

Variety	No. of planthoppers						
	7†	12†		Total	17†		Total
	Nymphs	Nymphs+Adults			Nymphs+Adults		
Mudgo	0.7	0.2	0.0	0.2	0.2	0.6	0.8
IR5	8.2	1.6	4.0	5.6	0.0	5.8	5.8
IR8	7.0	0.8	5.6	6.4	0.0	5.4	5.4
Taichung (Native) 1	8.1	1.6	3.9	5.5	0.0	6.2	6.2
DV 139	7.1	2.4	2.0	4.4	0.1	4.1	4.2
Peta	10.0	2.0	4.0	6.0	0.0	6.0	6.0
Dee-geo-woo-gen	8.5	0.8	3.4	4.2	0.0	5.0	5.0
Muey Nawng 62	8.1	0.1	2.9	3.0	0.0	6.5	6.5
81B-25	8.9	1.0	4.8	5.8	0.0	6.7	6.7
Garunbalay	8.8	3.2	2.5	5.7	0.0	6.5	6.5
Sigadis	8.8	1.8	3.6	5.4	0.0	8.5	8.5
Pankhari 203	8.8	1.9	2.4	4.3	0.0	3.3	3.3
Yabami Montakhab 55	7.0	2.1	1.6	3.7	0.0	5.0	5.0
Ratnachudi Bam 6	6.7	0.5	4.1	4.6	0.0	5.2	5.2
DV 29	5.9	1.7	3.9	5.6	0.0	4.9	4.9

*Average of five replications each consisting of 10 nymphs caged on individual plants at 20 days after transplanting.
†Days after caging.

the largest number of adults was recorded on IR8 and Taichung (Native) 1. Yabami Montakhab-55 and Sigadis showed the least resistance to brown planthopper feeding and were all killed at 32 days after infestation. No insect survival or plant mortality was recorded on Mudgo.

The number of progenies produced by the adults on different varieties was studied by transferring the adults to other uninfested plants of the same variety. Daily observations were made, and the nymphs were removed until all the adults had died. Cumulative figures at the end of the experiment for the total progeny produced on each variety revealed that larger populations developed on Pankhari-203, Ratnachudi Bam, 81B-28 and RNB-6 than on YM-55 and Mudgo. Nymphal survival was particularly low on Mudgo.

Resistance of Mudgo to the brown planthopper

These data show that the brown planthopper nymphs had very low survival and almost failed

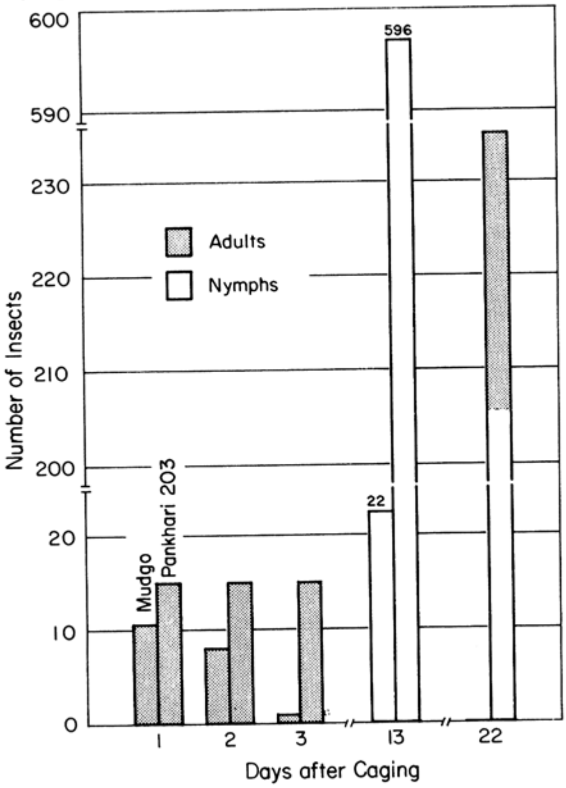


Fig. 11. Number of *Nilaparvata lugens* adults and their progeny at different days after caging rice varieties Mudgo and Pankhari-203. A total of 15 mated females were caged individually on a plant of each variety. IRRI, 1967.

to maintain populations on Mudgo while they survived well and multiplied fast on Pankhari-203. These two varieties were used in further intensive experiments in which mated females were caged singly on individual plants to determine the survival and the total number of progenies produced by the caged insects.

On Mudgo, most of the females died within the first 3 days of caging while none died on Pankhari-203 (Fig. 11). Ten days later there were only 28 nymphs on Mudgo as compared to 596 on Pankhari-203. Furthermore, all nymphs on Mudgo died in another 9 days while most of those on Pankhari-203 survived with 22 of them already reaching the adult stage. Also 53.5 percent of the Pankhari plants died because of planthopper feeding; this accounted for the decline in planthopper population from the previous observation on this variety, No mortality of Mudgo plants was recorded.

These data further confirm that Mudgo is not suitable for the survival and development of the brown planthopper while Pankhari appears to be a suitable host. The high resistance of Mudgo to the brown planthopper is significant, particularly since this insect has in recent years caused heavy crop losses in several areas throughout Asia. Significantly, too, a high percentage of nymphs and adults died on this variety within the first few days after caging, indicating that the plants either offer some mechanical barrier to their feeding or contain some strong repellant or toxin against this insect.

Resistance of variety Pankhari-203 to the rice green leafhopper

In contrast to its high resistance to the brown planthopper, Mudgo was, in separate experiments, found to be highly susceptible to the rice green leafhopper, *Nephotettix impicticeps* Motsch. In these tests, its susceptibility to the rice green leafhopper was compared with that of Pankhari-203 and Taichung (Native) 1. The methods used were identical to those used for the brown planthopper. When caged on 10-day-old plants of these three varieties 80 percent of the nymphs died within 6 days after caging on Pankhari-203 but those on Taichung (Native) 1 and Mudgo suffered less than 10 percent mortality. At 14 days after infestation more than 90

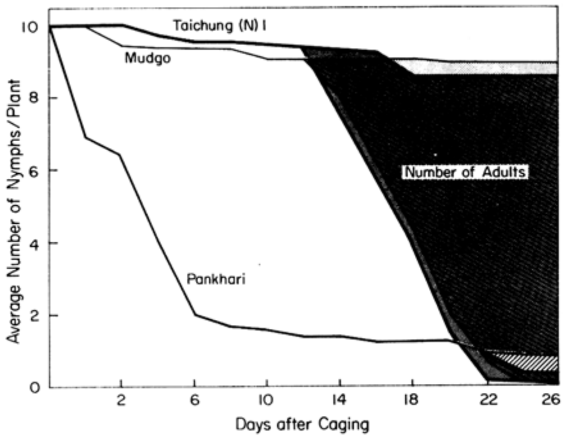


Fig. 12. Survival of freshly hatched *Nephotettix impicticeps* nymphs on three selected rice varieties. The rice plants were infested at 26 days after sowing. IRRI, 1967.

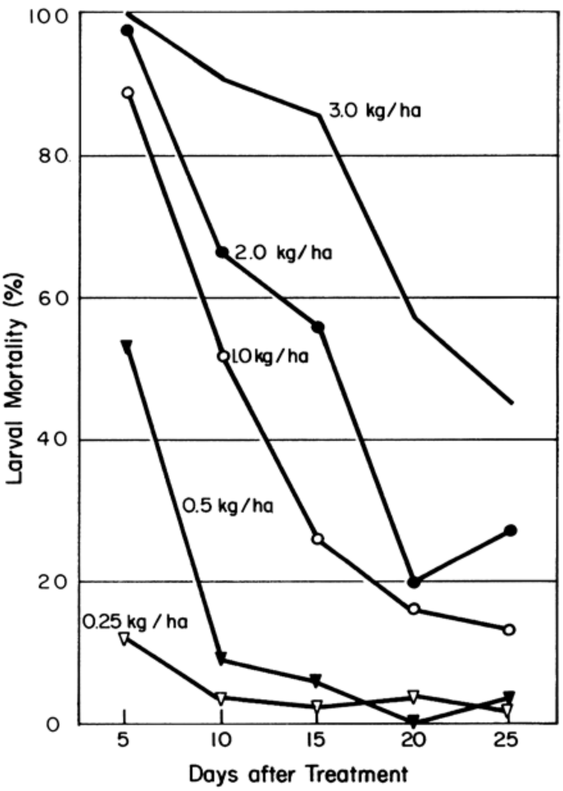


Fig. 13. Mortality of striped borer larvae caged for 48 hours on rice stems cut from plants treated with different rates of diazinon applied to the paddy water. IRRI, 1967. (Average of two experiments, replicated 9 times with 10 newly hatched larvae per treatment.)

percent of the nymphs were alive on Taichung (Native) 1 and Mudgo in contrast to only 14 percent on Pankhari-203 (Fig. 12). The nymphs caged on Taichung (Native) 1 and Mudgo became adults from 16 days onwards after caging while on Pankhari-203, no adults developed until 24 days after caging.

The resistance of Pankhari-203 to the green leafhopper followed almost the same pattern as that of Mudgo to the brown planthopper. Most of the green leafhoppers died within the first few days after caging, indicating factors of resistance similar to those in Mudgo to the brown planthopper. The low survival of nymphs on Pankhari-203 is also significant because this variety has been recorded as highly resistant to the tungro virus disease, transmitted by the rice green leafhopper, *N. impicticeps* (Annual Report, 1965). However, although the green leafhopper adults also have reduced longevity on this variety, its resistance to these insects does not appear to be the primary factor of resistance to the tungro virus (see Plant Pathology section).

These results which revealed the highly specific resistance of Mudgo and Pankhari-203 to the brown planthopper and the rice green leafhopper, respectively, provide valuable information for basic studies on this subject and for the practical use of varietal resistance in controlling the green leafhopper and brown planthopper pests of rice.

Insecticidal Control of Common Insect Pests

Further investigations on diazinon

During 1967, diazinon was tested intensively in laboratory, greenhouse and field experiments to determine its optimum rate and frequency of application and residual periods when applied to different types of soils.

In greenhouse experiments the insecticide was mixed with the irrigation water of single potted IR8 plants at 30 days after transplanting. Each plant was given 2 liters of water containing the desired quantity of the insecticide. The effect of this treatment was bioassayed by caging freshly hatched striped borer larvae on 3-inch long pieces of plant tillers obtained from 1 to 2 cm above the water surface of each pot. Ten lavae were caged on each piece which 48 hours later was dissected to determine the larval mortality. The average percentages of mortality were adjusted by using Abott's formula: $\frac{x - y}{x} \times 100$

where x and y represent the percentages of living larvae on untreated and treated plants, respectively.

Initial effectivity and residues of different rates on newly hatched striped borer larvae

In experiments using different rates of diazinon, more than 90 percent larval mortality was recorded on plants treated with 1 to 3 kg/ha a.i. (Fig. 13) at 5 days after treatment. Even as low a rate as 0.5 kg/ha caused more than 30 percent larval mortality but at 0.25 kg/ha, no significant mortality was recorded. More than 96 percent larval mortality was recorded on plants treated with 3 kg/ha of diazinon up to 15 days from treatment compared to only about 50 percent mortality on plants treated with 2 kg/ha. However, the residual effect of diazinon at lower rates was much shorter.

Effectivity of different rates of diazinon on striped borer larvae of different ages

The effect of different rates of diazinon on the striped borer larvae of different ages was also investigated in the laboratory and in the greenhouse. In greenhouse experiments, individual potted IR8 plants at 40 days after transplanting were artificially infested with 10 freshly hatched striped borer larvae. At different intervals after infestation, these plants, in separate treatments, were treated with different rates of diazinon mixed with the irrigation water. They were dissected 5 days later to record larval mortality. In the laboratory experiments, larvae of different ages cultured on rice stalks were caged in glass vials on tillers from plants treated with different rates of diazinon. Both procedures generally gave identical results except that in the laboratory tests larval recovery was almost 100 percent while in greenhouse experiments it was only about 50 percent. This was due to some natural larval mortality from the time of infestation to the time observations were made and also because some larvae migrate off the uncaged plants.

The results showed that even at such low rates as 0.25 and 0.5 kg/ha, diazinon caused more than 50 percent mortality of 5- to 10-day-old larvae but less than 20 percent mortality of larvae beyond this age at either rate (Fig. 14). Although at 1 kg/ha diazinon effectively controlled 5- to 10-day-old larvae, it caused more than 50 percent mortality of 20-day-old larvae only at rates of more than 2 kg/ha.

Effect on rice plants of paddy water application of diazinon

In almost all field experiments the diazinon-treated plots appeared greener and showed more luxuriant plant growth than the adjacent plots which had received similar treatments except diazinon. This common observation in fields where insect infestations did not cause visual differences in plant growth suggested the possibility that diazinon has some plant growth-stimulating effects. To verify this, diazinon-treated and untreated potted plants of IR8 were grown under insect-free conditions in a greenhouse. Frequent observations made on these plants from 15 days after transplanting until maturity showed no significant differences either

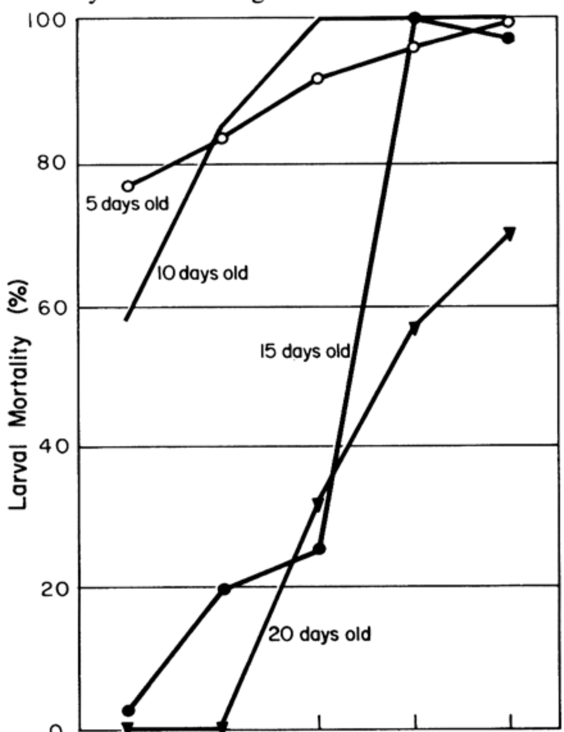


Fig. 14. Mortality of striped borer larvae of different ages caged for 48 hours on rice stems cut from plants treated with different rates of diazinon applied to the paddy water. IRRI, 1967. (Average of 6 replications each consisting of 10 larvae.)

Table 6. Mortality* of freshly hatched *Chilo suppressalis* Walker larvae on plants growing in soils treated with diazinon at the rate of 2 kg/ha a.i. IRRI, 1967.

Soil type	pH	Larval mortality (%)†				
		1‡	5‡	10‡	15‡	20‡
Maahas	6.6	81.80	75.3	37.26	10.38	2.0
Luisiana	4.6	70.54	92.87	97.30	72.98	6.03
Calcareous	7.6	51.42	84.50	88.75	67.91	54.58
Tungshan	5.8	29.79	72.01	53.30	28.71	—
Shuchia	7.81	65.64	89.73	91.21	79.4	1.02
Casiguran	4.8	45.44	44.79	43.58	17.91	0.0

*Average of five replications each consisting of 10 test insects. The experiment was conducted twice.
†Larval mortality adjusted using Abott's formula.
‡Days after treatment.

in plant height, number of tillers per hill or length of the roots of plants in different treatments. These indicate that the application of diazinon to the paddy water does not have a growth-stimulating effect on rice plants, and that the obvious differences in plant growth between diazinon-treated and untreated plots resulted from the protection of treated plots from insect infestation.

Effectivity of diazinon on rice plants grown in different types of soils

In previous experiments the effectivity of applying diazinon to the paddy water was investigated by applying it to Maahas clay soil. Its insecticidal activity was further evaluated in plants growing in such other soils as Luisiana, calcareous, Tungshan, Shuchia and Casiguran, which are representative of common rice soils of Southeast Asia.

Diazinon is more stable under alkaline conditions but is slowly hydrolized in acidic media; this was shown by its effectivity on different soils in this experiment. It not only exhibited high initial effectivity on plants growing in alkaline soils, such as calcareous and Shuchia, but also had the longest residual effect (Table 6). Its residual period, however, was considerably reduced on Tungshan and Casiguran, which have a pH of 5.8 and 4.8, respectively. The comparatively longer residual period of diazinon on Luisiana soil in spite of its low pH of 4.6 suggests that factors other than pH also affect its residual period.

Similar studies on γ-BHC (Annual Report, 1966) have shown its lower stability on alkaline soils, particularly calcareous soils. The longer stability of γ-BHC and diazinon under acidic and alkaline conditions, respectively, give a wider scope for the choice of one of these compounds to suit various kinds of rice soils.

Search for Newer, More Effective Insecticides

During the year about 40 new insecticides were evaluated in laboratory and field experiments for their effectivity in controlling insect pests of rice.

Seed treatments

The test compound was thoroughly mixed at the rate of 2 kg of active ingredient per 100 kg of IR8 seed. The wettable powder and emulsifiable concentrate formulations were first mixed with water adequate to saturate the seeds being treated. Methyl cellulose was then added to this mixture to make a 1-percent sticker solution. This was sprayed with a fine droplet atomizer on the seeds rotating in a cement mixer. For granular formulations, the seed was first wetted as described above with a 1-percent sticker solution and thoroughly mixed with the granules in a cement mixer.

Laboratory evaluation of seed treatments on rice green leafhopper control

The treated seeds were grown in 1 x 12-inch test tubes. At 11 and 20 days after sowing, the seedlings in the test tubes were caged with 2- to 4-day-old *Nephotettix impicticeps* adults. Insect mortality was recorded at 24 hours after caging.

Several treatments seriously reduced seed germination. Further studies are under way to determine whether these reductions were due to the formulations used or to the phytotoxic nature of the compound. It is highly significant that seed treatments with several compounds such as gusathion, ortho bux, dursban and terracur at 20 days after sowing caused more than 90 percent leafhopper mortality and several others also caused more than 50 percent insect mortality (Table 7). Although it is not known whether the mortality was due to the systemic effects of the compounds or to the vapors emitted by the toxicants on the seeds, the result is of great practical value in protecting the seedbeds or direct-seeded crops from the rice green leafhopper.

Effect of seed treatment on insect pest control in upland rice

The treated seeds were air-dried for 48 hours and drilled at the rate of 80 kg/ha in rows 30 cm apart in 4 x 8 m plots of upland rice fields. The seeds which did not receive any insecticidal treatment constituted the controls. Four replications were made, using a randomized complete block design.

The effect of different treatments on seed germination and number of seedlings damaged by various insects was recorded by counting the seedlings in a 1-meter long area in each of the three randomly selected rows at 13, 29 and 40 days after sowing. The crop was also graded visually for its percentages of germination and general crop growth at 10 and 29 days after seeding.

The treatments using roxion, No. 47470, No. 47031 and murfotox completely prevented the rice seeds from germinating while such other compounds as ortho-bux, A-3010, A-605 and S-6626 caused less than 10 percent germination. At 13 days after seeding the treatments with about 13 different compounds out of the 21 different insecticides tested effectively protected the crop from dead heart damage. At 29 days after seeding, the plots sown with seeds treated with dursban, terracur, temik, surecide, salithion and unden had significantly lower percentages of dead hearts than the controls (Fig. 15). These results are significant in that by seed treatment, which is both economical and convenient, the crop can be protected for up to 1 month from stem borer damage. Furthermore, the compounds dursban, terracur and surecide effec-

Table 7. Mortality of *Nephotettix impicticeps* adults caged for 24 hours on rice seedlings grown from seeds treated with different insecticides. IRRI, 1967.*

Insecticide†	Formulation	Seed germination (%)	Leafhopper mortality (%)	
			11‡	20‡
Cidial	50EC	50	77.5	27.67
Gusathion	5G	60	100.0	100.0
Cyanox	5G	60	72.72	38.22
Lannate	5G	60	9.65	0.0
Temik	10G	100	100.0	83.56
Nexagan	80EC	80	14.34	48.85
Methyl parathion	10G	50	85.68	75.89
Ortho Bux	10G	20	100.0	100.0
Perthane	45EC	90	42.04	36.98
Rothane	50WP	100	14.09	34.24
Salithion	5G	80	4.12	6.06
Surecide	5G	100	29.43	51.46
Unden	5G	100	100.0	78.08
Dursban	24EC	40	92.32	90.86
VCS 506	36EC	70	5.03	9.58
Terracur	10G	90	100.0	96.86

*Average of ten replications. Each replication contained 10 *N. impicticeps* adults.
†At rate of 2 kg/100 kg of rice seeds. The seeds treated with murfotox, A 3010, E 605, No. 47470, No. 6538 and roxion did not germinate.
‡Days after sowing.

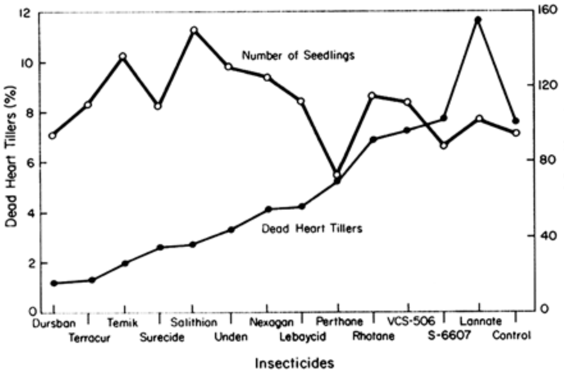


Fig. 15. The effectivity of various insecticides when used as seed treatment at rates of 2 kg/100 kg of seed in protecting the crop from stem borers. The observations were made at 29 days after seeding.

tively controlled the rice green leafhopper and protected the crop from dead hearts (Table 7, Fig. 15). These offer possibilities for a simple and practical method of controlling insects and of protecting the seeds from ants, mole crickets, soil grubs and other insects which affect the establishment of the direct-seeded crop.

Paddy water application: greenhouse experiments

The test compounds were applied at the rate of 2 kg/ha to the water of individual potted IR8 plants at 40 days after transplanting. At 3, 5, 10, 15, 20, and 25 days after the insecticidal treatment, individual tillers from treated plants were caged in 1 x 12-inch test tubes with 2- to 5-day-old rice green leafhopper adults. Ten leafhoppers were caged on each tiller and their mortality was recorded at 24 and 48 hours after caging. The experiment was replicated 5 times.

At 3 days after the treatments, high leafhopper mortality was recorded on tillers from plants treated with temik, CA 6757, terracur, UC 30044, unden, lebaycid and S 6607 (Table 8). Except S 6607, all these compounds effectively controlled the leafhoppers up to 15 days after treatment. Terracur had the longest residual effect, causing more than 75 percent leafhopper mortality throughout the test period of 25 days from treatment. Significantly, this compound, when used in seed treatment, also highly effectively controlled the rice green leafhoppers.

Treatments with other compounds caused generally inadequate mortality to bring about effective insect control under field conditions.

Field experiments

Twenty-nine insecticides were screened in field experiments for their effectivity in controlling insect pests of rice. These were applied at rates of 2 kg/ha at 20-day intervals to the paddy water of 5 x 8-meter plots of IR8. Each treatment was replicated three times. Quantitative data were obtained on stem borer, leafhopper, planthopper and virus incidence; in addition, the plots were graded visually for the incidence of stem maggots, leaf folders, hopper-burn, and for general crop growth. The latter observation referred to the over-all stand of the crop and can be used to indicate the yielding ability of the plots. This was particularly helpful as a severe typhoon, near crop harvest, damaged several plots, resulting in incomplete yield data.

The incidence of the rice leaf whorl maggot, *Hydrellia* sp., was severe during this experiment. The occurrence and economic significance of this pest generally has not been realized but it occurs over most of Southeast Asia and often severely infests the rice crop shortly after transplanting. The maggots feed on the unopen central whorl of the leaf by nibbling the innermost margin of the leaf blade. Heavy infestations cause marked stunting and uneven plant growth. Diazinon, dol mix, dursban and No. 47470 provided highly effective control (Fig. 16). Also, the compounds unden, terracur and methyl parathion had high initial effectivity but comparatively shorter residual effects.

The plots treated with the compounds dursban, diazinon, S-6626, methyl parathion and dol mix had less incidence of leaf folder, *Cnaphalocrosis medinalis* (Gúen), which was severe in the other treatments and in the control plots.

At 40 days after transplanting all treated plots had significantly lower percentages of dead hearts than the controls. Furthermore, most treated plots had lower stem borer populations. The larval population, determined by dissecting the infested tillers both at 39 and 99 days after transplanting, was comprised predominantly of *Tryporyza incertulas*, followed by *Chilo suppressalis*, *Sesamia inferens* and *Chilotraea polychrysa*. Generally the larval population of different species was too low to indicate the differential effectivity of various insecticides.

Table 8. Mortality of *Nephotettix impicticeps* adults caged for 24 hours on tillers from IR8 rice plants irrigated with 2 kg/ha rate of different insecticides. IRRI, 1967.

Insecticide	Leafhopper mortality* (%)					
	3†	5†	10†	15†	20†	25†
Temik	91.83	91.48	47.72	74.41	8.88	10.0
CA 6757	90.0	94.28	81.25	53.06	19.14	6.66
Terracur	89.79	93.61	90.9	97.67	91.11	76.0
UC 30044	85.71	95.74	75.0	74.41	48.88	24.0
Unden	69.38	95.74	43.18	69.76	26.66	28.0
Lebaycid	67.34	74.46	29.54	37.20	22.22	2.0
S 6607	65.30	36.17	0.0	0.0	22.22	2.0
Lannate	44.89	8.51	9.09	0.0	0.0	4.0
No. 47470	38.77	27.65	15.90	34.88	8.88	12.00
S-6626	16.32	0.0	0.0	9.30	17.77	6.0
Gusathion M	14.28	4.25	6.81	2.32	0.0	4.0
M 3182	14.28	6.38	0.0	0.0	6.66	8.0
No. 47031	14.0	42.85	8.33	8.16	2.12	0.0
Niran	6.12	8.51	0.0	2.32	6.66	4.0
Ortho Bux	6.0	25.71	4.16	2.04	4.25	0.0
B 5607	6.0	5.71	0.0	0.0	0.0	22.22
VCS 506	4.28	2.12	0.0	0.0	0.0	4.0
Murfotox	4.0	34.28	4.16	6.12	0.0	0.0
CA 6756	4.0	0.0	4.16	2.04	0.0	8.88
Gusathion E	2.0	34.28	14.58	18.36	19.14	8.88
Cidial	2.0	2.85	0.0	4.08	0.0	0.0
Salithion	0.0	22.85	2.08	10.2	0.0	2.22
Cyanox	0.0	37.14	0.0	8.16	4.25	14.88
Surecide	0.0	22.85	4.16	8.16	2.12	0.0
CA 6760	0.0	20.0	0.0	0.0	2.12	0.0
Endosulfan	0.0	22.85	0.0	2.04	6.38	0.0
B 5607	0.0	0.0	2.27	32.55	15.55	12.0

* Each figure represents average of five replications of 10 leafhoppers caged on individual tillers from treated plants. Mortality was adjusted using Abott's formula. Results obtained at 48 hours after caging followed the same general trend as at 24 hours after caging.
†Days after treatment.

However, the disproportionate abundance of certain species such as *S. inferens* larvae in S-6626, methyl parathion, and dol mix plots or *C. polychrysa* larvae in plots treated with salithion and No. 47470 indicates the lower effectivity of these compounds in controlling these species. Earlier experiments have confirmed that γ-BHC does not effectively control *S. inferens* larvae. Since the dol-mix used in this experiment contains γ-BHC as an active ingredient these data agree with previous findings.

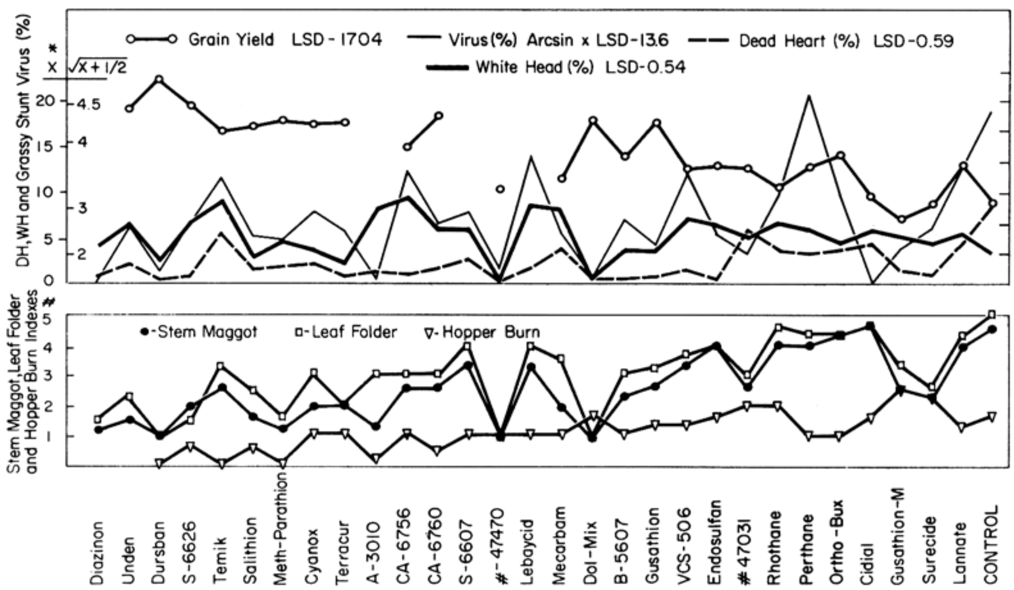
Except in plots treated with dol mix and No. 47470, which had low white head incidence, the percentages of white heads were high in all other treatments and did not differ significantly from those in the control plots. They were even higher in plots treated with temik, A-3010, CA 6756, lebaycid and mecarbam than in the controls. Such higher incidence of certain pests in treated plots, also observed in several other experiments, apparently is due to the ineffectivity of a treatment for certain species which are more attracted to these treatments than to the control plots damaged by other insects, but cannot be controlled.

A knapsack insect suction net was used to get a sample of leafhoppers and planthoppers. Two rows in each plot were sampled by passing the collection-nozzle from the base up to three-fourths the height of each alternate hill in the sampled row. During this experiment, *Inazuma dorsalis* and *Nilaparvata lugens* were the most abundant of the various leafhopper and planthopper species. The first and second leafhopper counts at 5 days before and 4 days after the insecticidal treatments, respectively, showed the

Table 9. Rice insect pest control effectivity of various insecticides applied to the paddy water at the rate of 2 kg/ha a.i. The treatments were made on 6, 26, 50, 76 and 96 days after transplanting. IRRI, July to November, 1967.

Visual grading* Stem maggot 18†	Stem maggot 24†	Stem maggot 43†	Gen. crop growth 59†	Gen. crop growth 101†	Grain yield (kg/ha) 102†	Insecticide	Formulation	Larvae recovered from 20 infested tillers Total 39†	Total 91†	Av. % of different borer species *C. suppressalis*	*T. incertulas*	*S. inferens*	*C. polychrysa*	Leafhoppers and planthoppers/2 rows of each test plot Total 45†	Total 54†	Av. % of different leafhopper and planthopper spp. *I. dorsalis*	*Nephotettix spp.*	*N. lugens*	*S. furcifera*
1.0	1.0	1.3	1.6	1.0	‡	Diazinon	10G	1.2	4.6	0.0	71.7	12.5	15.7	5.6	10.3	34.3	0.0	65.6	0.0
1.6	4.3	1.6	2.3	1.0	5731§	Unden	5G	2.3	4.6	24.7	71.9	0.0	3.2	4.6	5.6	10.5	0.0	83.9	5.4
1.0	1.0	1.0	2.0	1.3	6761§	Dursban (Dow)	5G	0.3	7.2	52.0	45.8	2.0	0.0	4.0	8.3	31.2	7.6	61.0	0.0
1.5	3.3	2.0	2.3	1.6	5936§	S-6626 (Sandoz)	5G	0.3	2.3	0.0	43.4	56.5	0.0	6.6	7.6	19.2	2.8	77.7	0.0
1.1	4.0	2.6	3.0	1.6	5098§	Temik	10G	4.9	1.6	42.4	57.7	0.0	0.0	7.3	10.0	25.6	6.9	63.2	4.1
2.0	4.3	1.6	2.6	1.6	5173§	Salithion	5G	0.6	0.6	25.0	0.0	25.0	50.0	11.3	14.0	32.1	5.5	58.7	3.4
1.6	4.3	1.3	3.0	1.6	5318§	Methyl-Parathion	10G	1.9	5.9	10.4	52.7	36.7	0.0	5.0	7.3	25.3	18.4	52.6	3.4
1.6	3.3	2.0	3.0	2.0	5391	Cyanox	5G	0.6	1.3	50.0	38.4	11.5	0.0	8.3	20.0	33.8	1.8	56.3	7.8
1.0	2.0	1.6	2.6	2.3	5363§	Terracur	10G	1.3	1.0	0.0	87.5	0.0	12.4	4.0	16.0	8.9	8.0	78.8	3.6
1.0	2.6	1.3	2.3	2.0	‡	A-3010 (Geigy)	28EC	1.6	9.5	11.4	75.3	3.1	9.9	7.0	16.3	27.9	0.0	69.4	2.5
1.5	3.6	2.6	3.0	2.0	4555§	CA-6756 (Cela)	10G	2.6	7.2	4.1	76.4	11.2	6.9	11.3	14.0	32.1	5.5	58.7	3.4
1.3	2.0	2.6	3.0	2.0	5541	CA-6760 (Cela)	10G	4.2	10.5	5.2	61.6	21.5	11.4	4.6	20.0	26.6	0.0	61.6	11.6
2.0	4.3	3.3	3.6	2.0	‡	S-6607 (Sandoz)	5G	5.6	5.9	25.6	71.8	0.0	2.5	11.0	15.0	20.3	8.3	68.5	2.3
1.0	1.0	1.0	2.0	2.0	3152§	No. 47470 (Cyanamid)	10G	2.3	2.0	0.0	0.0	21.4	78.5	5.0	36.0	7.6	3.1	82.9	6.2
1.8	4.0	3.3	2.6	2.0	‡	Lebaycid	5G	1.6	5.6	9.9	90.0	0.0	0.0	5.6	11.3	29.9	2.7	64.5	2.7
1.1	3.0	2.0	3.0	2.0	3450§	Mecarbam	4G	2.0	2.6	25.0	69.2	5.7	0.0	5.3	21.3	16.2	0.0	77.9	5.7
1.0	1.3	1.0	1.0	2.3	5456§	Dol Mix (Nihon Nohyaku)	6G	2.0	0.6	25.0	0.0	75.0	0.0	4.6	21.0	38.2	0.0	58.0	3.2
1.0	2.3	2.3	2.3	2.3	4269	B-5607 (Bayer)	5G	0.0	2.5	12.0	64.0	24.0	0.0	5.6	32.0	18.9	8.9	59.9	12.0
1.0	2.6	2.6	3.0	2.3	3875§	Gusathion E	5G	0.3	0.6	0.0	100.0	0.0	0.0	6.6	25.0	12.4	2.9	77.0	7.5
2.0	3.0	3.3	3.0	2.6	3853§	VCS-506 (Velsicol)	5G	1.3	7.5	4.0	90.0	2.0	4.0	4.0	25.0	27.6	9.8	53.3	9.0
1.8	4.6	4.0	3.3	3.0	3810§	Endosulfan	6G	4.0	3.9	50.0	46.1	3.8	0.0	14.3	63.0	15.0	5.3	74.5	5.0
2.0	4.0	2.6	3.0	3.0	1256	No. 47031 (Cyanamid)	10G	0.6	2.6	5.7	88.4	5.7	0.0	5.0	47.3	14.5	6.5	72.5	6.2
3.0	4.6	4.0	4.0	3.0	3266§	Rhothane	50WP	2.0	1.0	0.0	100.0	0.0	0.0	18.0	54.3	9.5	9.2	75.7	5.0
3.0	5.0	4.0	3.3	3.0	3860§	Perthane	45EC	3.6	4.6	31.8	64.8	0.0	3.2	10.0	18.6	16.4	10.7	67.5	5.1
2.4	5.0	4.3	3.6	3.0	4203§	Ortho Bux	10G	6.3	2.6	10.3	78.1	5.7	5.7	12.3	22.0	18.5	9.3	65.0	7.0
2.3	4.3	4.6	3.6	3.3	2949§	Cidial	5G	5.3	6.6	7.5	90.1	2.2	0.0	14.0	37.3	15.6	5.0	68.0	11.2
2.1	4.0	2.6	3.3	3.3	2210‖	Gusathion M	5G	0.6	2.0	0.0	75.0	25.0	0.0	9.3	100.3	20.5	0.4	72.3	6.6
1.5	3.3	2.3	2.6	3.3	2695‖	Surecide	5G	2.6	2.2	18.3	68.0	6.8	6.8	12.6	77.3	21.4	20.4	57.4	0.1
2.6	4.6	4.0	4.0	3.6	3815‖	Lannate	5G	3.9	4.2	3.8	81.3	7.6	7.1	14.0	25.0	11.4	3.6	72.2	12.6
3.0	5.0	4.6	5.0	4.0	2639‖	Control	—	4.3	6.3	15.3	82.2	2.3	0.0	20.3	95.0	10.3	6.2	76.8	6.4
LSD					1704			1.0	0.93‖					1.1‖	1.9‖				

*Smaller number indicates lower incidence or better crop growth.
†Days after transplanting.
‡Yield not available as the crop was damaged by a typhoon.
§Two replications only.
‖Calculated after transforming the data to $\sqrt{x+½}$. Data presented is not transformed.



* The LSD values for dead heart, white head and virus calculated after transforming the data to $\sqrt{X+1/2}$

\# Based on visual grading, low number denotes low incidence

Fig. 16. The effectivity of paddy water application of different insecticides at 2 kg/ha every 20 days in controlling rice insect pests on variety IR8. IRRI, 1967.

residual effectivity of the previous application (made 19 days before the count) and the immediate effects of various compounds on the existing population.

These data show that most treated plots had significantly lower leafhopper and planthopper populations than the controls. Although a fourfold increase in leafhopper and planthopper populations in the control plots was recorded 9 days after the first observation or 4 days after the next insecticidal treatment, the populations in plots treated with diazinon, unden, dursban, S-6626, temik, methyl parathion, and lebaycid were 9 to 10 times lower than those in control plots and showed very little increase from the previous sampling. In subsequent observations, these plots, except those with S-6626 and lebaycid, also had low brown planthopper populations which caused hopper-burn in most of the other treated plots and in the controls (Fig. 16). These compounds showed no distinct differences in toxicity to the common leafhopper and planthopper species (Table 9).

In all but a few treatments virus incidence was significantly lower than in the control plots (Fig. 16). Less than 5 percent of the plants treated with diazinon, dursban, methyl parathion, No. 47470, dol mix and cidial were infected with virus, predominantly grassy stunt, while 27.8 percent of the plants in the control plots were infected. This, about 80 percent reduction in virus incidence in treated plots, is significant because in most other crops insecticidal treatments generally fail to give protection against infection of viruses that persist in their vectors, to which type grassy stunt belongs.

As stated earlier, no complete yield data is available from this experiment because of the damage caused by a severe typhoon just before harvest. However, the data on the incidence of various pests and virus infection and on the visual grading of crop growth at maturity and the available yield data supplemented each other to show the generally high effectivity of dursban, diazinon, unden and S-6626.

Foliar spray

Each compound was tested as a foliar spray for its initial and residual effectivity in controlling the rice green leafhopper. Using a fine droplet atomizer at a pressure of 10 lb/sq in, 12 ml spray was applied uniformly on 30-day-old potted

Table 10. Mortality of *Nephotettix impicticeps* adults caged on plants sprayed with different insecticides. IRRI, 1967.

	Mortality of test insects†									
	24 hours after caging					48 hours after caging				
Insecticide*	1‡	5‡	10‡	15‡	20‡	1‡	5‡	10‡	15‡	20‡
CA 7755	97.95	87.75	64.0	43.22	12.5	100.0	86.95	75.0	43.22	14.89
No. 6607	97.95	8.16	4.0	—	—	97.87	17.39	0.0	—	—
N 4543	89.79	71.42	8.0	0.0	—	97.87	80.43	16.66	0.0	—
B 605	87.75	69.38	4.0	0.0	—	91.48	89.78	10.41	0.0	—
Surecide	75.51	48.97	0.0	0.0	—	93.61	60.86	33.33	0.0	—
I 6538	57.14	10.20	0.0	—	—	82.97	17.39	4.16	—	—
K 57	18.36	0.0	0.0	—	—	46.80	19.56	0.0	—	—
Elsan	12.24	8.16	0.0	—	—	46.80	23.91	0.0	—	—
Cyanox	12.24	12.24	0.0	—	—	25.53	39.13	4.16	—	—
Dursban	10.20	16.12	2.0	—	—	42.55	13.04	2.08	—	—
Cidial	8.16	0.0	0.0	—	—	19.14	6.52	0.0	—	—
Nexagan	8.16	0.0	0.0	—	—	36.17	19.56	2.08	—	—
Salithion	6.12	2.04	2.0	—	—	14.89	17.39	8.33	—	—
Ortho Bux	6.12	4.08	14.0	—	—	10.63	19.56	0.0	—	—
No. 47031	4.08	10.20	2.0	—	—	19.14	26.08	0.0	—	—
Rothane	4.08	14.28	4.0	—	—	48.93	39.13	8.33	—	—
No. 47470	2.04	0.0	2.0	—	—	40.42	13.04	2.08	—	—
Perthane	2.04	4.08	0.0	—	—	8.51	2.71	0.0	—	—
VCS 506	2.04	0.0	0.0	—	—	29.78	21.73	0.0	—	—
R 3422	2.04	0.0	2.0	—	—	21.27	23.91	4.16	—	—
C 9643	0.0	6.12	0.0	—	—	8.54	15.21	6.25	—	—

* All insecticides were applied as 0.04 percent spray except CA 7755 and B 605 which were used as 0.128 and 0.06 percent spray, respectively.
† Average of five replications each consisting of 10 test insects. Mortality was adjusted according to Abott's formula.
‡ Days after treatment.

plants rotating on a turntable. At desired intervals after this treatment, each of these plants in 6 x 26 inch cylindrical mylar cages was infested with ten 2- to 5-day-old rice green leafhoppers. Insect mortality was recorded at 24 and 48 hours after caging.

Several compounds such as CA 7755, No. 6609, N 4543 and B 605 showed high initial toxicity but most of them had short residual effects of not more than 5 days (Table 10). CA 7755 showed the longest residual effect, causing 43.2 percent leafhopper mortality at 15 days after treatment.

Effectivity of different rates and frequencies of γ-BHC and diazinon application

Several greenhouse studies described in earlier annual reports have shown that γ-BHC and diazinon, particularly the latter, can effectively control the rice stem borer and leafhopper even when used at as low a rate as 1 kg/ha. However, the residual effectivity at lower rates has been shorter than at higher rates. Therefore, in areas where the insects do not occur in overlapping generations this rate could be used if the treatment can be timed to coincide with the periods of occurrence of these pests. Experiments were also conducted to determine the optimum rates and frequencies of application at the Institute farm areas where the insects generally occur in overlapping generations throughout the year. In separate experiments, both γ-BHC and diazinon were used at six different rates, ranging from 0.5 to 2.5 kg/ha and at intervals of 20, 30 and 40 days.

In the dry season experiment, treatments of γ-BHC applied to the paddy water at 2 kg/ha every 30 days and supplemented with 0.1 percent carbaryl spray every 15 days, sevidol (1:1 mixture of γ-BHC and carbaryl), and birlane, also applied to the paddy water at 2 kg/ha every 30 days, served as the treated controls. However, in the wet season experiment, the plots treated with sevidol at 2 kg/ha applied every 20, 30 and 40 days in separate treatments, constituted the treated checks. In both experiments, the plots which were not treated with insecticides served as the untreated controls.

The experiments, using IR8, were conducted in 4.25 x 8 meter plots in three replications in a randomized complete block design. The blocks were used as replicates while the insecticides, rates and frequency of treatments constituted the subplots. All seedlings in the seedbed were treated with diazinon and starting at 5 days after transplanting, the respective insecticides were applied, continuing until the crop has matured.

The dry season experiment showed that for both γ-BHC and diazinon, the frequency of application was more important in increasing grain yield than the rate of application (Fig. 17). When treated every 20 days all plots which received γ-BHC or diazinon had significantly fewer dead hearts than most of the other plots treated every 30 or 40 days. However, the percentage of dead hearts among plots receiving different rates of either diazinon or γ-BHC did not differ significantly. Furthermore, when the γ-BHC and diazinon treatments were made every 30 or 40 days, the γ-BHC plots generally had fewer dead hearts than those treated with diazinon. A similar trend was recorded for white heads except that γ-BHC generally protected the crop from white heads more effectively than did diazinon. Also, diazinon treatments at rates lower than 1 kg/ha gave the crop little protection from white heads.

In this experiment, the high yields of 7,135 to 7,171 kg/ha were obtained in plots treated with 2.0-2.5 kg/ha of diazinon every 20 to 30 days. These yields, however, were not significantly higher than when only 1 kg/ha of the insecticide was used every 20 days. Therefore, when used at 1 kg/ha every 20 days, diazinon provided effective insect control. The grain yields obtained using the rate were identical to those of the plots which received 2.0 to 2.5 kg/ha every 20 to 30 days. The 1-kilogram rate also was more effective than any of the rates of diazinon applied every 40 days. The γ-BHC treatment also produced similar results. However, it controlled the brown planthoppers less effectively and many of the treated plots suffered severe hopper-burn.

The results of the wet season experiment

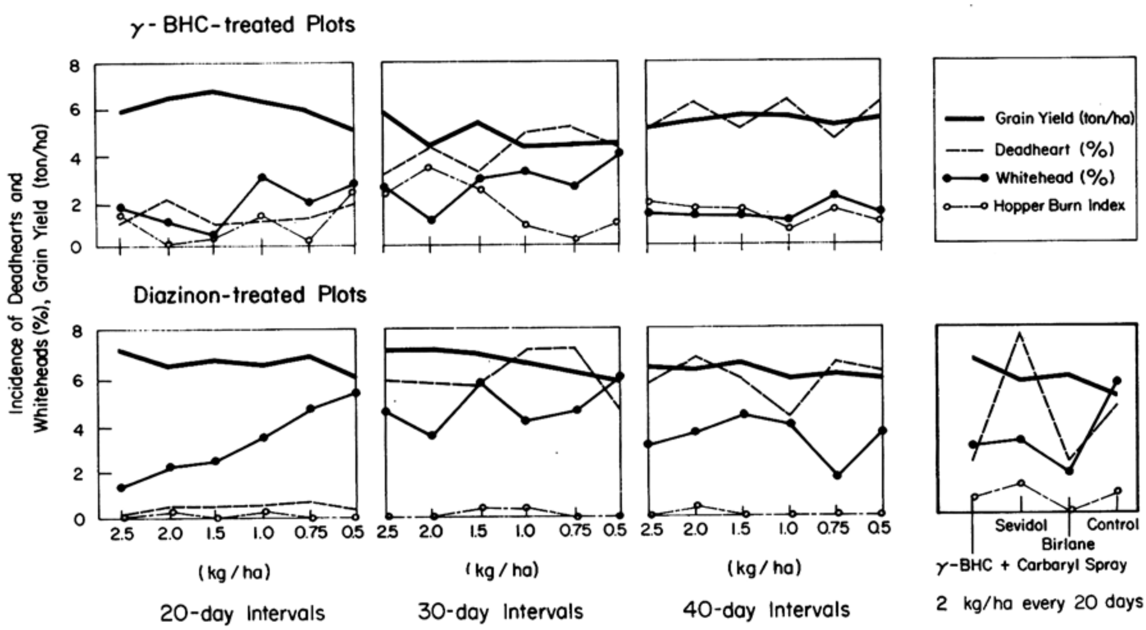


Fig. 17. Effect of different rates and frequencies of γ-BHC and diazinon application on stem borer and leaf whorl maggot control. IRRI, February to May, 1967.

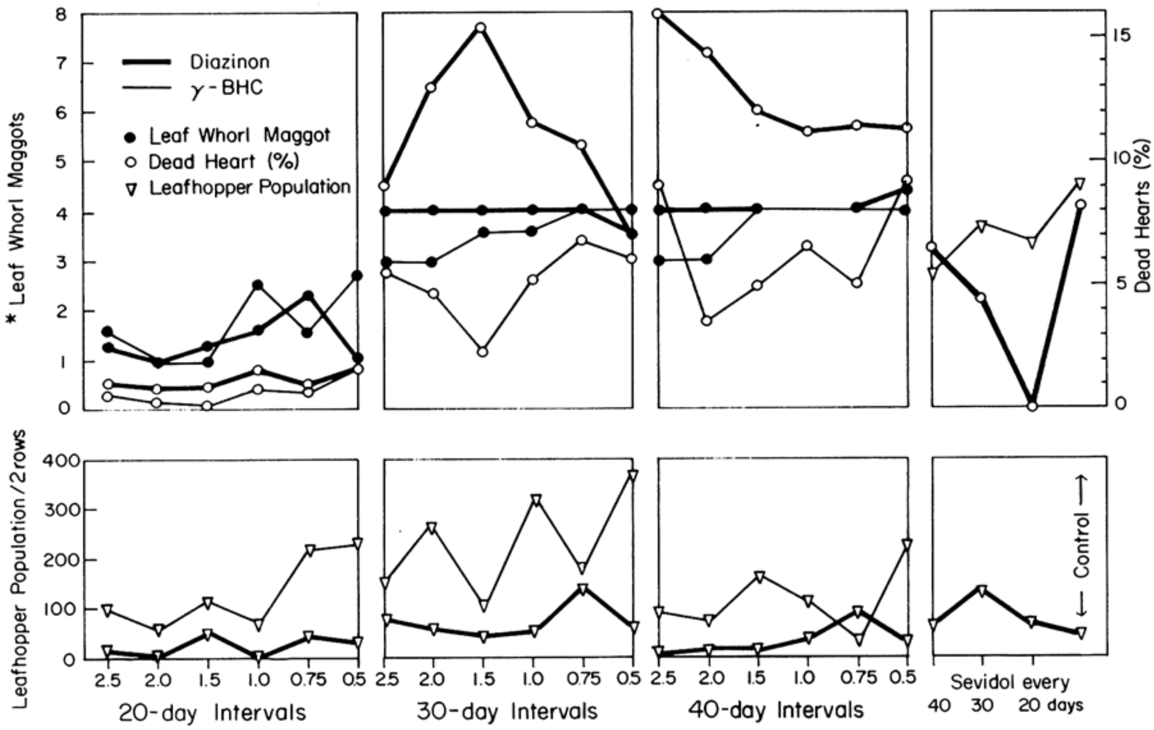


Fig. 18. Effect of different rates and frequencies of γ-BHC and diazinon application on stem borer and leaf whorl maggot control. IRRI, August to November, 1967. (Based on visual grading. Lower number denotes low incidence.)

generally agreed with those obtained during the dry season. They showed that the frequency of the insecticidal application using diazinon and γ-BHC was more important than the rate of application in reducing dead heart and rice whorl maggot incidence. However, diazinon was significantly more effective than γ-BHC in controlling leafhoppers and planthoppers for which both higher rates and shorter frequencies were important (Fig. 18). The treatments with γ-BHC at rates of 1 kg/ha and higher every 20 days also effectively reduced the leafhopper and planthopper populations. The application of both compounds at 20-day intervals was essential in controlling the maggots effectively but γ-BHC was more effective than diazinon when used at 30- and 40-day intervals. Unfortunately, no data on white head and yield could be taken as the crop was damaged by a severe typhoon.

The overall conclusion is that, when used at 20-day intervals, γ-BHC and diazinon are more effective in controlling the common insect pests of rice than when applied every 30 or 40 days. Except when used at 0.5 kg/ha, the differences in the rate of application were not as important at 20-day intervals as when applied at 30 and 40 days. At these latter intervals, lower rates were significantly less effective than 1.5 kg/ha or higher. Generally, diazinon treatments resulted in better yields than γ-BHC. This difference was mainly due to the brown planthopper infestation and severe hopper-burn suffered by the γ-BHC treated plots which explain the erratic yields in γ-BHC treatments. These data also illustrate that γ-BHC when used at rates of 0.5 and 0.75 kg/ha every 20 days was much less effective than when used at higher rates. Diazinon, however, when used every 20 days, except at 0.5 kg/ha, caused significant yield increases over the control plots but the differences in the yields of these treated plots were not significant. When used every 30 days, the 2 or 2.5 kg/ha diazinon treatments produced the highest yields, but lower rates and all other rates applied every 40 days produced erratic results.

Considering the over-all insect infestation, rice yields, and the capital input involved, the rates of 1 kg/ha for diazinon and 1.5 kg/ha for γ-BHC, applied every 20 days, appear to be the most appropriate for general field use.

Effect of timing and frequency of diazinon treatment on IR8 and Taichung (Native) 1

Data confirming the effectivity of diazinon when applied to the paddy water in controlling the rice green leafhopper and protecting the crop from the tungro virus have been recorded in the Institute's previous annual reports. In concurrent experiments, it was also reported that Taichung (Native) 1 under field conditions was about twice as susceptible to the tungro virus as IR8, and that virus infection on these varieties largely took place within the first 60 days after transplanting. Furthermore, both varieties under field conditions have shown equal susceptibility to stem borers.

With this information, an experiment was conducted during the 1967 dry season to find out the possibility of reducing the total number of diazinon treatments on these varieties.

However, it was the grassy stunt virus, and not tungro, which was prevalent during the experiment. IR8 and Taichung (Native) 1 exhibited equal field susceptibility to this virus and diazinon application to the paddy water provided both varieties with significant protection from virus infection (Fig. 19). Two seedling treatments were used—one treated with diazinon, at 2 kg/ha at seeding and again 15 days later for protection against leafhopper and planthopper infestations, and the other, not treated.

Virus incidence did not differ significantly between the seedlings protected and those not protected if the post-transplanting treatments were identical. Generally, a similar reaction was recorded for tungro virus incidence. The reasons for the apparent lack of need for seedbed treatment, although plants in the early seedling stage are much more susceptible to virus infection than older plants, are not fully understood. A possible reason might be the insect's lack of attraction to the seedbed or the comparatively fewer viruliferous insects in the seedbed.

Data collected at 20 and 40 days after transplanting revealed no significant differences in virus incidence among different treatments, but differences became evident at 60 and 90 days after transplanting. Generally, one to two diazinon applications, irrespective of timing, did not effectively reduce the virus incidence. Three applications significantly protected the crop from virus infection. There was no significant difference in virus incidence regardless of whether there were three or four treatments. Furthermore, the virus incidence was generally lower when the three applications were made consecutively from time of transplanting than when these were made with untreated periods. This indicates that both IR8 and Taichung (Native) 1 were more susceptible to virus infection within the first 60 days after transplanting. While earlier diazinon applications also significantly reduced the number of dead hearts caused by stem borers, the full yield potentials of the crop were not realized in the absence of a fourth treatment to protect it from white heads (Fig. 19). This latter application also protects

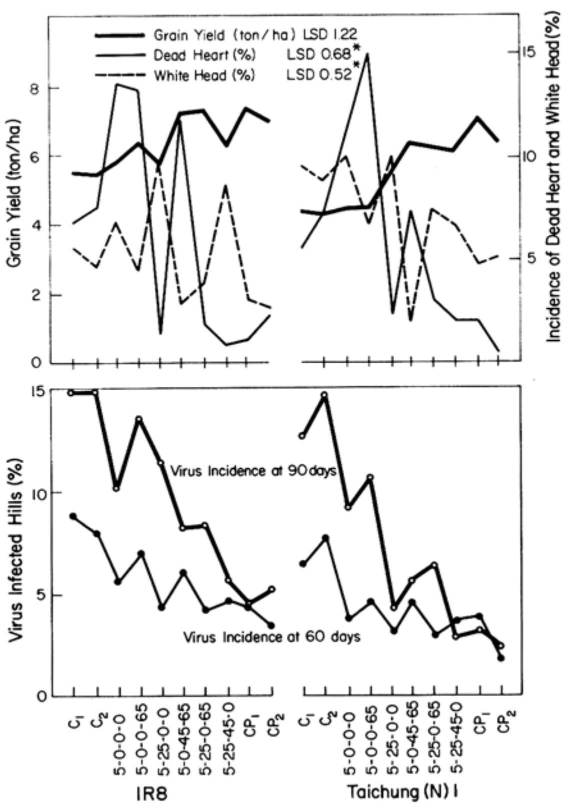


Fig. 19. Timing and frequency of diazinon application to the paddy water for rice insect pest control on varieties IR8 and Taichung (Native) 1. IRRI, 1967.

the crop toward maturity from leafhoppers, planthoppers and other insects.

Generally, the treated plots of both IR8 and Taichung (Native) 1 produced about 50 percent more rice than the controls. On both varieties, however, when the number of treatments was two or less, no significant yield increases over the control plots were recorded. These indicate that under intense infestations, an incomplete insect control program may have little value.

Effect of dipping seedling roots in insecticide solutions before transplanting

Insecticidal treatments in the seedbed or on the seedlings after uprooting them for transplanting are convenient in that only a small area need to be treated and less insecticide is used. Dipping the uprooted seedlings in some insecticide solutions just before transplanting, which is occasionally practised by some scientists and farmers, is known to provide protection against common insect pests for up to a week after transplanting. This method is both convenient and economical but extreme care must be taken not to use insecticides which have mammalian toxicity as contact compounds. The residual period of such treatments can be considerably prolonged provided that the insecticide is absorbed by the rice seedlings.

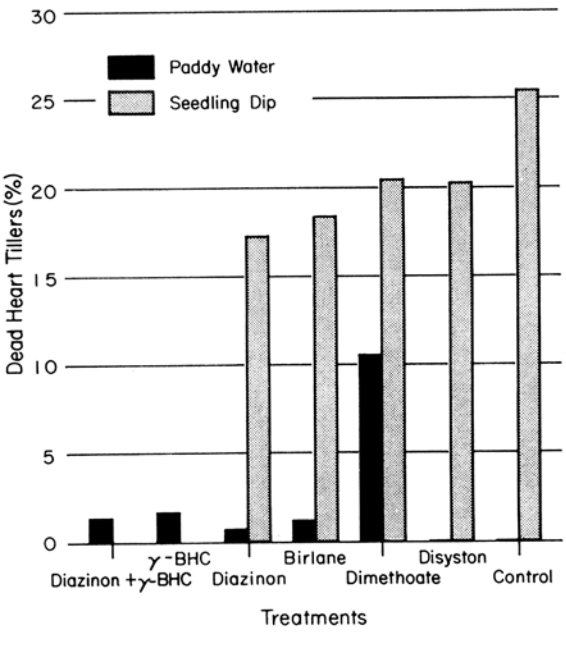


Fig. 20. Effect of dipping the roots in 6 ppm of various insecticide solutions for 24 hours before transplanting and of applying the insecticides to the paddy water at the rate of 2 kg/ha 5 days after transplanting on rice stem borer control. The data were recorded 56 days after transplanting. IRRI, October, 1966 to February, 1967.

To evaluate the effectivity of such treatments, the roots of rice seedlings prior to transplanting in a field experiment were dipped for 24 hours in 6 ppm solution of various test compounds. The effectivity of this treatment was compared with that of applying the same compound at 2 kg/ha to the paddy water of field plots planted with untreated seedlings. The study was conducted in 5 x 8 m plots in 4 replications. No distinct protection of the crop against such pests as the leaf whorl maggot and the stem borers resulted from the seedling dip treatment. While most plots in which insecticide was applied to the paddy water had less than 2 percent dead hearts caused by stem borers, the seedling-treated plots had more than 17 percent dead hearts (Fig. 20), not significantly different from the untreated plots which had 25 percent dead heart tillers. However, each of the test compounds when applied to the paddy water significantly reduced the percentage of dead heart tillers.

Residues of γ-BHC and Diazinon

Absorption, translocation and residues of γ-BHC in rice plants

As reported in the 1965 and 1966 Annual Reports, γ-BHC when applied to paddy water is absorbed and translocated into the different parts of the rice plant. It does not accumulate in any plant part, paddy water, or soil regardless of the rate or the number of treatments used, and the residues decline to low levels in about 30 days after treatment. The fate of γ-BHC residues beyond this period was investigated.

In greenhouse experiments, γ-BHC was applied at 3 kg/ha a.i. to the irrigation water of potted IR8 plants at 30 days after transplanting. At different intervals from the time of treatment, the γ-BHC content of the soils, water and various plant parts were determined in a gas chromatograph equipped with an electron capture detector. A high concentration of the insecticide was recorded in various plant parts, the highest being

of the toxicant (expressed in μg) in various plant parts was measured. The total amount of γ-BHC increased generally in all plant parts up to 20 days after treatment, after which it declined gradually. It appears, therefore, that the decline in the concentration of the insecticide was partly caused by dilution due to plant growth (as the ppm content of the insecticide in the plants starts descending generally 5 to 10 days after treatment), the major decline being due to the degradation of the compound. This decline was most evident up to 40 days after treatment, beyond which the loss was only gradual (Fig. 21). The total amount of γ-BHC in the roots did not decline appreciably throughout the experiment. This suggests the ability of roots to continuously pick up the insecticide from the soils. This is particularly evident from the much higher γ-BHC concentration in the roots than in the soils. Thus, the continuous uptake of γ-BHC by the roots and its translocation to the stem might have caused the slow decline of the insecticide in the straw.

Determining any off-flavor in root crops grown in γ-BHC-treated soils

The use of γ-BHC on upland crops has caused off-flavor in certain root crops when either treated directly or grown in rotation with other upland crops which had been treated with γ-BHC. Since non-significant amounts of γ-BHC were recorded in paddy soils at 30 days after treatment, it was assumed that no off-flavor would result in root crops if grown in rotation with rice in such fields. To verify this, sweet potatoes and taro, *Colocasia esculentum,* were grown in soils from plots previously treated with different rates of γ-BHC. Plants grown in soils never treated with γ-BHC constituted the controls. After harvest, the roots were analyzed for γ-BHC content; they also were boiled in water and evaluated for any off-flavor by a taste panel of nine persons.

The chemical analysis showed extremely low levels of γ-BHC in the samples. Significantly, there was no appreciable difference in the amount of residues present in the roots grown in the treated and untreated soils. Also, the residues recovered were of very low levels, and with the available information on the subject, are of almost negligible importance (Table 13). Also, except for one person, who reported some off-flavor in the sweet potatoes grown in the soils from γ-BHC-treated field plots, the taste panel recorded no distinct difference between the crops grown in treated and untreated soils. The reactions of the taste panel are given below. The + sign denotes preference while the − sign indicates that the sample did not taste normal.

Crop	Preference for samples grown in soils: Treated with γ-BHC at 48 kg/ha	As far known, never treated with γ-BHC	No difference
Sweet potato	−++	+++	+++
Taro	++	++++	++

Effect of cooking on γ-BHC residues in rice grain

As reported earlier, low levels of γ-BHC residues were recovered from polished rice, rice bran, and hulls obtained from plots treated with the toxicant at even much higher rates than those recommended. Significantly the amounts recovered are much below the permissible level for γ-BHC residues. An additional safety factor is the further reduction on boiling of α, β, γ and δ isomers by 56, 32, 46 and 40 percent, respectively (Fig. 22). This loss of various isomers was apparently due to volatilization on heating and not to any chemical degradation as neither any change in the retention time of different isomers nor any new peaks was recorded in the gas chromatograph.

Table 13. Gamma-BHC recovered from sweet potato and taro, *Colocasia esculentum* planted in soils from rice fields treated with varying amounts of γ-BHC. IRRI, 1967.

Rates of γ-BHC	γ-BHC (ppm) Sweet potato	Taro
24 kg/ha a.i.	0.010	0.024
48 kg/ha a.i.	0.018	0.026
γ-BHC†	0.008	0.010
Control‡	0.009	0.008

*Wet basis. Average of four replications.
†From untreated control plots of a field used for experiments on paddy water application of γ-BHC.
‡As far as is known the field was never treated with γ-BHC.

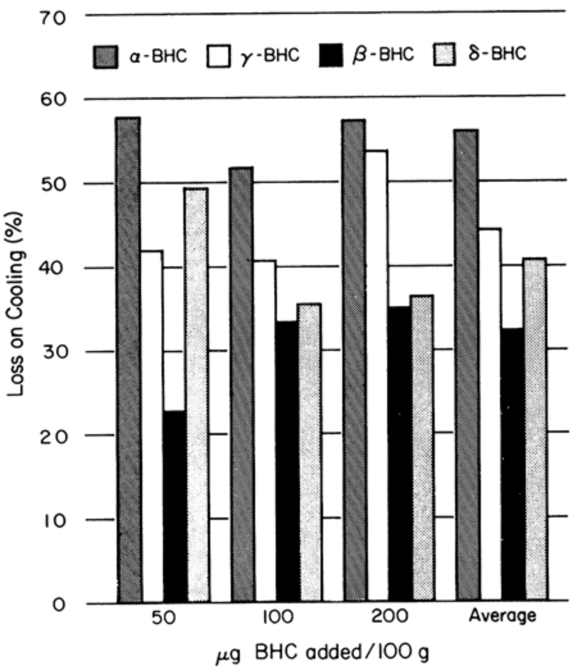


Fig. 22. Effect of cooking on the various isomers of γ-BHC present in 100 g polished rice. IRRI, 1967.

A known amount of the insecticide was added to a weighed sample of polished rice obtained from a field that had received no insecticidal treatment. The rice was cooked for 10 minutes in a rice cooker, cooled for 15 minutes and analyzed for residues in a gas chromatograph.

Residue studies on diazinon

During the year, studies on the persistence of diazinon in soils and paddy water and its absorption, translocation and residues in various plant parts were initiated.

The techniques of extraction and recovery of diazinon from water, soils and various plant parts have been standardized. Diazinon is extracted from the test samples by using acetone as a solvent and following the same general procedure as for γ-BHC. This procedure has shown 90 to 100 percent extraction efficiency. The diazinon content of the extract can be determined in a gas chromatograph fitted with an electron capture detector which is highly sensitive but not highly specific for organo-phosphorus compounds. Interference from other compounds, particularly the halogenated hydrocarbons, was a major limiting factor in this method. Therefore, a phosphorus detector instead of an electron capture detector is now being used for diazinon determination.

When applied to the paddy water at 2 kg/ha a.i., the concentration of diazinon in water one day after treatment was from 4 to 5 ppm. This declined to .007 ppm 20 days later. In the soils the highest concentration (0.137 ppm) was recorded also on the first day after treatment but was reduced to 0.013 ppm 20 days later. Only traces of the compound were recorded from the soils and water at 30 days after treatment when residues less than 0.05 ppm were recovered from polished rice, bran, hull or straw from field plots treated with diazinon at rates ranging from 0.5 to 2.5 kg/ha. The tolerance level for diazinon set by the U.S. Food and Drug Administration is 0.75 ppm.

Biological Control of Stem Borers

Studies on *Sturmiopsis inferens* Townsend

Further studies were conducted on *Sturmiopsis inferens,* a tachinid parasite of stem borers. This fly parasite is common in the Indo-Malayan region and is thus adapted to the warm humid climate. It was introduced by the Institute to the Philippines from India in July 1965, from which time it has been continuously reared in the laboratory to obtain basic information on its bionomics. Several releases of mated female flies have been made at five different sites in Luzon.

Parasitization of different stem borer species

This species parasitizes primarily the pink borer, *Sesamia inferens* Walker, although it also has been occasionally recorded to parasitize other rice borer species. Its ability to parasitize the common rice borer species and the oriental corn borer, *Ostrinia damoalis* (Hubn.), was investigated in laboratory experiments. The 5th to 6th instar borer larvae were artificially inoculated with fly maggots obtained by dissecting gravid females in a 0.10 percent saline solution. The inoculated larvae were caged on fresh rice stalks until they pupated (if not parasitized) or the parasite's puparia had formed.

The maggots parasitized 59 percent of the inoculated larvae of *Sesamia inferens* and 47 to 48 percent of *Chilo suppressalis* and *Chilotraea*

Table 14. Results of laboratory inoculations of *Sturmiopsis inferens* Townsend maggots on larvae of different rice borer species. IRRI, July, 1966 to October, 1967.

	No. of borer larvae			
	Inoculated	Recovered	Parasitized	Parasitization (%)
*Chilo suppressalis**	16788	15287	7207	47.14
Sesamia inferens†	1940	1592	943	59.23
Chilotraea polychrysa‡	560	481	235	48.95
Tryporyza incertulas	172	107	0	0
Ostrinia damoalis	30	25	0	0

*$X^2_{1,2}=84$
†$X^2_{2,3}=16$
‡$X^2_{1,3}=0.55^{n.s.}$

polychrysa but failed to parasitize *T. incertulas* and *O. damoalis* larvae (Table 14). The parasitization of *S. inferens* was significantly higher than those of *C. suppressalis* and *C. polychrysa* but the latter did not differ significantly among themselves. Also, the puparia obtained from *S. inferens* larvae weighed much more than those reared on *C. suppressalis* or *C. polychrysa*. Further experiments, where the host larvae used and the puparia obtained were weighed separately, suggested that the differences in the weights of puparia were more attributable to the weights

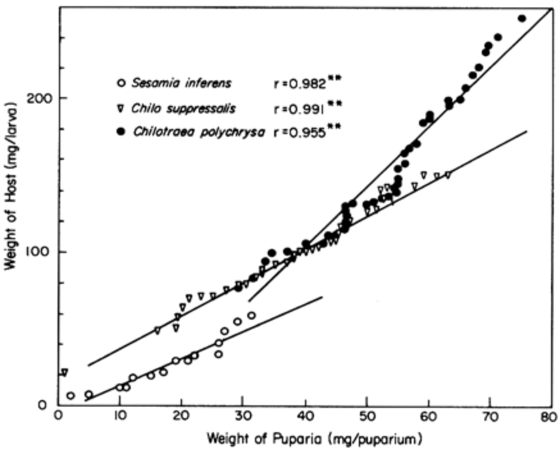


Fig. 23. Correlations between the weights of *Sturmiopsis inferens* puparia and the larvae of the host borer species. IRRI, 1967.

Table 15. Field releases of mated females of *Sturmiopsis inferens* and the subsequent recoveries of parasitized borer larvae. IRRI, 1967.

	No. of gravid females released	Date of release	Collection of samples (days after release)	No. of borers	
				Recovered	Parasitized
IRRI greenhouse	20	Sept. 27, 1966			
	18	Oct. 3, 1966	10-16	392	67
Farm	23	Oct. 12, 1966	19	50	0
	63	Dec. 24, 1966	30	248	0
		Feb. 15, 1967	52	223	0
		April 11, 1966	79	392	0
Bulacan					
San Miguel	25	Sept. 24, 1966	21	9	9
			23	2	2
	10	Oct. 15, 1966	31	10	0
	32	Dec. 16, 1966	50	400	4
Pangasinan					
Urdaneta	80	Dec. 13, 1966	22	140	7
			35	214	2
	54	Aug. 12, 1967			
Sta. Barbara	34	May 26, 1967	Samples could not be obtained because the crop at release-area was damaged by flood.		
Nueva Vizcaya					
Bambang	105	June 29, 1967	17	207	1
			31	104	1

Table 16. Laboratory inoculations of *Metagonistylum minense* maggots on larvae of different rice borer species. IRRI, 1967.

Parasite generation and borer species*	No. of borers			Parasitization (%)
	Inoculated	Recovered	Parasitized	
1st Generation				
C. suppressalis	2,015	1,743	6	0.3
S. inferens	344	291	0	0
C. polychrysa	113	84	2	0.4
2nd Generation				
C. suppressalis	212	195	2*	1.0
C. polychrysa	124	112	2*	1.8

*All emerging parasites were males.

of the host larvae rather than to their species (Fig. 23).

When reared at 27 ± 2 C and beyond 65 percent relative humidity the maggots took an average of 12 to 13 days to reach the pupal stage which lasted an average of 11.3 days, while the male and female flies lived for 12.9 and 13.5 days, respectively. No significant difference in the duration of the maggot period was recorded whether they were reared on *C. suppressalis* or on *S. inferens* larvae. These suggest that the three rice borer species tested were equally suitable hosts for this fly and the higher parasitization of *S. inferens* larvae as well as the higher weights of puparia developed on them were attributable to the larger size of the host larvae rather than to their species.

Field releases

To study their efficiency in parasitizing borer larvae feeding within rice plants, gravid females were released in a greenhouse containing rice plants artificially infested with a large number of striped borer larvae. Of the recovered borer larvae 17.35 percent were parasitized, indicating the ability of this species to locate and parasitize the striped borer larvae feeding within the rice stem (Table 15).

Following these results, a large number of laboratory-reared gravid females were released in 5 places. The release sites selected were areas with at least 500 hectares of rice fields, grew two rice crops a year so that borer larvae were available the year round, were places where stem borer species other than *T. incertulas* were also common, and where the farmers did not anticipate using insecticides.

The gravid females were taken to the release sites in 3 x 1 x 1 foot fine mesh nylon cages containing 20 percent honey solution and split resin as fly food. The top of the cage was opened and all flies were allowed to escape at one place.

Starting 2 to 3 weeks after the flies were released periodic samples of infested rice plants were collected to recover the laboratory-reared borer larvae. Significantly, parasitized borer larvae were recovered at most release sites, indicating the ability of the fly to parasitize in nature under Philippine conditions (Table 15). The recovery of parasitized larvae at two different sites beyond 30 days after the gravid females' release is encouraging. It establishes that the parasitization was caused by the second generation of the released flies. The non-recovery of parasitized larvae at the Institute could be atributed to the intensive use of insecticides on its farms.

Introduction of *Metagonistylum minense* Townsend

The fly, obtained from the Commonwealth Institute of Biological Control, West Indian Station, Trinidad, West Indies, appeared more delicate for rearing than the *Sturmiopsis inferens* and it exhibited low parasitization of *Chilo suppressalis* and *Chilotraea polychrysa* larvae even when fly maggots were artificially placed on each larva (Table 16). No parasitization of *Sesamia inferens* larvae was recorded. Under identical conditions, *Sturmiopsis inferens* parasitizes about 50 to 60 percent of the inoculated larvae. Further experiments on *Metagonistylum* will determine whether improved techniques can increase its parasitization potentials.

buted to (a) release of P from organic matter, (b) increase in solubility of calcium phosphates ($CaHPO_4 \cdot 2H_2O$, $Ca_4H(PO_4)_3 \cdot 3H_2O$, $Ca_{10}(PO_4)_6 \cdot (OH)_2$, $Ca_{10}(PO_4)_6CO_3$, $Ca_{10}(PO_4)_6F_2$) associated with the decrease in pH caused by accumulation of CO_2 in the calcareous soils, and (c) reduction of $FePO_4 \cdot 2H_2O$ to the more soluble $Fe_3(PO_4)_2 \cdot 8H_2O$ and increase in solubility of $FePO_4 \cdot 2H_2O$ and $AlPO_4 \cdot 2H_2O$ caused by the increase in pH accompanying reduction of the acid and strongly acid soils. The decrease in water-soluble P following the peak may be caused by adsorption, precipitation and isomorphous replacement reactions. These processes were most marked in acid clay soils high in Fe and Al. Hence, the very low concentration of P in the strongly acid latosolic soils compared with the coarse textured soils low in Fe.

The kinetics of P extractable with an acetate buffer at pH 4.8 (Fig. 14) followed courses that were roughly parallel to those of water-soluble P. The initial, peak, and final concentrations were highest in the calcareous soils high in organic matter and low in Fe; they were least in the strongly acid soils high in Fe. These observations are compatible with the fact that sodium acetate at pH 4.8 extracts calcium bonded P. As the pH increases, strengite and variscite release P which apparently combines with Ca and precipitates as calcium phosphates at a pH of 6.5—7.0.

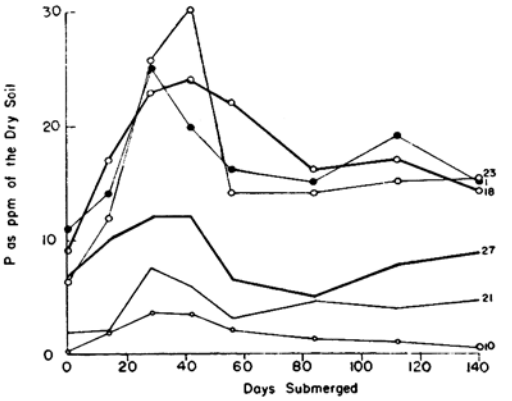


Fig. 14. Kinetics of P extractable with sodium acetate at pH 4.8 in flooded soils.

Soil No.	pH	O.M.%	Texture	Active Fe%
1	7.6	2.3	loamy fine sand	0.18
10	5.4	1.5	clay	1.67
18	5.6	6.0	sandy loam	0.27
21	4.6	4.1	clay loam	2.78
23	5.7	8.0	fine sandy loam	0.47
27	6.6	2.0	clay	1.60

These results suggest that the increase in availability of phosphorus on flooding is appreciable only in soils high in organic matter and low in iron; in strongly acid soils high in Fe a slight temporary increase is followed by a quick decline to levels even below the initial. In terms of P fertilization this means that (a) latosolic soils need heavy P applications and (b) considerable amounts of soluble P fertilizers may be fixed in flooded latosolic soils in spite of their reduced state.

Electrochemical Changes in Flooded Soils

Changes in pH Value

The pH value of flooded soils is ecologically important because it influences the availability of plant nutrients and markedly affects the concentration of constituents of the soil solution such as H_2CO_3, Fe^{++}, Mn^{++} and Al^{+++} which, in excess, are toxic to rice. Chemically, it holds the key to the understanding of equilibria involving CO_2, carbonates and hydroxides, and oxidation-reduction changes in flooded soils.

The earlier study (IRRI Annual Report, 1963) revealed that on flooding the pH values of the acid soils increased while those of the calcareous soils decreased. The present study attempted a quantitative explanation of pH changes in flooded soils.

The pH values of the soil and soil solution of 31 soils kept submerged in pots in a greenhouse were determined over a period of 16 weeks. The soil pH was measured in a 1:1 water suspension of a small plug of soil taken

Agricultural Engineering

The engineering and economic aspects of rice mechanization continued to receive attention during the year. Activities under the contract between the Institute and the United States Agency for International Development on the application of power to rice production were increased as a result of additions to the project staff and facilities.

The lack of organized machine design and development activity among equipment manufacturers in the tropical countries has hampered the mechanization of rice farms in these areas. The department, therefore, increased its efforts in developing special machines for commercial production within the tropical rice-producing countries. Increased emphasis was placed on projects of immediate interest to equipment manufacturers to accelerate the adoption of research findings in the field.

Studies on the economics of mechanization were continued. To obtain necessary background data, detailed surveys are underway in the three largest rice-growing areas of the Philippines. The cost and performance of different-sized power units were compared, and test data and other information on hand tractors in Laguna Province were obtained.

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Agricultural Machinery Research

A review of agricultural machinery research indicated that this field of activity at the Institute could have an impact on rice mechanization in the tropics if the results could be incorporated into commercially manufactured machinery. The research activities of the department were thus oriented toward the manufacturers of agricultural machinery in the tropics and in the industrialized countries.

The design and development of agricultural machines in the industrialized countries is primarily a function of the industry. General mechanization research is usually conducted at the public agricultural engineering research institutions. In contrast, most agricultural machinery manufacturers in the tropical rice-growing countries do not have the resources or the skill to develop machines that may be manufactured locally. A machinery design and development service at the Institute, patterned after commercial agricultural machinery development activities in the industrialized countries, can fill this need to provide local manufacturers with suitable designs. On the other hand, since the manufacturers in the industrialized countries have excellent resources for developing new and improved machines, the research activities at the Institute should be limited to specific farm mechanization problems which may assist them in their machinery development programs.

The agricultural machinery research and design activities at the Institute were, therefore, concentrated on:

(1) The design, testing and development of special rice machines suited for local manufacture within the rice-growing countries. Such activities should lead to the complete development of a machine from the basic concept to the final design and may even include the testing and evaluation of the initial trial production run before the machine is released for regular production. Providing local manufacturers with technical assistance in setting up their manufacturing plans may also be considered a part of the machine development function.

(2) Agricultural machinery research specifically aimed at assisting in the design and development of sophisticated rice machinery in the industrially advanced countries with emphasis on specific problems of mechanization faced by manufacturers abroad and not on the design and development of machines.

A total of seven agricultural machinery research projects were undertaken in 1967. These are described below:

Rotary tiller development

Three 400-cm tillers with extensions of up to 500 cm were fabricated and tested in the field. These machines were fitted with Japanese style tiller blades, axially mounted at 3.5 and 7.0 cm spacing and spirally arranged with 137 and 90^0 angles between adjacent blades (Fig. 1). The diameter of the rotor was 50 cm which resulted in a peripheral blade velocity of 4.5 m/sec at standard 540 PTO rpm. These tillers were designed to operate at travel speeds of 0.20 to 0.70 m/sec, increments of cut of 4 to 16 cm, and depth of cut of 10 to 20 cm. The horsepower requirement was estimated at 4 hp per 30 cm of tiller width or about 40 hp for a 300-cm and 50 hp for a 400-cm tiller. A 50-hp tractor was able to power a 500-cm tiller on friable loam soils and a 400-cm tiller on extremely hard puddle clay soils. The forward speed was 0.45 m/sec and the depth of cut varied from 6 to 20 cm, depending on the hardness of the soil. In other tests, a 40-Rhp tractor powered 300- and 360-cm wide tillers without difficulty.

The standard 8.5 Rhp Japanese tiller blades used on the large rotary tiller had adequate strength for hard dry clay except for occasional breakage. The PTO transmission of the large tractors seems to lack strength and durability as evidenced by two failures which occurred in a recent-model tractor. Manufacturers should make more stringent tests on the durability of PTO transmissions. The ability of the PTO shaft bearings to withstand thrust loads and the friction in the telescoping section of the drive shaft under varying torque loads need to be determined. Raising the rotary tiller under loaded conditions throws a heavy thrust load on the PTO shaft. A low-cost thrust bearing could probably prevent frequent repairs.

The quality of the tillage work from the large rotary tillers, which required 6 to 13 liters of diesel fuel per hectare (Table 1), compared cept for the two calcareous soils) and appreciably *lower* for all soils after a few weeks of submergence. This apparent inversion of the suspension effect which was at first surprising is easily explained by the higher partial pressure of CO_2 in the soil solution than in the soil.

The clues to the role of CO_2 (Table 14) were (a) the negative suspension effect in the calcareous soils from the start of flooding, (b) the inversion of the suspension effect in acid soils after reduction, (c) the higher values for the suspension effect for the calcareous soils and soils high in Mn than for the latosolic soils low in Mn, (d) the relatively small values for the soils high in organic matter which maintained high Pco_2's, and (e) the increase in value of the inverted suspension effect as Pco_2 decreased with increase in duration of submergence.

These observations suggested that the higher pH values of the soil suspensions than the equilibrium soil solutions of reduced soils were due to a decrease in concentration of CO_2 in the soil suspensions by (a) dilution and (b) loss of CO_2 during handling of the soil and stirring of the suspension. The marked influence of CO_2 on the pH values of flooded soils was dramatically demonstrated by stirring the soil solution from a flooded latosolic soil, in an atmosphere of nitrogen. After 30 minutes of gentle magnetic stirring, the pH increased from 6.60 to 7.80 and the Eh decreased from +40 mv to −320 mv, while a green precipitate of probably ferroso ferric hydroxide separated out. The effect of CO_2 is more pronounced at low than at high Pco_2's. This explains (a) the increase in − △pH values with duration of submergence, and (b) the smaller − △pH values for soils high in organic matter and low in Fe and Mn — soils that maintained high Pco_2 values throughout submergence (Table 14).

A satisfactory interpretation of the pH changes in flooded soils must explain quantitatively (a) the increase in pH in acid soils, (b) the decrease in pH followed by an increase in the calcareous soils, and (d) differences in final pH values among the soils.

The rate of pH increase was highest in the soils that rapidly underwent reduction and lowest in soils whose re-

TABLE 14. Influence of soil properties on the suspension effect (△pH = solution pH − soil pH) in pH determinations in flooded soils.

Soil No.	pH	O.M. %	Active Fe %	Active Mn %	pH at various times (weeks) of submergence — Weeks submerged: 0	1	2	3	7	12	16
1	7.6	2.3	0.2	0.03	−0.18	+0.18[a]	+0.20[a]	−0.10	−0.22	−0.65	−0.41
26	7.6	1.5	0.3	0.06	−0.45	−0.40	−0.24	−0.32	−0.37	−0.60	−0.60
17	7.0	1.8	1.0	0.15	−0.12	−0.31	−0.20	−0.27	−0.43	0.43	−0.49
7	5.9	3.3	1.7	0.33	+0.42	0.00	−0.45	−0.17	−0.31	−0.26	−0.90
3	5.7	1.3	0.8	0.36	+0.65	+0.17	+0.05	−0.04	−0.33	−0.10	−0.40
13	6.5	2.5	1.1	0.26	+1.35	−0.25	−0.25	−0.10	−0.20	−0.42	−0.61
14	4.6	2.8	2.1	0.06	+0.90	−0.44	−0.05	−0.27	−0.12	−0.31	−0.50
21	4.6	4.1	2.8	0.02	+1.00	−0.20	−0.20	—0.06	−0.01	−0.28	−0.11
28	4.7	3,2	2.9	0.05	+1.08	0.00	+0.05	−0.08	0.29	−0.26	+0.13
23	5.7	8.0	0.5	0.03	+0.07	−0.12	0.00	0.19	−0.13	−0.19	−0.10
18	5.6	6.0	0.3	0.01	+0.30	−0.22	+0.11	−0.30	−0.00	−0.20	−0.01
29	5.8	7.7	1.8	0.08	+0.30	−0.03	−0.05	−0.12	−0.16	−0.29	−0.31

[a] Anomaly due probably to loss of CO_2 caused by suction applied to clear gas bubbles obstructing the outlet tube.

Table 1. Diesel fuel and tractor time required for wet and dry land preparation with a Ford 4000 tractor and 400- and 500-cm wide rotary tillers.

Field condition*	Soil depth (cm† 20-35-70 psi)	Tiller width (cm)	Depth of tillage (cm)	Fuel liter/ha	Tractor time (hr/ha)	Tractor speed (kph)
Dry R-1		500	6	11.3	1.4	1.6
Wet R-1	10–19–26	500	15	8.9	1.3	1.7
Wet R-2		500	19	8.4	1.3	1.7
Dry R-1		400	12	13.2	1.5	1.9
Dry R-2		400	12	5.8	1.0	2.7
Dry R-1		400	6	11.7	1.5	1.8
Dry R-2		400	13	10.1	1.5	1.9
Dry R-1		400	11	10.0	1.6	1.7
Wet R-2		500	18	8.5	1.1	1.6
Wet R-1	11-18-26	500	19	11.1	1.6	1.3
Wet R-2		500	20	9.8	1.2	1.7
Wet R-1	14–19–27	500	13	8.6	1.3	1.6

*R-1 & R-2 refer to 1st and 2nd pass of tiller. Field sizes ranged from 2,067 to 2,781 sq m.
†Depth in cm before the soil resistance is 20, 35 and 70 psi on a U.S. Army Corps of Engineers WES Cone Penetrometer.

Table 2. Diesel fuel and time required for one pass of a 500-cm wide square and triangular puddling rotors on soft, flooded soils with 52 to 55 Rhp tractors. Depth of tillage 10 to 20 cm.

Rotor shape	Tractor speed (kph)	Fuel (liter/ha)	Tractor time (hr/ha)
Square	2.2	9.2	1.3
Square	2.7	8.1	1.0
Square	1.6	10.1	1.8
Triangular	.6	16.5	4.3
Triangular	.6	21.9	4.4
Triangular	.8	13.3	3.0
Triangular	.8	13.5	3.1
Triangular	1.1	10.0	2.3
Triangular	1.1	9.7	2.3
Triangular	1.5	6.6	1.6
Triangular	1.5	8.7	1.6
Triangular	1.5	8.9	1.7
Triangular	1.5	5.6	1.7
Triangular	2.2	7.1	1.2
Triangular	2.2	7.5	1.1
Triangular	3.4	3.3	.73
Triangular	3.4	3.6	.76
Triangular	4.7	2.2	.53
Triangular	4.7	1.8	.54
Triangular	4.7	3.6	.53
Triangular	4.7	2.7	.49

developing a drum-type power thresher for small farms and custom threshing.

Research on counterflow rice drying

The counterflow principle used in the experimental dryers for corn, wheat, oat and rye is being investigated for use in drying rice.

Counterflow is accomplished by passing the heated air through a dryer in the opposite direction of the grain. The hot incoming dry air comes in initial contact with the dry outgoing grain and then successively passes through

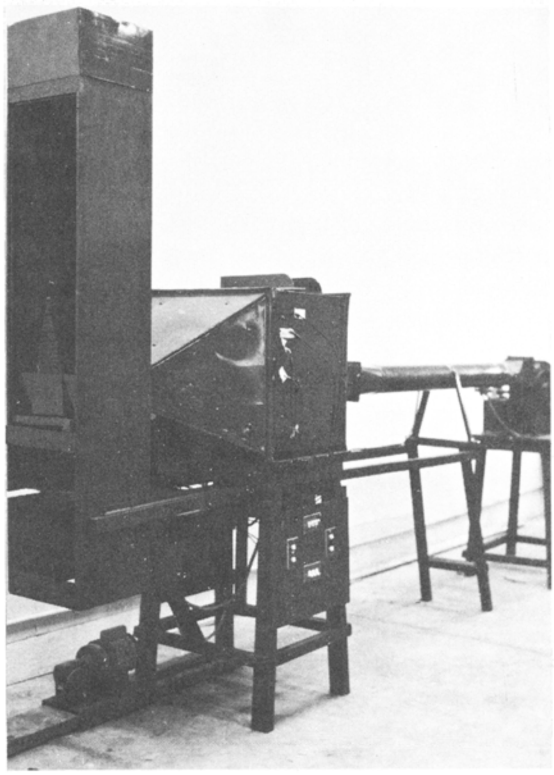

Fig. 2. Laboratory model of a counterflow dryer.

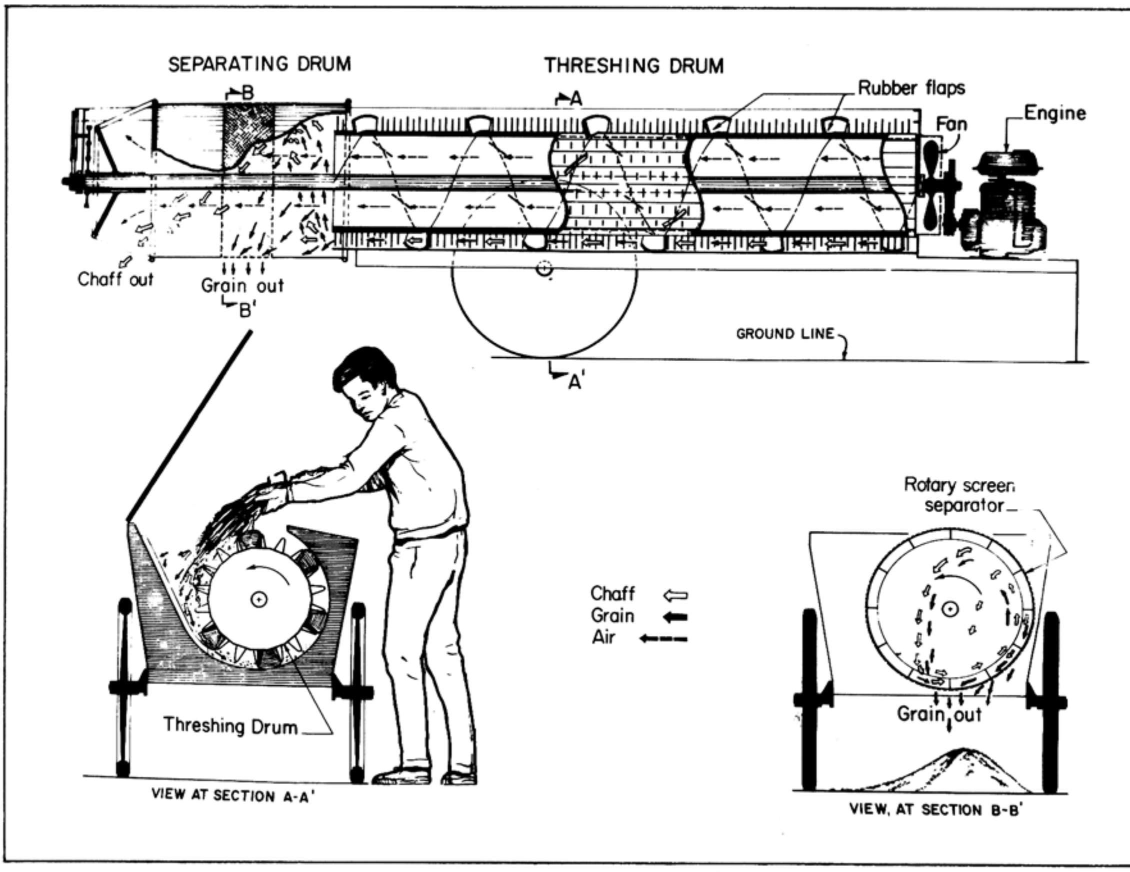

Fig. 3. Schematic drawing of drum-type power thresher.

increasingly high-moisture layers of grain. The air finally leaves the dryer at the point of entry of the high-moisture grain.

The first and most readily available moisture to be removed from the grain is evaporated into the lowest-temperature and highest-humidity air. The kernel progressively loses moisture as it is exposed to higher and higher air temperatures. The grain approaches its lowest moisture content at the point of highest air temperature.

Counterflow drying permits the use of air temperature higher than that used in batch-type drying and results in a greater drying capacity per unit of dryer volume. The rate of grain flow is controlled to achieve a desired level of drying. With the hottest air in contact with the driest grain, a constant drying rate is maintained throughout the dryer, thus preventing excessive drying rates and reducing kernel damage.

It is felt that in smaller dryer designs, high thermal efficiency, optimum drying rates, simplicity of operation, and ease of fabrication can be achieved by the use of the counterflow principle. A small laboratory model dryer (Fig. 2) using this principle has been built in the department. Its efficiency in drying rice will be tested in 1968.

Drum-type power thresher

A low-cost, power-operated paddy thresher was designed and developed to meet the requirements of the small farmer and the custom operator in the tropical countries. The large McCormick type conventional threshers are too expensive and are no longer being produced. The Japanese type threshers have not been as well accepted in the tropical countries because of poor performance with wet crops, complicated mechanism, and poor service facilities. Consequently, in areas of high humidity, paddy is threshed immediately after harvest manually or with the use of animals. Custom threshing by power equipment is not practiced on small

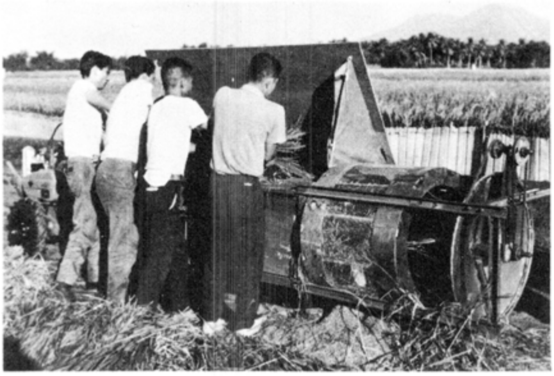

Fig. 4. Prototype drum-type power thresher.

farms because of lack of suitable equipment.

The Japanese style walking tractors have been increasingly used for custom tillage in recent years. However, the custom operators can use their tractors effectively for only a relatively short period. A suitable low-cost thresher, which could be towed and powered by a small tractor, would solve this problem. The machine should be designed such that it will require a short set-up time since custom work may involve threshing at many different locations within a single day.

With the above objectives, the development of a drum-type trailer-mounted paddy thresher was undertaken. Figure 3 shows a schematic drawing of the thresher which is now being further developed.

The first prototype of the machine (Fig. 4) was successfully tested during the later part of the year. A second prototype using the same basic concept but incorporating many functional and manufacturing refinements has been completed. The design made maximum use of locally available components and was kept as simple as possible for ease of manufacture, operation and service. Extensive field trials of the second prototype are planned for the next harvest season. Development work will be continued until the design is ready for release to local manufacturers.

This thresher utilizes a Japanese style wire loop type threshing drum which has been widely used and has proved effective as a threshing device with low power requirements. The design departs considerably from existing practices for conveying, separating, and cleaning the threshed materials.

The 6-ft long hollow threshing drum is mounted within a sheet metal trough. Rubber flaps mounted spirally on the drum sweep the trough bottom to deliver the threshed materials to the rear end mounted rotary screen separator. An axially mounted fan blows an air stream through the hollow threshing drum and the rotary screen separator. The air stream blows the light straw leaves and chaff to the rear of the machine leaving the grains to fall through the rotating screen. The tumbling action results in a more agressive sieve separation under wet-crop conditions. Four men can simultaneously feed bundles of paddy for non-stop threshing. The machine can be powered either by an independent 4-hp air-cooled engine or by the small tractor engines used for towing the thresher.

Light table-type power thresher

A design project was initiated to develop a simple, portable, power-operated paddy thresher light enough to be manually carried to the fields. In many countries, paddy fields usually have no

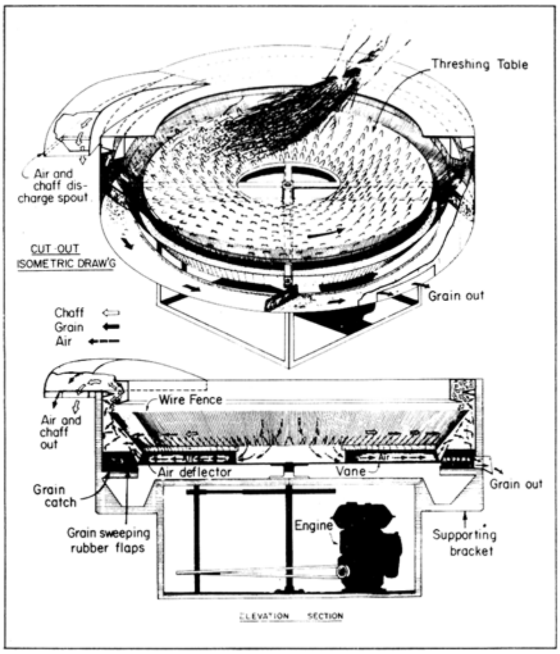

Fig. 5. Schematic drawing of a table-type thresher.

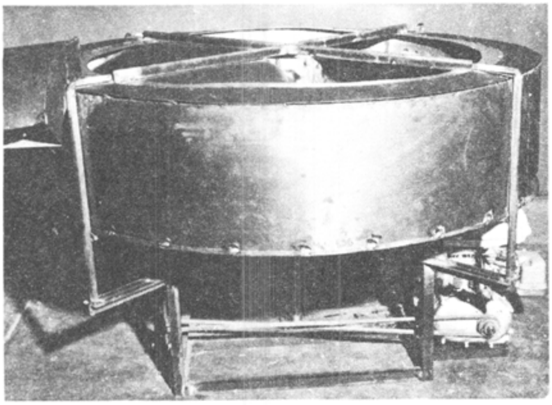

Fig. 6. Prototype table-type thresher.

access roads and a trailer-type thresher cannot be taken to the field for threshing. Considerable manual labor is needed as the crop has to be moved to another location for threshing.

The wire loop method of threshing is excellent for wet crops. The arrangement of loops at the periphery of a conventional drum, however, restricts the effective threshing area to about one-fourth of the total drum surface. To provide a maximum threshing area with minimum weight, a flat, circular, rotating table-type surface with wire loops could be more effective. Such a thresher would also permit a compact, multiple-operator feeding arrangement at the periphery of the circular threshing surface. Figure 5 shows a schematic drawing of this thresher type now being developed.

A prototype machine (Fig. 6) utilizing this concept has been built and tested. The machine uses a 4-ft diameter threshing surface with wire loops mounted at 45^0 angle from vertical in a self-cleaning spiral arrangement. A wire fence at the periphery of the threshing table mechanically separates the straw from the grain. The underside of the threshing table has a large radial fan and air deflector to help blow the chaff from the grain. The grain collects at the bottom where it is swept and delivered to one end by rubber flaps. The chaff and straw are carried by the air to the top and delivered to one side of the machine. The machine utilizes partly mechanical and partly pneumatic means for straw-grain separation. It is equipped with a 4-hp air-cooled engine and can be conveniently carried to the field by four persons.

No major problem has been encountered with the threshing operation, but further work is needed and is now underway, on the separating mechanism.

Tractor tillage and mobility under soft wet land conditions

Adequate traction is difficult to achieve under submerged wet land conditions, hence, the lack of mobility and bogging of large tractors is a serious problem. Non-traction-dependent tillage devices, such as rotary tillers, have shown considerable promise under these difficult field conditions.

The Department has been developing lightweight, wide rotary tillers for use with 40- to 50-hp tractors. Figure 7(a) shows a schematic drawing of such a tiller. A conventional rotary tiller provides a pushing reaction on the tractor of about 50 lb/ft of tiller width under wet land conditions. The degree of tillage is more than adequate under wet land conditions but the pushing reaction on the tractor is inadequate. Conventional rotary tiller blades are designed for tillage and do not significantly contribute to the support of the tractor-tillage weight during operation. The two major problems encountered in the use of conventional rotary tillers on wet land are: (a) inadequate tractor mobility, and (b) excessive ground contact pressures under the tractor rear wheels, resulting in deep wheel tracks, uneven field surface, and increased tractor bogging.

A project was initiated to improve tractor mobility by increasing the forward tiller reaction and by supporting part of the tractor-tiller weight on the tiller.

Figure 8 shows the differences in soil reaction on a conventional tiller rotor and on an experimental push-type tiller rotor. The horizontal component of the soil reaction is greater with a larger diameter tiller rotor for the same depth of tillage. Figure 7(b) shows the schematic drawing of an experimental push-type wet land rotary tiller with an alternate cutting and supporting blade arrangement for increased ground support and forward push. The experimental tiller is designed to be used with special tractor cage wheels which would have a similar blade

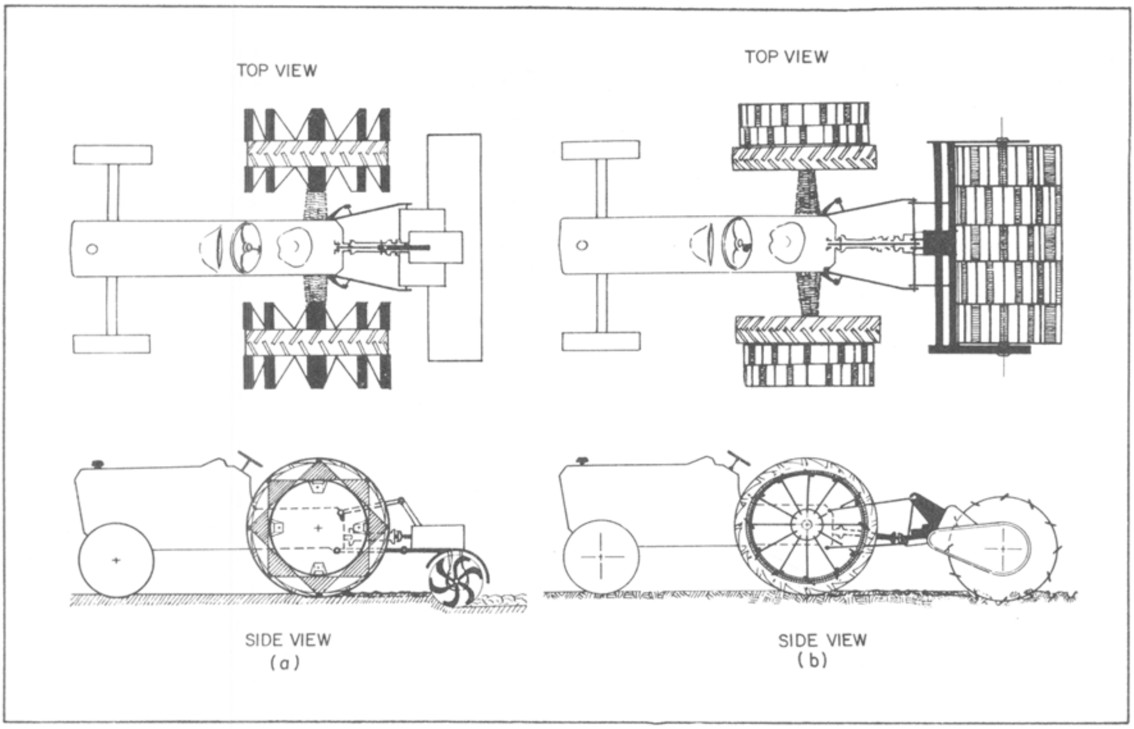

Fig. 7. Schematic drawing of (a) a conventional and (b) an experimental push-type wetland rotary tiller.

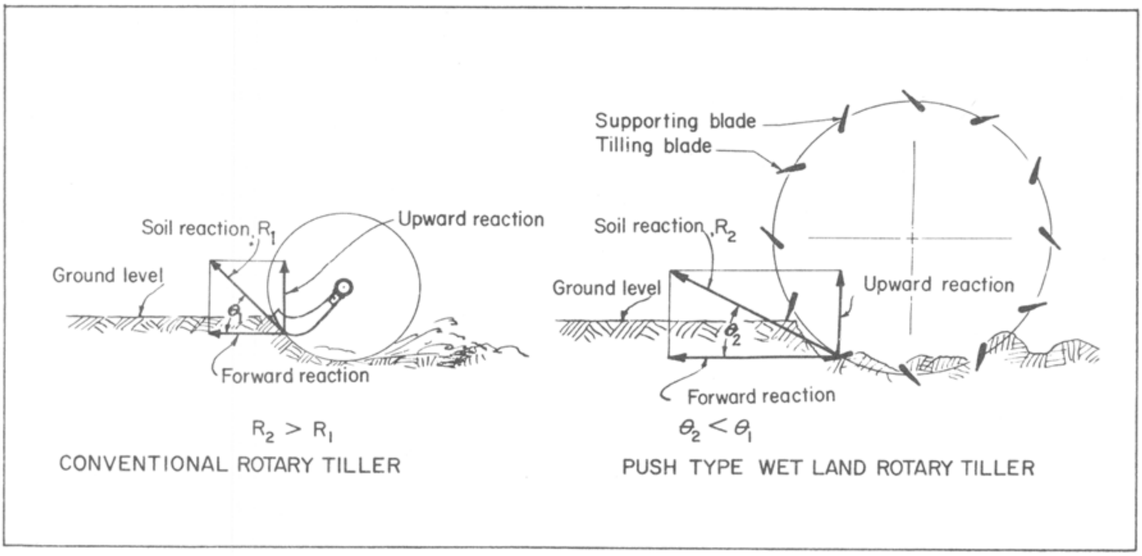

Fig. 8. Schematic drawing showing the effect of tiller diameter and blade arrangement on forward reaction.

arrangement for tillage and support.

Field tests with walking rotary tillers indicate reduced tractor bogging at lower tiller blade speeds. Little is known about the effect of blade speed on forward tiller reaction. It is believed that low blade velocities result in reduced energy transfer to the soil and an increased soil reaction on the blade. The blade velocity could perhaps be used to vary the forward tiller reaction and obtain a desired degree of tillage or mobility under soft wet land conditions. Maximum mobility may be achieved at low tiller blade

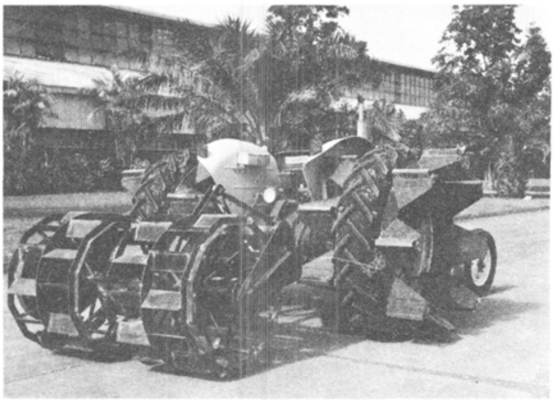

Fig. 9. An experimental push-type wetland rotary tiller.

velocities whereas maximum tillage may be achieved at high tiller blade velocities.

An experimental PTO-driven, 40-inch diameter, push-type wet land rotary tiller (Fig. 9) using alternate cutting and supporting blades was designed and built to study its performance under wet land conditions. Special tractor cage wheels for use with this tiller are being constructed. The experimental tiller is driven through a mechanical step transmission which provides peripheral blade velocities of 400 to 800 ft/min. Conventional rotary tiller blade peripheral velocities generally vary from 600 to 1,500 ft/min. A hydraulic stepless variable tiller drive arrangement is being investigated to permit stepless speed changes during field operations.

The experimental machine will be tested in the near future. The following behaviors of the machine will be studied during the field tests: (1) effect of experimental tiller diameter on tiller forward reaction, (2) effect of experimental tiller blade velocity on tiller forward reaction, (3) relationship of pitch of cut and tiller forward reaction, (4) power required by the experimental tiller at different tiller speeds, (5) dynamic weight distribution under the tractor wheels and the experimental tiller, and (6) optimum blade design for effective tillage and support.

Use of mechanical power for rotary weeding

Weed control significantly affects rice yields. A joint UPCA-IRRI experiment had shown that weeds reduce rice yields by as much as 36 percent. Available Institute data show that an average of 120 hours is required to handweed one hectare. A push-type rotary handweeder reduces this labor requirement to 70 hr/ha. High costs and problems of application limit in many areas the use of herbicides for weed control.

Rice planting in rows has made possible the use of a rotary hand weeder, thus reducing the labor requirement. However, the push-type manual rotary weeder has to be pushed two to three times to obtain satisfactory weeding performance. It is desirable to multiply the human effort by the use of mechanical power.

Although small tractors have adquately replaced human and animal labor for plowing, harrowing, and puddling, they cannot function satisfactorily for weeding because of the extremely soft field conditions. The weeds are turned under the soil generally at a very shallow depth by manual rotary weeders. A mechanically powered machine, which is ground-supported for motion, tends to sink deeper than the desired weeding depth and also requires uncultivated headland areas for turning at the end of the rows.

It was felt that the problem could be solved by having the operator support the weight of the machine to provide the desired mobility and turning capability. Many Japanese manufacturers have developed light-weight engine-driven saws which are mounted on the operator. A similar possibility for applying power on weeding is being studied. Improved mounting and better balance of machine would have to be achieved for a multi-row weeder as it would be heavier than the portable saws. The weeding head design should provide adequate flotation to avoid bogging in soft areas. It should have enough slicing and cutting action to scrape the top soil and assist in mixing and burying the weeds. A multi-row weeding rotor should provide adequate clearance between the axle and the rice plants. Handling characteristics and operator comfort during weeding and turning at the end of the rows need to be studied.

A three-row power weeder (Fig. 10), weighing 24 kg, and using a light Japanese portable saw engine, was designed. Many different shapes of blades were tried to achieve proper weeding performance. Weeding performance was satis-

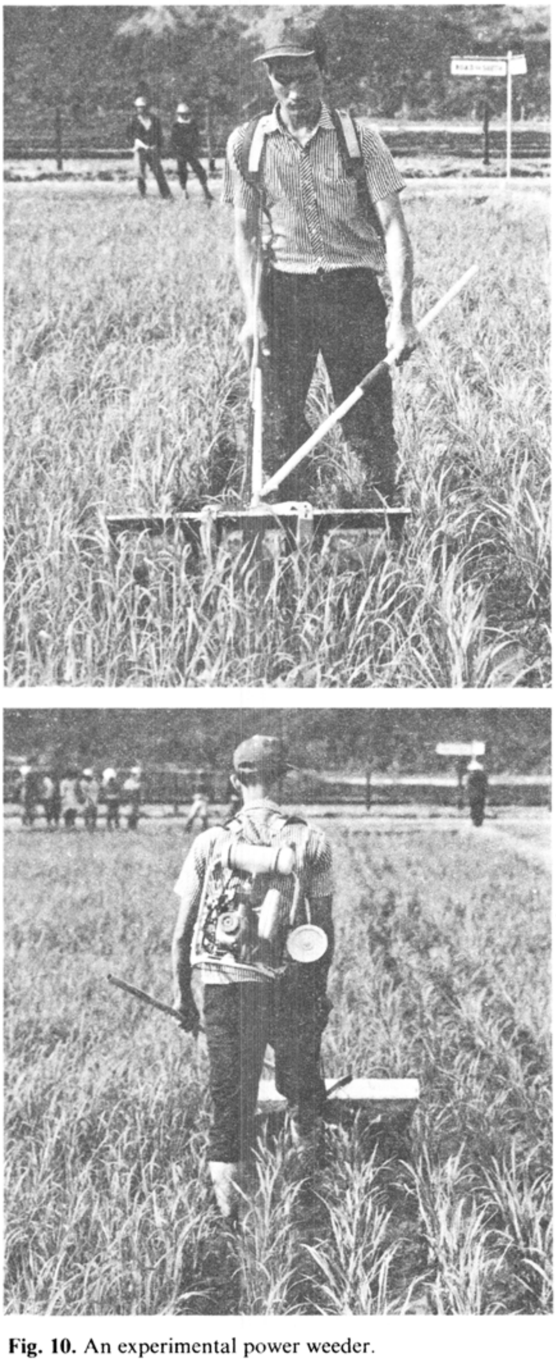

Fig. 10. An experimental power weeder.

factory; however, the load distribution and mounting arrangement on the operator needs improvement. Work is underway to find better ways of mounting the mechanical weeder on the operator. The project will cover studies to: (1) determine the optimum rotor diameter, rpm, and axle clearance, (2) determine the optimum blade design and arrangement for optimum flotation, and mixing of weeds in the mud, (3) measure operator fatigue and weeding output, and (4) determine the optimum suspension and mounting system for the machine.

Economics of Rice Mechanization

Reliable quantitative data are needed on rice farm operations in Southeast Asia to study the extent and potential for mechanization. Surveys are underway in the three major rice-producing areas of the Philippines: Central Luzon, Cagayan Valley in Northeastern Luzon, and Cotabato Province in Southwestern Mindanao. Data are collected using two methods: (1) by observing weekly a number of randomly selected fields, and (2) by interviewing the operators of the observed fields. An analysis of some of the data for Central Luzon is presented below.

Weekly survey of Central Luzon

The Central Luzon "valley" historically has been largely planted to rice. In 1966, of the 2 million hectares planted to lowland rice in the Philippines, 480,000 hectares, or almost one-fourth of the paddy land hectarage, were in the Central Luzon provinces. The greater part of the valley lies in the watershed of the Pampanga River, which flows south into Manila Bay; the remaining northern part is in the watershed area flowing into Lingayen Gulf. Laguna Province, lying south of Manila, is included in the survey, and is of interest because of the high percentage of irrigated farms. However, of the hectarage in Central Luzon, only 10 percent is irrigated for a second rice crop.

To sample the area initially, 145 rice fields were randomly selected for weekly surveys. At each site, observations are made on cultural practices, plant type, water control, the need for and use of fertilizers, pesticides and herbicides, soil depth and other soil and crop conditions, and a yield sample is taken.

The planting and harvesting sequence for the sampled one- and two-crop rice fields during the period mid-1966 to mid-1967 is shown in Figure 11. It plots time on the x-axis and a cumulative frequency for 109 one-crop fields and for 31 two-

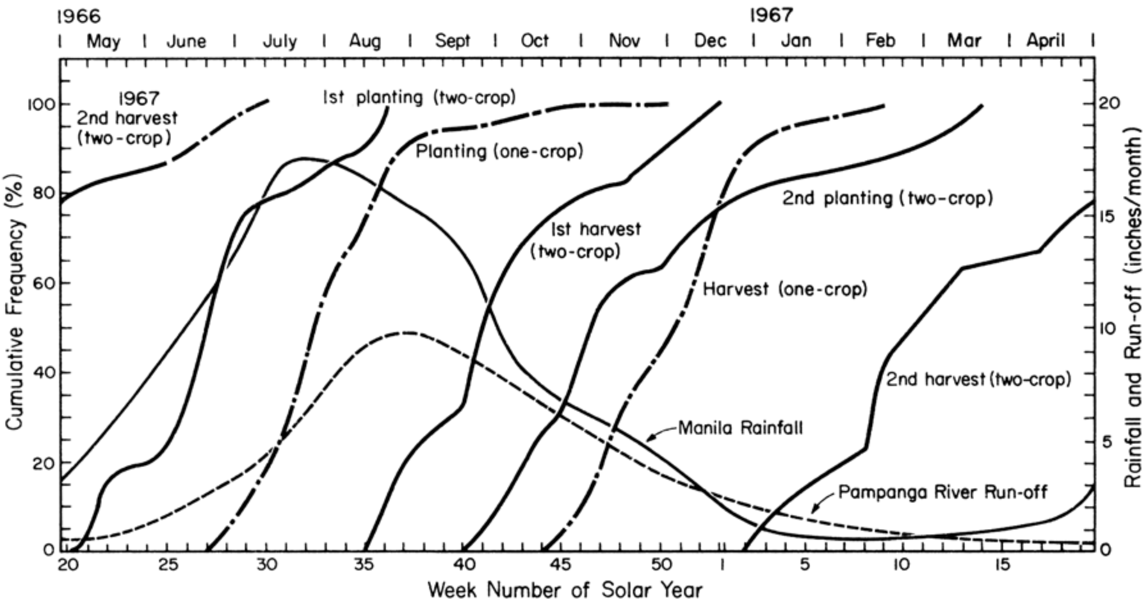

Fig. 11. Planting and harvest cycles for one- and two-crop rice sites in Central Luzon, Philippines, May, 1966 to July, 1967 (31 one-crop and 109 two-crop sites.) (Compared with the average rainfall of Manila, Philippines and average run-off from the Pampanga River Basin.)

crop fields on the y-axis. Superimposed are the rainfall data for the Manila area and the run-off data of the Pampanga River. For the one-crop or rainfall-dependent farms, planting took place in July and August, considerably after the start of the monsoon rains. Land preparation on these farms was delayed until the ground was soft enough to be prepared by animal power. The two-crop farms used supplemental irrigation to soak the fields in advance. These farms were planted 6 weeks before those dependent on rainfall. The maximum rate of planting or harvesting was about 15 percent per week. The steep slopes of the lines for the first planting indicate that a majority of farmers in the valley perform cultural operations simultaneously. The seasonality of rainfall thus creates conditions of high labor and power use for short time periods.

The two-crop farms were planted to shorter season varieties that required about 14 weeks from transplanting to harvest, while the one-crop sites were planted to varieties requiring about 17 weeks from planting to maturity. The first crop from the two-crop sites, and a major portion of the one-crop sites, were harvested during the rainy season. This timing was necessary so that adequate water would be available for growing the single non-irrigated crop and the residual run-off water may be used for irrigating the second crop.

Rice yields were obtained from as many of the sites as possible. The yield estimates were obtained by harvesting a 4-sq m area at each site and through interviews.

Data were obtained on a number of factors considered as determinants of yield. Although under actual farming conditions many other factors condition yield response, a regression analysis was used to determine the relative effect on yield of the measured variables. Two regression equations are listed below. The numbers in parenthesis below the regression coefficients are the standard errors of the regression coefficients*.

$$Y_1 = 1861 + \underset{(45.7)}{83.3X_1} - \underset{(26.7)}{55.6X_2^*} + \underset{(21.7)}{10.0X_3} - \underset{(20.9)}{15.7X_4}$$

$$- \underset{(62.1)}{39.0X_5} - \underset{(102.0)}{145.6X_6} + \underset{(3.70)}{3.10X_7} + \underset{(5.81)}{19.3X_8^*} - \underset{(0.396)}{0.297X_9}$$

$R^2 = .37$, D.F. = 81.

$$Y_2 = 1860 + \underset{(114.3)}{202.5X_1} - \underset{(57.1)}{89.2X_2} - \underset{(76.9)}{140.2X_3} - \underset{(78.9)}{83.9X_4}$$

*Significant at 5% level or better.

$$+ 299.1X_5 - 113.4X_6 - 4.30X_7 + 19.2X_8 + 0.852X_9$$
$$(149.1) \quad (104.2) \quad (8.34) \quad (10.7) \quad (0.997)$$

$R^2 = 68$, D.F. $= 19$.

where:

Y_1 = Yield (in kg) of rough rice (local name: palay) per hectare—one-crop sites
Y_2 = Yield (in kg) of rough rice per hectare—two-crop sites
X_1 = Number of weeks in a rice crop
X_2 = Number of weeks that rice crop needed weeding
X_3 = Number of weeks that rice crop needed nitrogen
X_4 = Number of weeks that rice crop needed insecticide
X_5 = Number of weeks that rice crop showed dead heart
X_6 = Number of weeks that rice crop showed white head
X_7 = Percent of reproductive weeks that rice crop was dry
X_8 = Percent of reproductive weeks that rice crop was lodged
X_9 = Average soil depth in centimeters to a cone index of 70 psi.

The regression coefficients compared with the standard errors obtained demonstrate that the data indicating weeks in rice, percent lodged, weeding need, nutrient need, and white head were more highly correlated with yields.

Many of the rice varieties in the survey were susceptible to lodging. For the improved short-statured varieties, early lodging is expected to result in reduced yield. However, most of the varieties planted with surveyed fields were of the tall type that lodge easily. Thus, the sign of the regression coefficient is positive as the higher yielding, tall varieties lodged earlier. In the future, as higher yields are obtained from improved lodging-resistant varieties, the sign of the regression coefficient should become negative for the higher yields.

Trafficability problems and soft soils

A major reason for conducting the weekly field survey of Central Luzon was to obtain data on the soil conditions throughout the season. The U.S. Army Corps of Engineers WES cone penetrometer was used weekly on all sites. Two pressures, 35 psi and 70 psi, representing soft and firm soil conditions, were chosen. The cone penetration before reaching the two pressures was recorded in centimeters. One-crop sites were found to be firmer than two-crop sites (Fig. 12), which is expected since the longer saturation softens the soil. The softest soil conditions occurred during harrowing when the soil was completely puddled. However, soil conditions did not change much between harrowing and harvest. An arbitrary "go" and "no-go" criterion for a 50-hp tractor with cage wheels is about a 70 psi cone index at 30-cm (12-inch) depth. With this criterion for Central Luzon, about 90 percent of the one-crop sites would be suitable for heavy equipment compared to about 60 percent of the two-crop sites. As irrigation becomes available for the second crop, soil trafficability problems will increase. Trafficability, too, can vary according to soil type. The small sample of the heavier clay soils of Laguna Province indicated that only 30 to 45 percent of the sites were below the 70 psi cone index criterion of 30 cm. The high percentage of soft soils in Laguna is one of the major reasons why a higher proportion of the land is prepared by hand tractors as compared to standard-sized tractors.

Economic survey of Central Luzon farmers

Farm operators of the fields sampled were located and interviewed. The results are presented below.

Description of the area. The Central Luzon farmers are largely share-tenants. The 1960 Census of Agriculture indicates that Pampanga and Nueva Ecija Provinces are 85 percent tenant-operated, and Laguna, 72 percent. The average farm size is about 3 ha. Of 114 farmers interviewed, 63 reported a farm size of between 1.6 and 3.5 ha.

Outside sources indicate that about 9 percent of Central Luzon is irrigated for a second rice crop. In Laguna Province, 8 farms out of 13 reporting were irrigated, while in Central Luzon, 22 out of 108.

The cultural practices are centered on the use of carabao (water buffalo) and manual labor. Table 3 contains a summary of farm equipment and animals owned. For farms below 1.5 ha in size, the typical equipment was 1 plow, 1 harrow and 1 carabao. For farms between 1.6 and 3.5 ha, the equipment in average terms was 1.4 plows, 1.5 harrows and 1.5 work animals. For farms above 3.6 ha, the equipment was 2 plows, 2 harrows, and 2 carabaos. Of the 114 farms reporting, while several indicated tractor use, only 1 farm owned a tractor. Furthermore,

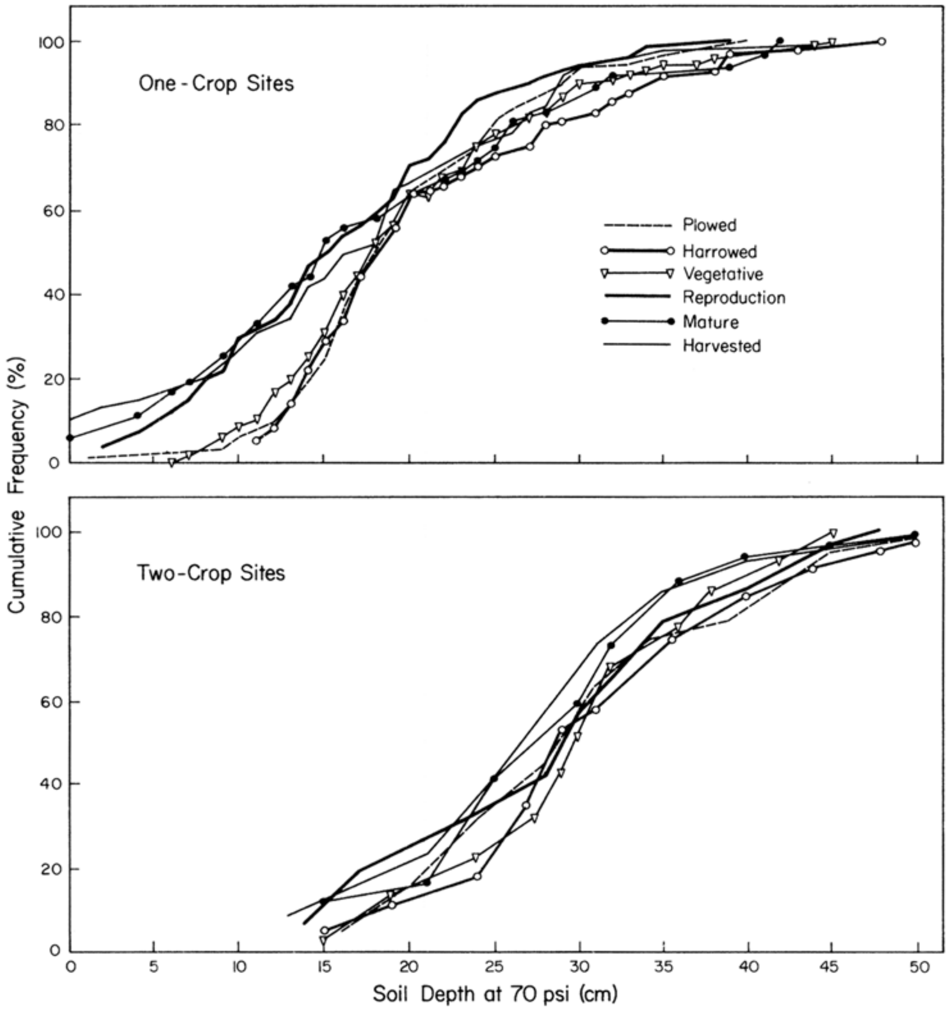

Fig. 12. Cumulative frequency of various soil depths (cm) at which a U.S. Army Corps of Engineers WES cone penetrometer had a resistance of 70 psi.

the use of tractors and carabaos was limited to land preparation.

General comments on labor and power use in Central Luzon

Several questions were asked concerning the demand for and supply of farm labor, and power use.

The first questions were aimed at determining the amount of labor used throughout the crop year. The extent of the farm operations requiring reliance on hired labor may indicate the immediate potential for more economical changes in the operation. Additionally, labor shortage at peak periods may indicate a production bottleneck. Table 4 contains estimates of average labor requirements of rice farms in the Central Luzon survey. There are three peak periods of labor use: land preparation, transplanting, and harvesting-threshing.

On share-tenant farms, a common arrangement is that the landowner and tenant share equally the total receipts. The owner usually pays for all of the costs pertaining to the land and improvements, all the transplanting labor cost, half of the materials and seed used, and half of the harvesting and threshing costs.

Table 3. Farm equipment and animals owned, by area of farm, 1966-67 Central Luzon Survey.

Hectarage	No. of farms reporting	Tractor	Plow	Harrow*	Weeder	Sprayer	Carabao	Cattle
Below 1.5	17†	(2)‡	19	21	3	2	16	1
1.6 - 2.5	30	(5)	42	42	3	1	43	0
2.6 - 3.5	33	1(12)	47	54	6	4	54	5
3.6 - 5.5	16	(1)	34	35	2	3	37	0
5.6 -above	18	(2)	45	43	4	7	44	0
All farms	114	1(22)	187	195	18	17	194	6

*Includes upland harrow used in lowland paddies, specifically in Pangasinan.
†Two farmers reported no equipment owned.
‡Numbers enclosed are tractors hired.

Table 4. Average labor requirements of rice farms using carabaos, Laguna Province and Central Luzon Survey, 1966-67.

Labor Requirement	No. of Farms		
	27	39	41
	Irrigated		Non-irrigated
	2-crop	1-crop	1-crop
	Man-days (8 hr/day)/ha		
Seedbed preparation and care	2.51	2.68	3.12
Plowing	5.94	7.91	8.32
Harrowing	8.06	9.30	10.42
Repair and cleaning of dikes	2.43	3.87	4.52
Pulling and rolling seedlings	2.53	2.44	2.83
Transplanting	10.85	13.47	14.11
Weeding	4.58	6.55	4.79
Fertilizing	0.28	0.72	0.48
Spraying	1.08	0.44	0.62
Harvesting-threshing	18.33	16.12	15.30
Total	56.59	63.50	64.51

Table 5. Some data about the carabao.

Province	No. of farms surveyed	No. of farms reporting no carabao	Average no. of carabaos owned	Carabaos worked	Age in years	Age limit to work	Hours/day work	Hours/wk to look after carabao	Cost of 2-year-old carabao
Laguna	11	6	2	1.6	9	21	5	19	P240
Bulacan	24	1	1.7	1.4	11	20.6	8.1	22.4	P218
Nueva Ecija	53	5	2.2	1.8	9.1	19.7	7.5	24.9	P206
Pangasinan	17	1	2.3	2.3	9.8	22.8	6.8	21.9	P206
Tarlac	5	0	2.6	2.2	8.0	22.4	8.2	26.6	P192
Pampanga	6	0	3.3	2.0	8.8	20.0	5.6	22.6	P217

The remaining costs are borne by the tenant.

The use of operator, family, exchange, or hired labor varies according to family size, skill required, or payment source. Since land preparation requires some skill and is heavy work, it is performed by men. The other operations may need skill but can be done by men, women and children. The extent of work done by hired labor also varied with the type of operation. Hired labor was used almost exclusively for transplanting. Almost one-half of the weeding and one-sixth of the total for plowing and harrowing were by hired labor.

When asked about labor shortages during

peak periods of labor need, the farmers stated that they had little difficulty in obtaining transplanting and harvesting labor, jobs for which women and children were available. Farmers noted some difficulty in obtaining labor for plowing and harrowing. The labor shortage may be aggravated by the practice in local communities of performing particular farm operations simultaneously.

The intensity of land preparation varies considerably between farms. The frequency of land preparation operations among the farms interviewed is as follows (each harrowing contains two "passes" of the field):

Operation	Frequency
one plow, three harrow	61
two plow, three harrow	10
one plow, two harrow	9
two plow, two harrow	8
one plow, five harrow	6
one plow, four harrow	5
one plow, six harrow	5
others	17
Total farmers responding	121

The farmers did not view weeding labor as a problem. Weeding practices among the 121 farmers were as follows:

no weeding	30
one hand or rotary weeding	66
two or more weedings	22
no data	3
Total farmers responding	121

Hence, on one-fourth of the farms there was no weeding; on over three-fourths there was one weeding or less. However, this situation is likely to change towards a greater demand for weeding labor, since the improved varieties need to be weeded well to produce better yields.

In brief, only in one farm operation, land preparation, was there any comment regarding labor shortage. This situation is created by the practice of the entire community (barrio) of performing this particular farm operation simultaneously. There will be little change in this practice for rainfall-dependent operations. However, in the irrigated two-crop areas (15% of the total area, or less) the practice is less common. Thus, mechanizing land preparation will have the least undesirable effect on employment.

Work animals can be either owned or hired. The data on hiring a man with carabao for custom work indicate that the prevailing cost is ₱7.50 to ₱10/day.* The computation of the cost of maintaining one's own carabao is more difficult. Some of the data on carabao are listed in Table 5. Carabaos have a working life of from age 5 to 20, or an average of 15 years. If the farmer buys his replacements (60% said they did), he may have to pay ₱200 for a 2-year-old animal. Other data indicate that these farmers hire little help to look after the carabao when it is not working. No pasture or grazing land is set aside for the animal, and the practice of buying supplemental feed for the animal is not common. Only 20 percent of the farmers indicated use of a veterinarian or of medicines for the animals. However, farmers thought that the carabao is getting scarce and harder to find.

In examining the farmers' attitudes toward tractors, over 50 percent indicated they would use the tractor for land preparation if they could conveniently hire one. They listed as reasons for tractor use: timeliness, ease of killing weeds, a less tedious operation, and a lack of carabaos.

Power weeder tests

A test was run comparing the experimental 3-row power weeder with the hand single-row rotary weeder and with hand weeding. Two were chosen randomly out of six adjacent subplots for each type of treatment. The rice had been transplanted 22 days earlier, at a spacing of 25 x 25 cm. The power and hand rotary weeders made two passes, once in each direction. The results of the test are as follows:

	1st plot	2nd plot	Average	Endurance trial
	Man-hr/ha			
Power weeder (2 men)	16.4 (32.8)	26.0 (52.0)	21.2 (42.4)	20.2 (40.4)
Rotary weeder	56.4	48.7	52.6	66.6
Handweeding	107.7	153.5	130.6	137.6

As two men operated alternately the power weeder, the time per hectare was doubled. The

*The present rate of exchange is US$1 = P3.90, or roughly, 1 : 4.

Table 6. Gasoline used for preparing flooded Institute rice fields from stubble to final puddle using 4- to 6-Rhp 2-wheel tractive-type power tillers. (Field condition: stubble—soft.)

Weed weight (g/sq m)	Soil depth, cm* 20–35–70	Area (sq m)	Number of passes and liters of fuel used per ha			
			Plowing	Harrowing	Levelling	Total
No rec.	15–20–29	2623	0 – – – –	4 – 23.01 (5.75)	1 – 1.91	24.9*
No rec.	17–22–27	2624	0 – – – –	5 – 27.05 (5.41)	1 – 2.47	29.5
No rec.	16–25–31	2667	1 – 12.13	6 – 28.61 (4.77)	1 – 1.99	42.7
156	15–25–33	2675	0 – – – –	7 – 32.97 (4.71)	1 – 2.19	35.2
116	15–24–31	2667	1 – 10.55*	5 – 23.47 (4.70)	1 – 2.96*	37.0
125	15–22–30	1320	0 – – – –	4 – 24.24 (6.06)	1 – 2.93	27.2
169	14–24–34	2656	1 – 11.60	5 – 24.72 (4.94)	1 – 2.90	39.2
134	17–23–34	2642	1 – 11.79	5 – 22.14 (4.43)	1 – 2.23	36.2
480	21–25–35	647	0 – – – –	7 – 40.42* (5.77)	1 – 2.05	42.5
480	21–25–35	647	0 – – – –	7 – 35.70 (5.10)	1 – 2.05	37.7
98	16–21–29	667	1 – 15.59	5 – 19.41* (3.88)	1 – 2.29	37.2
98	16–21–29	667	1 – 14.54	7 – 27.96 (3.99)	1 – 2.29	44.7
170	14–26–36	673	1 – 14.26	7 – 30.01 (4.29)	1 – 2.64	46.9
170	14–26–36	673	1 – 11.89	5 – 32.24 (6.44)	1 – 2.64	46.8
135	24–34–38	669	1 – 20.60	4 – 25.19 (6.30)	1 – 1.37*	47.2
135	24–34–38	669	1 – 16.22	4 – 24.29 (6.07)	1 – 1.37	41.9
203	17–29–37	668	1 – 21.86	5 – 31.51 (6.30)	1 – 1.78	55.1*
203	17–29–37	668	1 – 22.45*	7 – 21.78 (3.11)	1 – 1.78	46.0
	Average (per pass)		1.0 15.3	5.5 27.5 (5.11)	1.0 2.21	39.9

*Depth (cm) before the soil resistance was 20, 35, and 70 psi on a standard U.S. Army Corps of Engineers WES Cone Penetrometer.

endurance trial was to compute the time for the various operations as they continued through the day. The data do not include rest time which was considerable for the rotary hand weeders as the day progressed. For an initial test, the performance of the power weeder was good.

Hand tractor studies

During late 1966 and in 1967 studies were conducted on the engineering and economic aspects of hand tractors for tillage operations on lowland rice farms in Laguna Province. While the purpose was not to obtain an accurate count of all tractors, it was noted that 9 tractors were reported to have been purchased before 1960, and by 1967, 431 tractors were counted.

The hand tractors in Laguna Province are largely the tractive type of 4 to 6 hp, designed to pull plows, comb harrows and small trailers. To a lesser extent the larger (6 to 13 hp) rotary tiller types are being purchased. Few standard-sized 4-wheel tractors have been noted doing rice work in this area of soft soils.

Time studies were made on Institute experimental fields where closer observations could be made. The fields had already produced one crop during the monsoon season and were still very soft as shown by the cone index readings in Table 6. From 1 to 5 ton/ha of weeds and stubble were incorporated and the land was prepared for transplanting. Six of the fields were so soft that the comb harrow was used instead of the plow, and in several fields the tillers bogged often. The total fuel consumption of the tillers averaged 39.9 liter/ha. Plowing averaged 15.3 liter/ha; harrowing averaged 5.11 liter/ha per pass, and 5.5 passes for a total of 27.5 liter/ha; and levelling averaged 2.21 liter/ha. The average fuel consumption was about 0.25 liter per rated horsepower-hour. The fuel requirement per pass for harrowing Institute fields (5.11 liter/ha) was comparable with the results of the field survey in 1966 of 4.87 liter/ha, while the fuel requirement of 15.3 liter/ha for plowing the IRRI fields was much less than the 33.7 liter/ha obtained in the 1966 field survey. The apparent explanation is that the farmers' fields were firmer and the farmers plowed a narrower furrow slice.

Comparison of hand tractors and animals. During 1967 a series of trials were conducted on four adjacent quarter-hectare plots at the Institute experimental farm to compare two power units. Four 4- to 6-hp tractive type hand tractors with two operators each, and eight carabaos with their individual owners were used in the trials. One hectare was subdivided into 16 plots each measuring approximately 25 x 26 meters. The whole area was flooded 5 days before the test. The depth of soil penetrated before reaching a bearing capacity of 20, 35, and 70 psi was determined with a WES cone penetrometer; depths were found to be about 18, 28, and 35 cm, respectively. Hand tractors and carabaos were started simultaneously in adjacent plots. Two plots were each plowed once and harrowed a few times by two hand tractors. The degree of puddling and incorporation of vegetation into the soil after every pass with the comb harrow was observed. Harrowing was stopped when the operators considered the plots comparable to outside farmers' fields that were ready for planting. Having completed one plowing, the two carabaos were then required to pass the comb harrow as many times as necessary to approximate the quality of work done by the hand tractors. The same procedure was followed in the other plots.

Each pass with the plow and the harrow was timed; the number of passes and of rounds per pass was noted.

The effective field capacity (efc) was computed by substituting values in the formula:

$$\text{efc (sq m/hr)} = \frac{60 \times 2 : N : L : W}{t}$$

where:

60 = No. of minutes in 1 hour
2 = No. of trip/round
N = No. of rounds
L = Length of trip (m)
W = Width of implement (m)
t = Time used during operation (min)

The plowing or harrowing time was obtained by substituting values in the formula:

Plowing or harrowing time per single pass (hr/ha)

$$= \frac{10{,}000}{A} \times T \times P$$

where:

10,000 = No. of square meters in a hectare
A = Area of plot in square meters
T = Time used during operation (hr)
P = No. of passes of the implement, usually 1 for plowing and several for harrowing.

Hand tractors with 18-cm moldboard plows were computed to have a mean effective field capacity of 311 sq m/hr. This would require a plowing time of 32.2 hr/ha. However, the actual mean time used was only 12.90 hr/ha (Table 7). This indicates that the plows were cutting furrows 18 cm wide and covering unplowed strips about 27 cm wide.

With the 137-cm comb harrows, the same hand tractors had to make three to four passes through the test plots to complete preparation of the land for transplanting. These three to four passes took 13.90 hours to finish a hectare. However, with their mean effective field capacity

Table 7. Performance of the 4- to 6-horsepower tractive-type hand tractor in wet land preparation.

Plowing (18-cm moldboard plow)			Harrowing (137-cm comb harrow)			
No. of passes	Effective field capacity (sq m/hr)	Plowing time (hr/ha)	No. of passes	Mean effective field capacity (sq m/hr)	Total harrowing time (hr/ha)	Total tillage time
1	341	13.00	3	2524	11.31	24.31
1	264	13.10	4	2625	15.32	28.42
1	255	12.82	4	2423	15.17	27.99
1	250	14.60	3	1739	13.31	27.92
1	263	11.22	4	2271	16.62	27.85
1	279	11.58	3	2698	13.39	24.98
1	325	14.43	3	2427	11.44	25.87
1	415	12.47	4	2344	14.61	27.08
ΣX	2492	103.24	28	19051	111.17	214.41
$\bar{X}$	311	12.90	3.5	2381	13.90	26.80
2 s	119	2.39	1.1	590	3.77	3.11

of 2,381 sq m/hr, 14.7 hours would be required to harrow a hectare. This shows that about 6 percent of the area, at one time or another, was not harrowed. Adding up the time used for plowing and harrowing a hectare of land, we have 26.80±3.11 hours or roughly 4.5 days (Table 7).

With the 12-cm moldboard plows, the carabaos have a mean effective field capacity of 138 sq m/hr. Although a mean time of 72.5 hr/ha would be required, the actual time required was only 36.34 hours (Table 8). The plows, therefore, were cutting furrows about 12 cm wide and covering unplowed strips about 12 cm wide. The animal and machine plowing methods were about the same. The mean depth of plowing was 16 cm. As in the case of the hand tractor-drawn plows, the carabao-drawn plows operated through soft soil.

With the 137-cm comb harrow, the carabaos had to traverse the test plots 9 to 13 times to achieve a finish comparable to that in the plots prepared by hand tractors. These 9 to 13 passes took 83.41 hours to finish a hectare. With a mean effective field capacity of 1,554 sq m/hr, it would take 73.3 hours to harrow a hectare. This shows that there was overlapping of about 20 cm in the operation, or about 14 percent of the area was harrowed twice on each pass. Some 119.75±29.54 hours (about 20 days) are needed to plow and harrow a hectare adequately for planting (Table 8).

Survey of hand tractor operators. In Laguna Province, on data tabulated for the tractive type hand tractor, based on interviews with tractor owners, about one-third of the farmers owning the tractors operated 2 to 3 hectares of paddy. A further third operated 3 to 4 ha, while most of the remaining third had from 5 to 8 ha. In addition to land preparation on the machine owner's farm, contract work away from the owner's farm was common. The most frequently mentioned number of days worked was 15 to 30 days of contract hire. Thus, for a typical owner, the machine would be used on the 2 to 8 hectares of land for two crops, with an additional 15 to 30 days of contract hire.

Several types of small hand tractors, mostly Japanese, were sold in Laguna. The tractive type tillers were of comparable size and horsepower. Payments made for these tractors ranged from ₱1,000 to ₱4,900, depending on size, equipment, and type of payment. A typical cash price for a 6-hp tractive type tiller with cage wheels, plow and comb harrow was ₱3,700. Terms could usually be obtained for two-crop farmers by extending the payments over seven crops, or $3\frac{1}{2}$ years. In this case, in addition to the ₱3,700 base price, a service charge of ₱1,200 was made, making each of the seven payments ₱700. The two most quoted range of total payments were between ₱2,500 to ₱2,900 and ₱4,500 to ₱4,900.

The daily contract rate for hand tractor work

Table 8. Performance of the carabao in wet land preparation.

Plowing (18-cm moldboard plow)			Harrowing (137-cm comb harrow)			
No. of passes	Effective field capacity (sq m/hr)	Plowing time (hr/ha)	No. of passes	Mean effective field capacity (sq m/hr)	Total harrowing time (hr/ha)	Total tillage time
1	137	40.84	12	1950	69.32	110.16
1	146	41.24	10	1668	55.45	96.70
1	149	35.99	12	1822	76.16	112.15
1	158	39.06	13	1606	91.01	130.07
1	119	33.27	9	1085	91.16	124.43
1	139	35.75	12	1331	109.45	145.21
1	131	35.82	13	1555	89.54	125.36
1	125	28.76	10	1412	85.18	113.93
X	1104	290.73	91	12429	667.27	958.01
X	138	36.34	11.4	1554	83.41	119.75
2 s	26	8.26	3.0	552	32.68	29.54

varied between ₱25 to ₱35. However, the lower rates required that meals be provided for the two operators of each tractor. The present rate around Los Baños (IRRI) is ₱35/day.

The cost of a 6-hp tractor with equipment is ₱3,700 cash or ₱4,900 spread out over 42 months. Several ways to examine this fixed cost are presented. Straight-line depreciation for the cash price yields the following, considering a 7-year life:

$$\frac{\text{₱}3{,}700}{7} = \text{₱}530/\text{year}$$

For the tractor cost plus interest, at a more pessimistic 5-year life:

$$\frac{\text{₱}4{,}900}{5} = \text{₱}980/\text{year}$$

For the farmer to meet his payment of ₱700/crop, he needs to earn 2 x ₱700 = ₱1,400/year.

One can estimate the farmer's break-even (B/E) workload to meet his payments or to compare with computed depreciation. The simplest form of the break-even formula is to compute a ratio of the amount of money needed to be paid or earned to the variable profit per unit of measurement. The ratio is:

$$B/E = \frac{\text{Fixed cost (FC)}}{\text{Total revenue/unit} - \text{variable cost/unit}}$$

The variable costs of tractor operation are the hire of the tractor operators and the fuel and repair costs.

Two men combine to operate a tractor at a daily wage of ₱5 plus meals and snacks. The total daily cost may be ₱15. Fuel cost per day is roughly ₱4. Not enough data on repairs have been collected to adequately estimate repair costs. A repair cost is assumed to be ₱100 per year, or for 100 days of operation, ₱1/day.

Tractor contract costs vary from ₱25 to ₱35. The latter amount is typical of rates which include meals.

Using these operating costs,

(Cash cost, 7-year life):

$$B/E = \frac{\text{₱}530}{\text{₱}35 - \text{₱}15 - \text{₱}4 - \text{₱}1}$$

$$= \frac{\text{₱}530}{\text{₱}15}$$

$$= 35.3 \text{ days;}$$

(Installment cost, 5-year life):

$$B/E = \frac{\text{₱}980}{\text{₱}15} = 65.3 \text{ days;}$$

(To meet yearly payment of ₱1,400.00):

$$B/E = \frac{\text{₱}1{,}400}{\text{₱}15} = 93.3 \text{ days.}$$

Under favorable assumptions of depreciation and length of life, the number of tractor-operating days needed to cover the fixed cost is 35.3. For the shortest life assumption and depreciation based on computed cost plus interest, the number of work days needed rises to 65.3. And, finally, the number of working days approaches 100 to meet the yearly payment. These requirements could be reduced by one-third if the owner personally operates the machine.

Table 9. Comparison in time and costs of plowing and harrowing with a carabao and a 6-hp hand tractor.

Time, Cost	Plowing*		Harrowing†	
	Carabao‡	Tractor§	Carabao	Tractor
Mean time (hr/ha)	36.3	12.9	83.4	13.9
Range (hr/ha)	28.8 –41.2	11.2 –14.6	55.5 –109.5	11.3 –16.6
Average cost (₱)	48.33 (60.69)‖	56.50	110.94 (139.29)‖	60.88
Range (₱)	38.25–54.85 (48.03–68.87)‖	49.14–63.95	73.75–145.57 (92.60–182.78)‖	49.54–72.80

*Plowing = one pass.
†Harrowing = "adequate" at 9 to 13 passes of the carabao and 3 to 4 passes of the tractor.
‡Contract rate: ₱8/6-hr a day or ₱1.33/hr.
§Contract rate: ₱35/8-hr a day or ₱4.38/hr.
‖at ₱10/day.

The mean length of time to prepare 1 ha of land by tractor is 27 hours, or 3.4 days (Table 9). Then the number of hectares of prepared land necessary to cover the annual fixed cost is, for the low estimate, $65.3 + 3.4 = 19.4$ ha. Thus, if the contract rate is the appropriate measure, the farmer needs to prepare between 10 and 20 ha of land per year to cover the tractor costs, or roughly 30 ha, to meet the twice-yearly tractor payment.

Another means of comparison is to compute the cost of land preparation before the tractor purchase. For instance, if the work is done by animal on a contractual basis, the cost of preparing 1 ha (using mean data from Table 9) is ₱160. From these data, the tractor owner can calculate if his hectarage is sizeable enough to warrant the purchase of a tractor.

One must also recognize the amount of time worked off the tractor owner's farm. If the owner works the tractor 30 days off his own farm, he contributes ₱15/day to cover fixed cost or ₱450 for 30 days.

Agricultural Economics

The research program in Agricultural Economics has focused on problems of concern at both the farm and the national level. The report is divided into three major sections. The first section presents the results of farm level surveys and controlled experiments designed to determine the cultural practices for rice production currently being adopted by farmers, and the practices that are most economical. The second discusses seed multiplication in the Philippines, the first in a series of studies relating to input requirements for rice production. The final section reports on research in national pricing policy.

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Productivity and Efficiency in Rice Production

The adoption of IR8 and other new rice varieties is proceeding at an unusually rapid pace in some regions of Asia. IR8 was first planted on a large-scale in the Philippines during the 1967 wet season. This was the first season in which seed was not a limiting factor. Unofficial reports indicate that approximately 200,000 hectares were planted to this variety, representing about 10 percent of the wet-season lowland rice areas. The studies reported in this section compare the physical and economic performance of IR8 and other improved varieties with that of local varieties. The objectives are to report the changes that are taking place on the farm and determine the optimum cultural practices for the local and improved varieties. The first of the three sections which follow deals with the results of farm surveys; the two subsequent ones, with the economic analysis of experimental data.

Factors affecting the spread of new varieties

This section reports the findings of three farm surveys showing the changes in yields, cultural practices, costs, and returns associated with the adoption of new rice varieties. The farms surveyed cannot be considered typical of the whole Philippines, for they are located in predominantly lowland, irrigated areas. Nevertheless, the results provide a picture of the impact at the farm level in those regions where the adoption has been most rapid.

A survey of farms in Pampanga and Bataan provinces. A survey was made in the summer of 1967 to determine the differences in yields, costs, and returns on those farms using improved Seedboard (IR8 and BPI-76-1), other Seedboard, and local varieties. Seedboard varieties are those which have been approved by the Philippine Seedboard and in this survey include Peta, Milfor, Seraup Ketchil, BE-3, and Tjeremas besides IR8 and BPI-76-1. Comparisons were made among improved, other Seedboard, and local varieties and between owner-operated and tenant farms (Table 1). Although the 1966 wet season is compared with the 1967 dry season, records show that wet- and dry-season yields on these farms have in the past been almost identical.

The results in Table 1 indicate: (1) no consistent difference in yield performance and income between farms planting other Seedboard and local varieties, (2) a significant difference in performance between improved and other varieties, and (3) a significant difference in performance between owner/operator and tenant farms. Farms using improved varieties had higher yields, higher cash costs, higher labor inputs and higher net returns than those using other varieties. The same could be said for owner/operator vs tenant farms. In computing net returns, the price was standardized at P16 (US$4.10) per cavan (1 cavan = 44 kg). However, farm prices are normally 10 to 20 percent higher in the dry season.

A survey of farms in Rizal province. The Agricultural Development Council of Rizal (ADCR) was formed in 1966 to further the agricultural development of that province. One of its first steps was to promote the production of IR8, which it has named Rizal Seed No. 1. The first major planting of IR8 took place in the 1966 wet season. The results from 45 farms under the ADCR program (37 irrigated and 8 rainfed) are shown in the two right-hand columns of Table 2. Both irrigated and rainfed farms obtained yields in excess of 100 cavans per hectare.

More complete information was obtained for the dry season through a random sample survey conducted by the ADCR in 1967 in Rizal Province. A 10-percent sample of lowland rice farms was drawn (with a minimum of two farms per municipality). The farmers were asked to recall their yields and expenses for the 1966 as well as the 1967 dry season. The results are shown in the first four columns of Table 2 for IR8 and for Binato (or Thailand), a popular local variety. The yield frequency distribution for both varieties is also shown in Fig. 1.

As in Central Luzon, the yields, costs, and net returns in Rizal were higher for IR8 than for the local variety. For comparable input levels, however, the yields in Rizal were higher than those in Pampanga and Bataan and consequently the returns were also higher. To facilitate comparison, the returns were based upon a standardized value of P16 ($4.10) per cavan. Many Rizal farmers sold IR8 seed at a considerably higher price during this period.

Table 1. Returns and costs per hectare of rough rice on irrigated farms using improved, Seedboard-approved, and local varieties. Pampanga and Bataan, 1966-67.*

Item	1967 dry season				1966 wet season			
	IR8		BPI-76-1		Other Seedboard		Local	
	Owner/ operator	50/50 share	Owner/ operator	50/50 share	Owner/ operator	50/50 share	Owner/ operator	50/50 share
No. of farms		28	4	7	8	22	9	6
Costs								
Fertilizer (₱)	194	128	172	101	53	49	46	22
Chemicals (₱)	51	47	32	6	12	8	14	31
Other cash costs† (₱)	334	210	157	163	189	105	167	135
Cost in kind‡ (₱)	106	182	235	138	131	119	111	141
Total cash costs and in kind (₱)	685	567	596	408	385	281	338	329
Total costs (₱)	957	828	664	527	765	650	728	667
Labor input (man-days)	85.7	74.6	90.1	78.3	71.9	59.0	64.6	64.5
Yield of rough rice in								
Kg/ha	4523	4268	3740	3080	3036	2464	2948	2200
Cavan/ha	103	97	85	70	69	56	67	50
Average area of variety farm (ha)	1.96	1.72	2.38	2.40	1.87	3.59	2.71	2.18
Gross return§ (₱)	1648	1552	1360	1120	1104	896	1072	800
Net return								
Over cash costs and in kind (₱)	963	985	764	712	719	615	734	471
Over-all costs‖ (₱)	691	724	696	593	339	246	344	133

*Improved varieties include IR8 and BPI-76-1. Other Seedboard varieties include Peta, Milfor, Seraup Ketchil, BE-3, and Tjeremas.
†Include cash costs for land preparation, pulling of seedlings, transplanting, and transportation.
‡Include costs of harvesting, threshing, and seeds.
§At ₱16/cavan or ₱0.36/kilogram of rough rice. $1.00 = ₱3.90.
‖Include charge for land, and family and operator labor.

A survey of farms in Laguna province. A study was undertaken in three municipalities of Laguna (Calamba, Cabuyao, and Biñan) in the fall of 1967 to inquire into the physical, economic, and social factors influencing the spread of new rice varieties. A group of 155 predominantly tenant-operated farms were surveyed. These farms had been visited in an earlier study which provided a basis for comparing current and previous records of performance.

Preliminary findings reported in Table 3 show the yields of three groups of farmers: (1) adopters, (2) non-adopters, and (3) partial adopters. The first group of 61 farmers (40%) made the complete switch to improved varieties. The second group of 44 (29%) continued to plant the same varieties. The third group of 47 (31%) used the new varieties in about one-half of their farms.

Figure 2 shows the distribution of yields in Laguna. It is similar to Fig. 1 for Rizal except that there are fewer observations at high yields.

Table 3 shows yield and input data for the three types of farms mentioned. As with the two earlier surveys, both yield and input levels are higher. The evidence is that farmers have not adopted a new variety, but a whole package of new practices. The two right-hand columns of Table 3 compare old and new varieties grown side by side on the same farms. For the traditional varieties the input levels are the same as in 1967. However, for the improved varieties cash crop expenses are much higher.

Another important piece of information

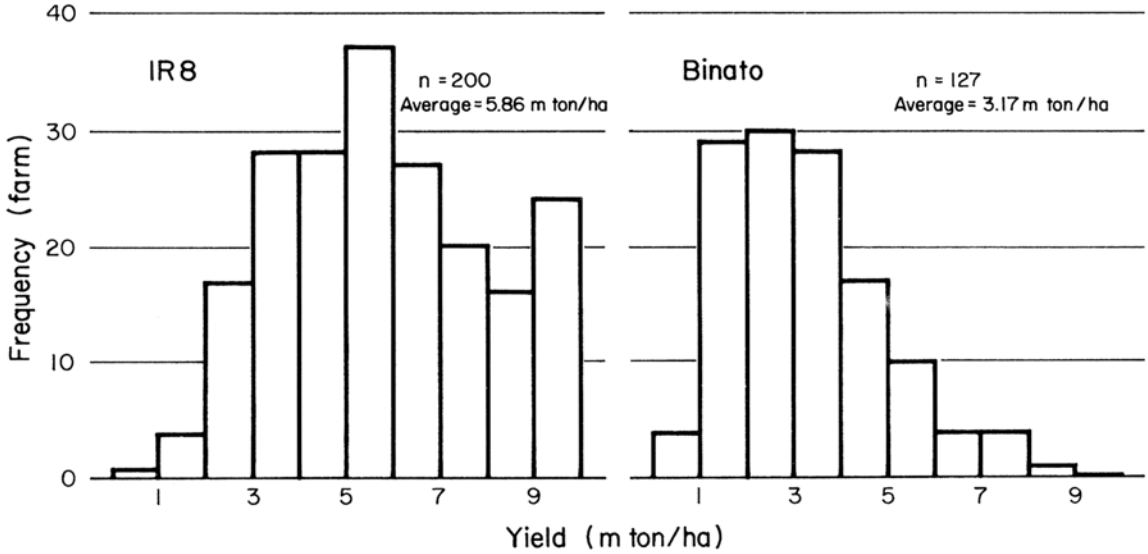


Fig. 1. Yield distribution of IR8 and Binato rice varieties, Rizal. 1966-1967 dry season.

Table 2. Returns and costs per hectare of rough rice on farms using two rice varieties. Rizal, 1966 and 1967 dry season, 1966 wet season.

Item	1966 dry season		1967 dry season		1966 wet/dry season	
	IR8	Binato†	IR8	Binato	Irrigated	Rainfed
No. of farms	4	143	200	127	37	8
Costs						
Fertilizer (₱)	270	50	146	39	159	91
Chemicals (₱)	45	10	61	4	114	132
Other cash costs‡ (₱)	287	210	193	83	—	—
Costs in kind (₱)	539	176	379	249	—	—
Total cash cost and in kind§ (₱)	1141	446	779	375	—	—
Yield						
Kilograms	7267	3276	5852	3165	5332	4721
Cavans	165	75	133	72	121	107
Area (ha)	0.81	0.71	0.63	0.64	0.82	0.98
Gross return‖ (₱)	2640	1200	2128	1152	1936	1712
Net return						
Over cash costs and in kind (₱)	1829	904	1615	921	—	—

*These data are summarized from the records of the Agricultural Development Council of Rizal. Results of the 1966 and 1967 dry seasons are based upon a random sample taken throughout the province in 1967. The data for 1966 wet season are from those farms participating in the ADCR program.
†This variety is also known as Thailand.
‡Include cash costs of land preparation, weeding, transplanting, and pulling of seedlings.
§Costs in kind include costs of harvesting, threshing and seeds.
‖At ₱16/cavan.

reported in this survey is typhoon damage. One of the most severe typhoons recorded in Laguna struck at almost the peak of the harvest period. Twenty-eight farmers growing new varieties (26%) and 11 farmers growing local varieties (19%) reported typhoon damage. The estimated yield decline due to the typhoon was 31 cavans for IR8 and 10 cavans for the local varieties. IR8 did not lodge but shattered (part of the panicle was "blown away"). In the aggregate, the loss estimate represented 12 percent of the total IR8 crop on these farms, 4.5 percent of the

Table 3. Input and output information for lowland rice farms of three selected areas. Laguna, 1966 and 1967 wet seasons.*

Item	Varieties						
	Local to improved		Local		Local to improved and local		
	1966	1967	1966	1967	1966	1967	1967
No. of farmers	59	59†	44	44†	46	46‡	46‡
Nitrogen application (kg/ha)	16	75	15	20	19	76	24
Fertilizer expense (P/ha)	28	99	24	30	31	106	38
Weedicide expenses (₱/ha)	5	8	4	9	4	7	2
Insecticide expenses (P/ha)	3	19	2	5	3	18	5
Labor§ (man-day/ha)	54	76	52	50	53	79	51
Yield of rough rice in							
kg/ha	2420	4224	2288	2112	2596	4752	2420
cavans/ha	55	98	52	48	59	109	57
Average area of variety per farm (ha)	2.4	2.4	2.4	2.4	2.5	1.1	1.3

*The term "local" includes all native varieties.
†Typhoon damage was reported on 15 farms growing IR8 variety and 11 farms growing local varieties in 1967. The estimated loss per hectare was 32 cavans for IR8 and 9.6 for the local varieties.
‡Typhoon damage was reported on farms growing IR8 and local varieties as follows:
12 farms estimated damage of 28.5 cavans per hectare on IR8 and six farms estimated damage of 7.5 cavans per hectare on local varieties.
§Labor inputs did not include labor for harvesting and for threshing.

local crop, and 10 percent of the total crop.

The farmers in this survey were asked further why they adopted or did not adopt new varieties. Their answers are shown in Tables 4 and 5. Expected high yield was the first reason given for shifting varieties and cultural practices. Landlord's decision and high cost of input were the primary reasons given by those that did not shift varieties.

During the course of the survey, it became apparent that farmers were considerably disturbed by the low price obtained for IR8. Millers discounted the price of IR8 because of reported poor milling and inferior eating qualities. Further price discounting occurred because much of the rice was sold wet in the field. IR8 matured earlier than most local varieties before the end of the wet season and adequate drying facilities were not available. The sensitivity of farmers to the price and cost of growing IR8 is reflected in Table 6. Forty-eight farmers (44% of those now growing IR8) said they would not plant this variety again. Another 17 farmers (16%) said they would reduce the area planted to IR8. The major reasons given were low selling price and high production cost.

Finally, Table 7 gives the opinions of farmers regarding the relative advantage of improved over local varieties with respect to price, yield and other factors. IR8 was rated better in yield and resistance to lodging, but poorer in price, eating quality, disease resistance, and amount of weeding required. In spite of some

Table 4. Reasons given for the adoption of improved rice varieties. Laguna, Philippines, 1967 wet season.

Reason	Number of farmers giving reason	Number of farmers indicating the single most important factor
a. Expected high yield	105	97
b. Landlord's decision	55	6
c. Follow advice of extension worker	68	0
d. Expected high price	41	1
e. Follow advice of neighbor	11	0
f. Others	21	6
		110
Total number of adopters	110	
Total number of respondents	110	

TABLE 2. Algal populations developing in flooded soil[a].

Days submerged	*Oscilla-phyceae*	*Oscilla-toriaceae*	*Nosto-caceae*
		$\times 10^2$/g soil	
0	5.0	2.0	2.0
13	19.0	19.0	2.0
48	17.0	17.0	17.0
69	13.0	0	0
90	12.0	2	1.0

[a] Soil 27: Clay, pH 6.6; O.M. 2.0%. Total N 0.14%.

with Soil 28 (Clay, pH 4.7; O.M. 3.2%).

Certain blue-green algae can fix atmospheric nitrogen and are often found in rice paddies. However, to make significant nitrogen contributions a large and active population must be present. From the data in Table 2 it is difficult to assign a major role in nitrogen fixation to these algae in the soil studied. Alkaline soils, well supplied with phosphorus, would represent a more suitable medium for developing blue-green algae. In such soils, the nitrogen contributions of blue-green algae are possibly more important.

The role of the anaerobic nitrogen fixing bacteria in flooded soils has not attracted much attention although a large portion of the soil profile under lowland rice culture is anaerobic. Perhaps the chief reason is that these organisms require an adequate source of carbohydrate. At each harvest, large amounts of organic matter are returned to the soil in the form of root systems, stubble, straw, and weeds. The carbohydrate in this organic matter may supply the needs of the heterotrophic nitrogen-fixing organisms.

Populations of anaerobic nitrogen fixing bacteria were estimated in two Luzon soils (Table 3). Significant populations were found. The reasons for the decline in populations with time are not known, but may have been caused by a depletion of some essential growth substance.

TABLE 3. Numbers of nitrogen-fixing anaerobes in two submerged soils.

Days Submerged	Soil 27[a]	Soil 28[b]
	x 10^3/g soil	
0	550	58
13	280	37
48	46	63
69	12	10
90	22	12

[a]Soil 27: Clay, pH 6.6, O.M. 2.0%, Total N 0.14%.
[b]Soil 28: Clay, pH 4.7, O.M. 3.2%, Total N 0.21%.

Fifty isolates derived from submerged rice soils and the rhizosphere of rice plants were collected and their ability to fix atmospheric nitrogen in liquid culture tested. Table 4 shows the results obtained with 15 of the cultures. Efficiencies of fixation were

TABLE 4. Fixation of molecular nitrogen by anaerobes isolated from submerged rice soils and the rhizosphere of rice plants.

Isolate	Nitrogen fixed[a] (μg N/ml)	Sucrose utilized (mg Sucrose/ml)	Nitrogen assimilated (mg N/g Sucrose)
1	87	24	3.6
2	67	25	2.7
3	65	25	2.6
4	68	25	2.7
5	67	24	2.8
6	117	23	5.1
7	141	22	6.4
8	67	22	3.0
9	66	22	3.0
10	68	17	4.0
11	94	23	4.1
12	68	23	3.0
13	209	22	9.5
14	96	22	4.4
15	79	19	4.2

[a]Total N at 2 weeks — Total N at zero time.

Table 7. Relative advantages between new varieties and local varieties as reported by 153 farmers. Laguna, Philippines, 1967 wet season.

Item	Number of farmers reporting		
	Better	Worse	Same
Price	3	148	2
Yield	150	2	1
Eating quality	4	144	5
Disease resistance	22	119	12
Lodging	151	2	0
Amount of weeding labor requirement	7	120	26

a local variety which originated from Indonesia, is typical of many of the tall native indicas in its tendency to lodge even under modest levels of nitrogen application.

Functions were fitted separately according to season (wet vs dry), variety and location. The available data for 1966 and 1967 were combined except for the Maligaya wet-season results. The latter were not used because a severe attack of bacterial leaf blight greatly reduced yields.

An example of the regression analysis is illustrated by the following equation:

$$(1) \qquad Y = 3060.7 + \underset{(4.725)}{56.823\,N} - \underset{(.030)}{0.248\,N^2}$$

where

Y = yield of rough rice in kg — IR8

N = application of elemental nitrogen in kg

The equation was fitted using data from the Maligaya 1966 wet season. The number in parentheses is the standard error of the coefficient.

Benefit:cost ratios. Using the production functions, partial budgets were developed to compute the marginal benefit:cost ratios for the use of nitrogen fertilizer. An example, based on equation 1, is shown in Table 8. Yields were established for 30-kg intervals of nitrogen application ranging from 0 to 120 kg/ha. The return due to fertilizer was computed by establishing the increase above the yield without fertilizer. This increase was reduced by one-sixth to allow for the harvester's share, and multiplied by P0.36 ($0.09), the price per kilogram of rice. The cost of fertilizer was subtracted from the return to obtain the net return to fertilizer.

Added return is the return per additional 30 kg of nitrogen applied. Added cost is the cost for 30 kg of fertilizer. Added return divided by added cost is the marginal benefit:cost ratio. This ratio declined with each additional input of 30 kg of nitrogen.

Using the same procedure shown in Table 8, benefit:cost ratios were calculated at varying fertilizer levels for all of the four varieties mentioned at two locations during both the wet and dry seasons. These ratios are presented in Table 9. The marginal benefit:cost ratios declined and neared zero as more nitrogen was added. For a given level of nitrogen, the magnitude of the benefit:cost ratio varied according to variety, location, and season.

In a strict theoretical sense, profit maximization occurs at a point where added return equals added cost (marginal benefit:cost ratios = 1). Beyond this point (which occurs at about 120 kg/ha of nitrogen in the example in Table 8), an additional amount of fertilizer applied will not provide sufficient yield to cover the fertilizer cost. However, a more realistic interpretation should consider other factors such as shortage of capital, high interest rates, and risk.

In Table 10, a minimum acceptable benefit:cost ratio of 2.5 was adopted and the optimum level of fertilizer input was computed on the basis of this ratio. The optimum level computed was rounded off to the nearest 30 kg. Thus, the fertilizer levels shown in Table 10 vary by 30-kg intervals from 0 to 120 kg.

For the wet season, the fertilizer levels were uniform between varieties, except Peta, which was consistently lower than the other three varieties. However, the optimum levels of fertilizer application were higher at Maligaya than at the Institute. For the dry season, the optimum level differed according to variety, but was not consistently different for different locations.

The difference in cloud cover of available solar energy as well as soil type resulted in a difference in response due to location during the wet season. For example, with the heavier cloud cover at the Institute, optimum fertilizer levels for three of the four varieties were 60 kg less than at Maligaya. However, when the solar energy

Table 8. The change in cost and return associated with a 30-kg increase in fertilizer level, IR8. Maligaya Rice Research and Training Center, 1966 wet season.*

N applied (kg/ha)	Grain yield (kg/ha)	Return from fertilizer† (P)	Cost of fertilizer (P)	Net return from fertilizer (P)	Added return (P)	Added cost (P)	Added return/Added cost
0	3060.7	0	0	0	0	0	0
30	4542.2	444.45	35.40	409.50	444.45	35.40	12.6
60	5577.3	754.99	70.80	684.19	310.54	35.40	8.8
90	6166.0	931.61	106.20	825.41	176.62	35.40	5.0
120	6308.3	974.27	141.60	832.67	42.66	35.40	1.2

*Based on equation (1) and price of rice = P0.36/kg; price of N = P1.18/kg N from urea.
†Includes deduction for cost of harvesting increased production due to N application.

Table 9. Marginal Benefit: cost ratios for each additional 30 kg of nitrogen applied to selected varieties, IRRI and Maligaya Rice Research and Training Center, 1966 wet and dry seasons, 1966 and 1967 observations combined.*

Nitrogen applied	Dry season, 1966 and 1967							Wet season, 1966 and 1967						
	IRRI				Maligaya			IRRI				Maligaya		
(kg/ha)	IR8	C-18	BPI-76-1†	Peta	IR8	C-18†	Peta	IR8	C-18	BPI-76-1	Peta	IR8‡	BPI-76-1‡	Peta‡
0	9.2	14.2	9.8	0	9.9	4.4	2.7	5.5	7.7	3.6	0	14.4	9.1	8.3
30	9.1	8.0	7.5	0	8.1	3.6	1.5	3.4	1.0	2.3	0	10.7	7.1	4.9
60	6.3	1.9	5.2	0	6.3	2.8	0.3	1.3	0	0.9	0	6.9	4.5	1.6
90	4.9	0	2.9	0	4.5	2.0	0	0	0	0	0	3.1	1.9	0
120	3.5	0	0.6	0	2.7	1.1	0	0	0	0	0	0	0	0

*Procedures for computation differ slightly from Table 10 since calculus was used to obtain point instead of interval estimates. Rice was valued at P0.36/kg with 1/6 of the added profit deducted as harvesters' share.
†Only 1967 data were available.
‡Only 1966 data were used as the 1967 crop was badly damaged by bacterial leaf blight.
§Dotted lines indicate approximate location of 2.5 to 1 marginal benefit:cost ratio.

"ceiling" was removed in the dry season, the response to fertilizer was limited by the capacity of the variety to respond, which was highest for IR8 and lowest for Peta. Location as a factor became less important.

Relationship between cultural practices and rice yields

The preliminary results of a study of physical and economic relationships between rice yield and land preparation, weeding, fertilizer and variety were reported last year. The equipment and methods used are shown in Table 11. They are for the most part similar to those now being used by farmers in the Philippines. However, for experimental purposes insect and pest control have been maintained at a high level. The experiments were conducted on the Institute farm during the 1966 wet season and the 1967 dry and wet seasons. The results reported here are principally those of the 1967 dry and wet seasons.

The analysis of experimental results follows the broad conceptual framework expressed in the four equations below:

(1) Yield = f (amount of land preparation, weeds removed at weeding, date of weeding, weeds at harvest, nitrogen level, variety)

(2) Weeds removed at weeding time = f (amount of land preparation and date of weeding)

(3) Manpower input at weeding time = f (weeds removed at weeding and date of weeding)

(4) Cost of inputs = f (cost of land preparation, cost of weeding, and cost of nitrogen)

These equations do not show all the factors influencing the dependent variables, but only those allowed to vary in the experiment. Gross

Table 10. Estimated nitrogen requirement (kg/ha) based on benefit:cost ratio of 2.5 to 1.*

Season	IR8	C-18	BPI-76-1	Peta
Wet				
IRRI	60	30	30	0
Maligaya	90	—	90	60
Dry				
IRRI	150	60	90	0
Maligaya	120	90	—	30

*Results are rounded to the nearest 30 kg.

returns were measured by multiplying yield in equation (1) by the price of rice. Equation (2) shows the physical relationship between weed removal and land preparation. Equation (3) shows the physical relationship between weed removal and manpower input. The latter two equations are linked since the amount of land preparation determines the amount of weeds remaining to be removed at weeding time, which in turn determines the manpower needed to perform one complete weeding. Together they provide the information necessary to determine the cost of weeding and land preparation shown in equation (4).

The economic objective is to obtain the highest returns possible by choosing the optimum combination of inputs. Since land preparation and weeding are in part substitutes for one another, the problem is to determine the optimum quantities of these inputs plus the optimum date of weeding. This is achieved by maximizing gross return minus the cost of inputs (i.e. maximizing equation (1) times price of rice minus equation (4)).

Optimum date of weeding. Figure 3 illustrates how the above relationships are used to identify this maximum. The analysis concerns only date of weeding and rice yield as variables (land preparation, 6 passes of carabao; nitrogen level, 75 kg; variety, IR8). The results are based upon data obtained in the 1967 dry season.

Three curves are shown: gross return, cost, and net return. These curves were obtained as follows: First, a quadratic equation was fit for yield as a function of weeding date. This equation was multiplied by the assumed rice price (P0.36/kg or $0.09/kg) to obtain the function for gross returns. Next, a quadratic equation was fit for man-hour requirements for weeding as a function of date of weeding. This equation was multiplied by P0.44 ($0.11) (the minimum Philippine farm wage rate) to obtain the cost function shown in Fig. 3. Finally, the net return function was determined by subtracting cost from gross return.

All rice plots received only one complete handweeding. However, the time of weeding varied by 7-day intervals beginning at the date of transplanting and ending at 35 days after transplanting. Yield increased as the weeding date was delayed after transplanting, reached a maximum at 18 days, after which it declined. In the period from 7 to 28 days after transplanting the

Table 11. Equipment and methods used in land preparation and weeding. IRRI, 1966-67.

Year and season	Equipment and methods			
	Land preparation	Weeding	Fertilizer	Insecticide
1966 wet season	Carabao (water buffalo); 12-cm moldboard plow; 137-cm comb tooth harrow	Handweeding; rotary weeder; MCPA herbicide	Ammonium sulfate	Lindane Sevin
1967 dry season	Carabao; 12-cm moldboard plow; 137-cm comb tooth harrow; 6-hp Landmaster tractor; 18-cm moldboard plow; 137-cm comb tooth harrow	Handweeding	Ammonium sulfate	Diazinon
1967 wet season	Carabao; 12-cm moldboard plow; 137-cm comb tooth harrow; 6-hp Landmaster tractor; 18-cm moldboard plow; 137-cm comb tooth harrow 8.5-hp Iseki tractor rototiller	Handweeding	Ammonium sulfate	Diazinon

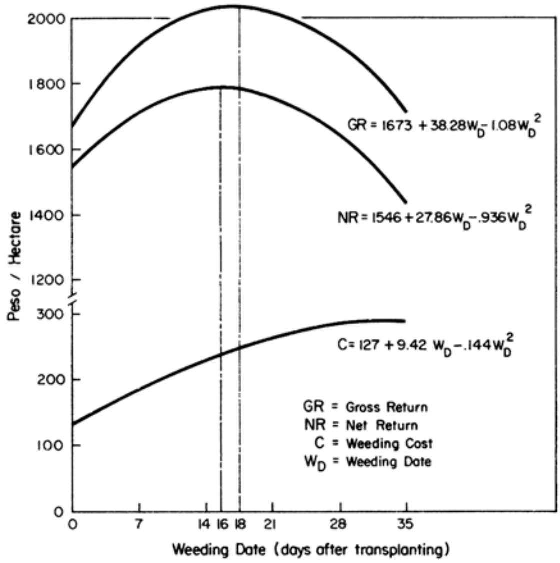


Fig. 3. Costs and return to weeding at various weeding dates for IR8, IRRI, 1967 dry season.

difference in yield level from low to high was about 300 kg. Assuming that the price of rough rice was P0.36 ($0.09) per kg, the difference was P108 ($27.69). The cost of weeding rose steadily. For example, it required 100 hr/ha more to weed at 28 days than at 7 days after transplanting.

The net return function reaches a maximum at 16 days for the prices assumed. As the cost of labor decreases, weeding can be delayed by as much as a week. In fact, a 2-week delay (14 to 28 days after transplanting) will have little effect upon yield but will make the job more costly labor-wise. These results emphasize the importance of early weeding not only in maintaining high yields but particularly in reducing labor requirements.

Similar results were obtained for IR8 in the wet season. The picture for H-4, however, is far more complex since both nitrogen level and date of weeding influenced the date of lodging and hence, yields. Only a few of the H-4 treatments lodged during the dry season and lodging occurred very close to harvest. There was essentially no loss in yield due to lodging. Maximum yields were obtained when weeding was done at 7 or 14 days after transplanting, generally earlier than with IR8.

During the wet season, all of the H-4 plots lodged. The relationships among lodging date, weeding, and fertilizer are shown for two replications in Table 12. Most of those plots weeded early and fertilized heavily lodged during a heavy rain 22 days before harvest. Other plots lodged during a typhoon 3 days before harvest. Highest yields were obtained for most fertilizer levels by delaying weeding to 21 or 28 days after transplanting.

The following sections show the physical relationships for equations (1), (2), and (3).

Yield as a function of land preparation, weeds, and variety. Figure 4 follows the framework illustrated by equation (1), modified as follows:

(5) Yield = f (amount of land preparation, weeds present at harvest, and variety)

The results reported were obtained in the 1966 wet season. Yield is a function of three independent variables. No record was kept of weeds removed at weeding time because the weeding methods used varied. Weeds removed by rotary weeder or by herbicides could not be weighed.

The curves shown in Fig. 4 were computed at different levels of land preparation by regressing weed weight 70 days after transplanting against yield. The extreme right of each curve shows the weed weight with no weeding. From right to left, the level of weeding increases. (Dots falling along the curve are the points estimated from the equation for observed weed weights.) Lowest weed weights were obtained with two handweedings and one MCPA spray or, in some cases, with two handweedings alone.

At low levels of land preparation (1 plowing and no harrowing) IR8 and BPI-76-1 responded almost identically to weeding. Thus, the observations were combined into one equation. However, at a given weeding intensity, fewer weeds were present with IR8. For example, with no weeding IR8 had 2,000 kg less weeds at harvest than BPI-76-1 (Fig. 4).

At higher levels of land preparation, separate equations were computed for each variety. The yield of IR8 was higher than that of BPI-76-1 for both single and double harrowings. The functions plotted in Fig. 4 have not been extrapolated beyond the range of observed values. The "tail" of the curve becomes shorter with increased levels of land preparation, reflecting the reduction in weed population. Also, as land

Table 12. Relationships among date of lodging prior to harvest, date of weeding after transplanting and fertilizer level, H-4. IRRI, 1967 wet season.

Date of weeding	Repli-cation	Date of lodging* (days before harvest)					
		Nitrogen level (kg N/ha)					
		0	10	20	30	40	50
(days after transplanting)							
0	1	22	22	22	22	22	25
	2	22	22	22	22	22	22
7	1	22	22	22	22	22	22
	2	22	22	22	22	22	22
14	1	3*	3	3	3	23	23
	2	22	22	22	22	22	22
21	1	3	3	3	3	3	3
	2	3	3	3	3	22	22
28	1	3	3	3	3	3	3
	2	3	3	3	3	22	22
Control Rep 1		22	22	22	22	22	22
(No weeding)—Rep 2		22	22	22	22	22	22

*After typhoon Welming and three days before harvest, all the rice plants lodged.

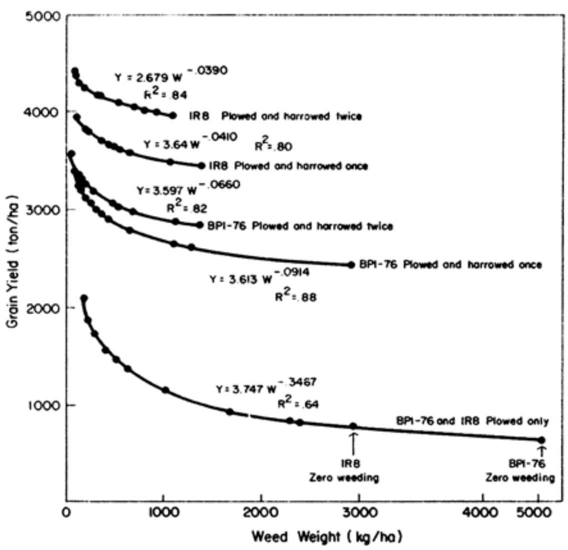


Fig. 4. Relationship between grain yield and weed weight taken at 70 days after transplanting for BPI-76-1 (non-seasonal) and IR8, IRRI, 1966 wet season.

preparation improved, yield response to weeding declined.

The analysis suggests that IR8 is not only more responsive to better land preparation, but also more competitive with weeds. These findings appear to contradict the opinion of farmers expressed in Table 7, in which 120 out of 153 farmers reported that the weeding labor requirement was greater with IR8 than with local varieties.

In the discussion above, the concept of weed weight, as measured 70 days after transplanting, sheds light on the relationship between land preparation and weeding. Nevertheless, from the viewpoint of measuring cost relationships, it would be better to measure weed weight at the date of weeding. For this reason the design was revised for the 1967 dry and wet seasons.

Weeds removed at weeding time as a function of land preparation and date of weeding. As mentioned previously, for the 1967 experiments, weeds were removed by hand and weighed at 7-day intervals following transplanting (0, 7, 14, 21, 28, 35). Each plot was weeded only once. Ten levels of land preparation (6 tractors, 3 carabaos, and no tillage) were used to: (1) permit a quantitative estimate of the effect of additional passes of the tiller on weed weights at harvest, and (2) allow a comparison between the performance of a tractor and carabao (water buffalo).

Figures 5a and 5b show grain yield and weed weights at weeding for varying levels of land preparation with varieties IR8 and H-4 in the wet and dry seasons. The yields shown are the means for all dates of weeding and all nitrogen levels (75 kg N for IR8 and half of this amount

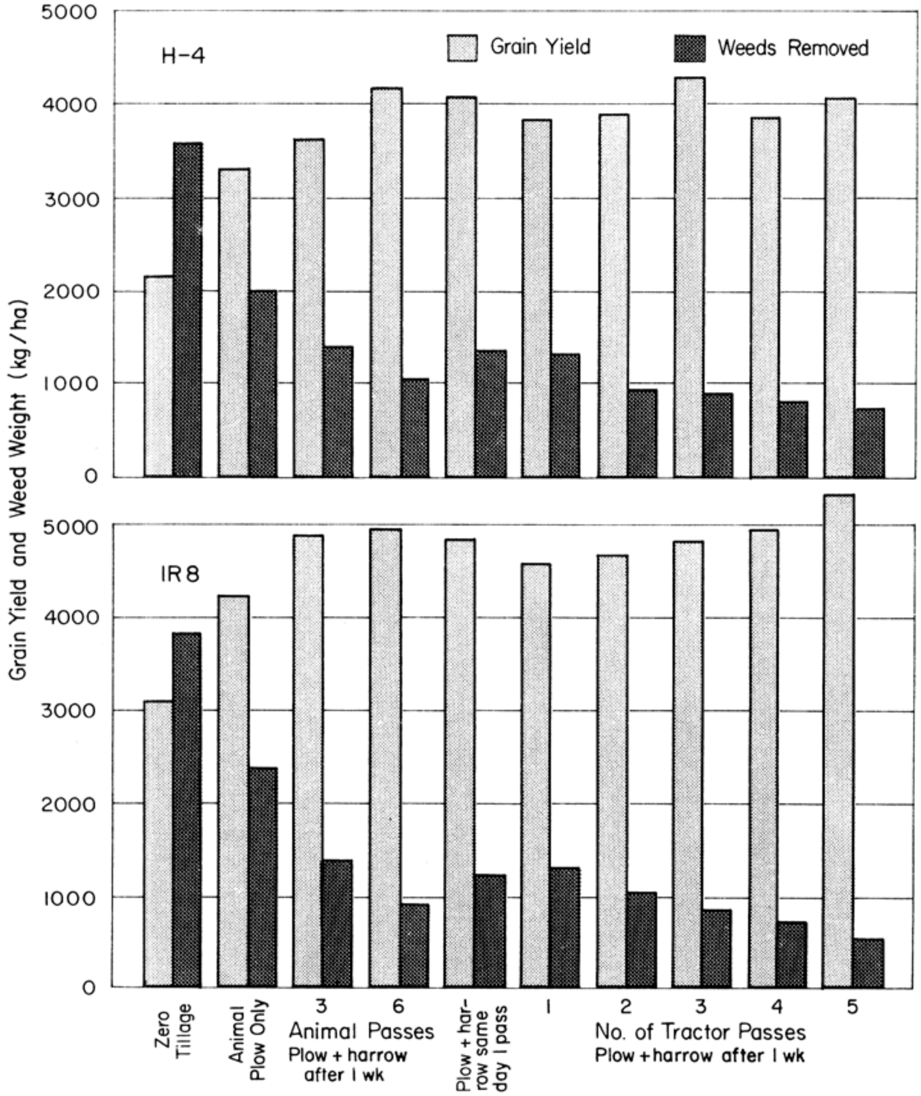


Fig. 5a. Relationship between grain yield and weeds removed with different types of land preparation, IR8 and H-4, IRRI, 1967 dry season.

for H-4 in the dry season, 37.5 kg N for IR8 and 25 kg N for H-4 in the wet season).

With increasing levels of land preparation, the amount of weeds removed by one complete handweeding declined. Once a minimum level of land preparation was achieved (3 passes of the harrow with the carabao and/or 1 pass of the harrow with a tractor) yield levels did not tend to change with increasing degree of land preparation. In terms of weeds removed, one pass of the harrow with the tractor was approximately equal to 3 passes of the harrow with the carabao. (Compare 1 tractor pass vs 3 carabao passes, or 2 tractor passes vs 6 carabao passes in Fig. 5a, or 4 tractor passes with 12 carabao passes in Fig. 5b.)

Figures 6a and 6b show the relationship between the number of passes of the harrow and the weight of the weeds removed at different dates of weeding during the dry and wet seasons. The sets of equations shown were based upon the relationship set forth in equation (2). There was no difference in weed weight at weeding between varieties except at 28 days after transplanting during the wet season. Therefore, the data for varieties were pooled in computing

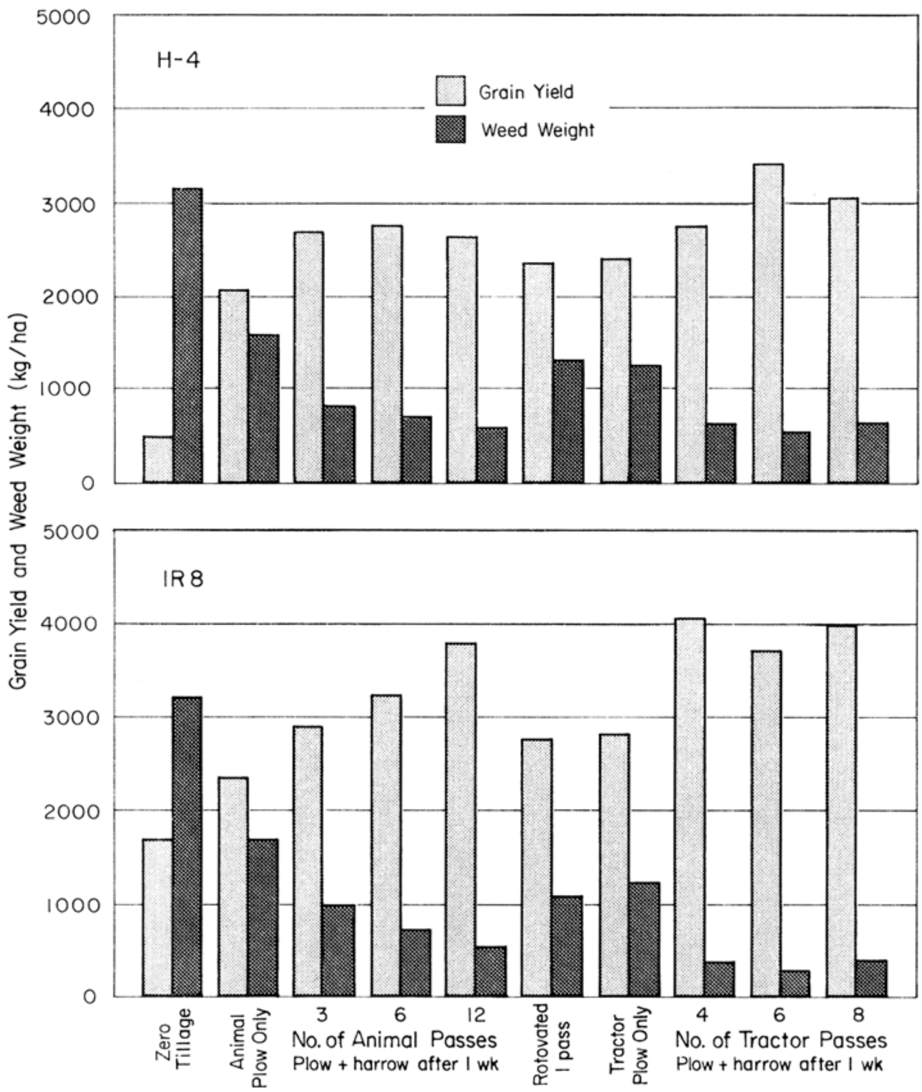


Fig. 5b. Relationship between grain yield and weeds removed with different types of land preparation, IR8 and H-4, IRRI, 1967 wet season.

these functions. For each date of weeding, horsepower-hours were regressed against weeds removed by hand (dry matter, kg/ha).

The result showed a negative correlation. The more horsepower-hours used in land preparation, the fewer the weeds subsequently removed by handweeding. All the functions in Figs. 6a and 6b break and level off sharply at about one tractor pass (three carabao passes) with the harrow, the break being more pronounced the earlier the weeding date. Compared with the first pass, weeds removed by additional passes of the harrow were much fewer. The fact that the IR8 curve falls below that for H-4 at 28 days provides further evidence of the competitive ability of IR8.

For a given date of weeding and land preparation fewer weeds remained in the wet than in the dry season. This was due to factors other than difference in season, since the experimental plots were relocated in the wet season. One difference between the locations was depth of soil. A reading of 35 lb/sq inch on the WES cone penetrometer was obtained on the average at 24.51 cm in the dry season location and at only 16.7 cm in the wet season location.

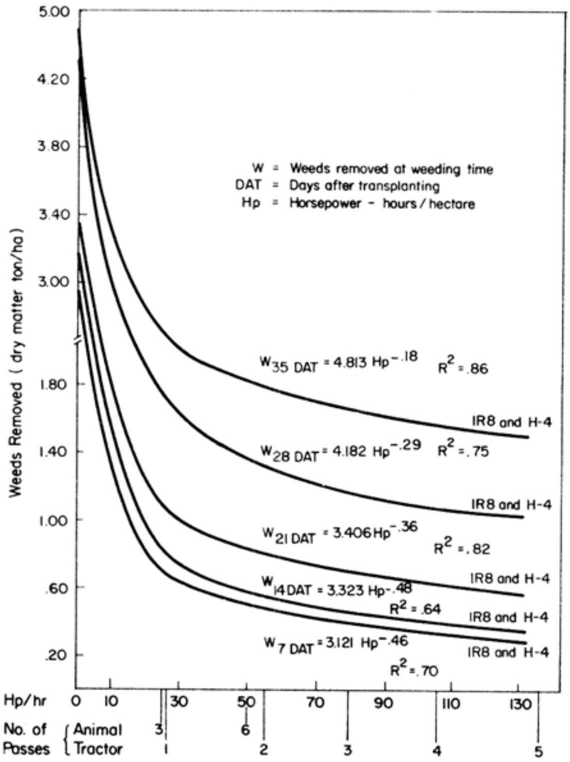


Fig. 6a. Relationship between weeds removed at weeding time and horsepower-hours for harrowing, IRRI, 1967 dry season.

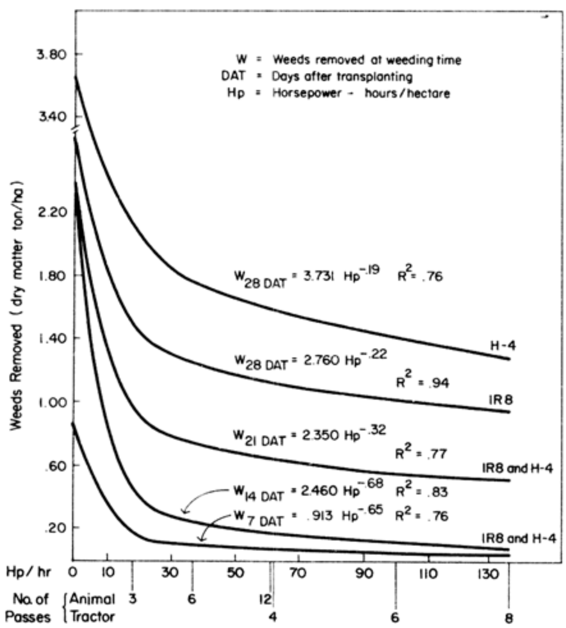


Fig. 6b. Relationship between weeds removed at weeding time and horsepower-hours for harrowing, IRRI, 1967 wet season.

These results provide all the physical data needed to compute the cost of weed removal by land preparation. They may somewhat differ from those a farmer would obtain, however, for the time interval between harrowings was zero while most farmers allow days or even weeks to elapse between these operations.

Manpower input at weeding as a function of weeds removed at weeding time and date of weeding. The relationships shown in Figs. 7a and 7b are as described in equation (3). For each date of weeding, the quantity of weeds removed (dry matter, kg/ha) was regressed on man-hours of labor used for weeding. As the date of weeding was delayed, the relationship between weeds removed and labor used changed. With good land preparation (the left edge of each function), there generally was little difference in labor requirement. Although considerably more weeds were removed at 28 and 35 days, only a little more labor was required (100-200 hr/ha). With poor land preparation (the right edge of each function), labor requirement was much greater as date of weeding was delayed. For a given level of land preparation, weeding in the wet season required generally less labor than in the dry season. Again, labor requirement may have little to do with difference in season, but it may be related to other factors, such as location, soil depth, and weed population.

Cost of land preparation vs cost of weeding. The results shown in Fig. 5a suggest that land preparation and weeding substitute for each other between 2 and 5 passes of the tractor. Within this range more time devoted to land preparation will mean less time required for later weeding. Also within this range, weeding, whether by land or by hand, had no significant effect upon yields.

An analysis based upon this information was conducted to determine the optimum combination of land preparation and weeding. This optimum will depend upon date of weeding. As indicated in Fig. 3, the optimum date of weeding is at 16 days after transplanting. However, frequently weeding is delayed until much later in the season. To show the effect of date of weeding, an analysis was conducted using the functional relationships (Figs. 6a, 6b, 7a and 7b) computed for weeding 14 and 28 days after transplanting. The results are presented in Table 13 for the 1967 dry season.

The time required for each pass of the harrow did not change with the number of tractor harrowings. Therefore, the cost per harrowing remained constant at P17 ($4.36) (based on the local rate of P35 ($8.97)/day). However, the cost of weeding declined with each pass of the harrow since the labor required was reduced. For every level of land preparation, the weight of remaining weeds can be determined directly from Fig. 6a by referring to the equation for the appropriate date of weeding. The manpower required can be determined from Fig. 7a. For example, 0.732 metric tons of weeds remained to be removed at weeding 14 days after transplanting (Fig. 6a, Table 13). It required 415 man-hours of labor to remove the weeds (Fig. 7a, Table 13). The cost of removal was based upon a wage rate of P0.44 ($0.11) per hour. With each pass of the harrow, fewer weeds remained to be removed.

The optimum was reached when the savings in cost of weeding for the last pass approximately equalled P17 ($4.36), the added cost of one more pass of the harrow. This occurred at about 3 passes of the harrow at 14 days after transplanting and at 4 to 5 passes of the harrow at 28 days after transplanting.

A similar analysis was conducted for the 1967 wet season. The difference in soil depth resulted in considerable savings in cost of land preparation. Cost per pass of the harrow was reduced from P17 ($4.36) to P10 ($2.56). Nevertheless, weeding operations were also more efficient. This may have been due, among other factors, to differences in the type of weeds between locations. The optimum number of harrowings was 3 and 5 for 14 and 28 days weeding after transplanting, respectively.

It is, of course, difficult to select an appropriate wage rate for labor engaged in weeding. Sometimes the weeding is performed by the farm operator, sometimes it is done as a part of the harvesting contract. However, one can easily adjust the results in Table 13 assuming a lower wage rate. For example, if the wage rate is P0.22 ($0.05)/hr of labor (one-half of the minimum wage) the costs would be reduced for weeding by 50 percent. The new optimum land preparation level is 2 passes (instead of 3) of the harrow for weeding at 14 days and 3 passes

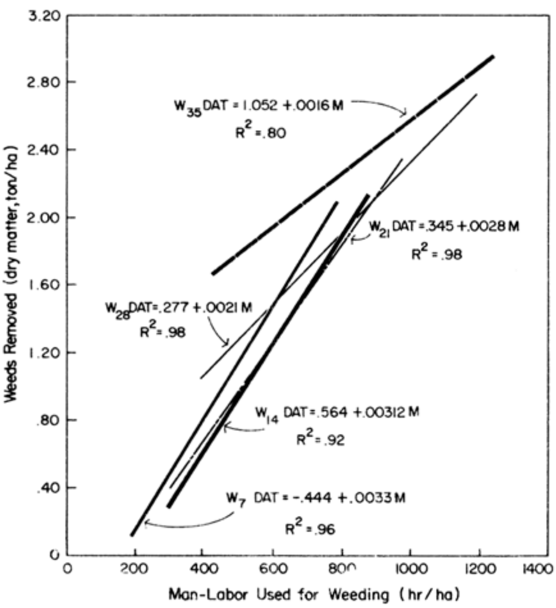


Fig. 7a. Relationship between weeds removed and man-hours used for weeding at different weeding times (days after transplanting), IRRI, 1967 dry season.

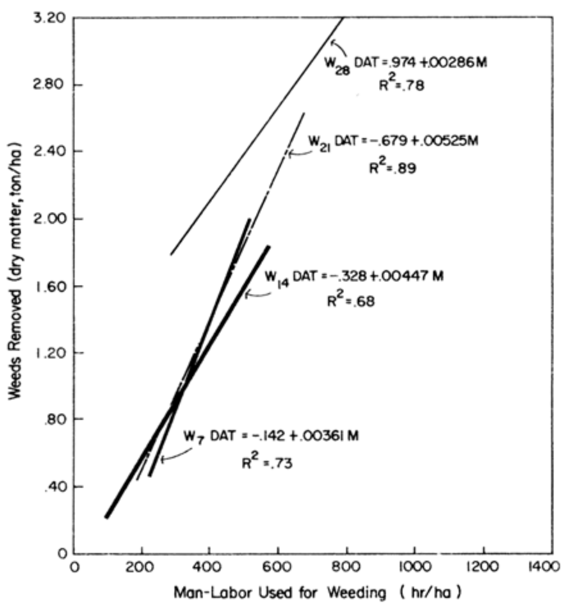


Fig. 7b. Relationship between weeds removed and man-hours used for weeding at different weeding times (days after transplanting), IRRI, 1967 wet season.

Table 13. Relationship between cost of harrowing and cost of weeding. One hectare of rice, 14 and 28 days after transplanting. IRRI, 1967 dry season.

Cost	Number of passes with harrow						
	6-hp tractor					Carabao	
	1	2	3	4	5	3	6
Harrowing							
Time used (hr/ha)	3.90	7.80	11.70	15.60	19.50	24.45	48.90
Total cost* (P)	17	34	51	68	85	31	61
Added cost (P)		17	17	17	17		30
Weeding 14 DAT†							
Weed weight (ton/ha)	.732	.525	.432	.376	.338	.716	.514
Man-hours (6)	415	349	319	301	289	410	346
Total cost‡ (P)	183	154	140	133	127	181	152
Reduced cost (P)		29	14	7	6		29
Weeding 28 DAT							
Weed weight (ton/ha)	1.676	1.371	1.219	1.121	1.051	1.655	1.354
Man-hours (10)	666	521	448	402	368	656	513
Total cost* (P)	293	229	197	177	162	289	226
Reduced cost (P)		64	32	20	15		63

*Based on a custom rate of P35/day for the tractor with two operators and P10/day for the carabao with operator.
†DAT = days after transplanting.
‡Based on P3.50/day or P0.44 hr of labor.

(instead of 4 to 5) of the harrow for weeding at 28 days. According to survey data collected by the Department of Agricultural Engineering, farmers in Central Luzon typically plow once and follow this with 6 passes of the comb tooth harrow with carabao (which is equivalent to 2 passes with tractor).

Tractor vs carabao. The relationship between tractor and carabao cost also is shown in Table 13. Based upon the work performance in harrowing (as measured by weed removal) one pass of the tractor appears to be approximately equal to 3 passes of the carabao. This relationship is shown in Figs. 5a and 5b. There were no significant differences in yield or weed weights between treatments of (1) 3 passes of the carabao vs 1 tractor pass, (2) 6 passes of the carabao vs 2 tractor passes, and (3) 12 passes of the carabao vs 4 tractor passes.

If one assumes the carabao to be equivalent to 1 horsepower and the tractor to 6 horsepower, the horsepower-hours per hectare can be calculated by multiplying time per hectare by horsepower rating. Using time required for 1 pass of the harrow in column 2 of Table 13:

Tractor horsepower hr/ha/pass = 3.9 hr/ha x 6 horsepower

Carabao horsepower hr/ha/pass = 8.15 hr/ha x 1 horsepower

Three passes of the carabao is required to deliver the horsepower-hours equivalent to 1 pass of the tractor. Thus, a horsepower-hour per hectare with the tractor is approximately equivalent in performance to a horsepower-hour per hectare with the carabao. However, beyond 6 passes with the carabao, the data were not sufficient to determine whether this relationship continues.

Current local rates are P35 ($8.97)/day for a tractor with two operators and P10 ($2.56)/day for a carabao with an operator. At these rates the cost of the tractor is less than that of the carabao for equivalent work performed in harrowing. While one pass of the tractor costs P17 ($4.36), three passes of the carabao costs P31 ($7.95). This gap is even greater for the wet season location. The tractor cost falls at P10 ($2.56) per pass due to savings in time. Fuel consumption is also lower (4.41 liters/ha/pass vs 6.85 liters/ha/pass). The carabao costs P24 ($6.15) for 3 passes. Harrowing with a tractor in the shallower paddy required 41 percent less time and 36 percent less fuel per pass. Harrowing with a carabao required 23 percent less time per pass.

For plowing, the cost efficiency in some situations favored the carabao. Figure 5b shows that fewer weeds were left to be harvested after plowing with a tractor. However, the cost for plowing using local rates was P74 ($18.97)/ha for the tractor and P60 ($15.38)/ha for the carabao during the dry season. The cost for both was P50 ($12.82)/ha during the wet season. Again, there is evidence that the efficiency of the tractor increases relative to the carabao in a shallower paddy. Plowing with a tractor in the shallower paddy (35 p.s.i. at 16.7 cm vs 24.5 cm) required 31 percent less time but approximately the same amount of fuel (24.48 liters/ha/pass vs 26.29 liters/ha/pass). Plowing with a carabao required 17 percent less time. A farm survey in Laguna conducted by the Department of Agricultural Economics, UPCA, in 1964-65 suggested that some farmers were aware of the greater efficiency of the tractor for use in harrowing as compared to plowing. Of 126 tractors used in custom work, 80 were used for plowing and harrowing, 39 for harrowing only, and 12 for plowing only.

Summary. The results of the field experiments (1) indicate that weeding and land preparation substituted for each other within the range of 2 to 5 passes of the harrow with hand tractor, (2) emphasize the economic importance of early weeding, and (3) suggest that tractors as compared with carabaos have a relative advantage in harrowing vs plowing and in shallow vs deep soils.

Seed Multiplication and Distribution

The introduction of improved rice varieties has brought about an increased demand for production inputs—fertilizer, chemicals and most important, the seed itself. Through a contract with the Department of Agricultural Economics, UPCA, a study was made of the seed multiplication and distribution system in the Philippines.* The results are reported below.

The government program of seed multiplication and distribution has had three objectives:

(1) Approval and recommendation of varieties which have met specified breeding and yield performance standard.

(2) Multiplication and distribution of certified or "good" seeds from the list of Seedboard-approved varieties.

(3) Rapid multiplication and distribution of new and promising varieties.

The Bureau of Plant Industry began producing certified seeds in 1957. However, in early 1966 the Rice and Corn Coordinating Council (of which BPI is a member) set up a special seed multiplication plan for IR8 to meet the third objective.

Program of the Bureau of Plant Industry

The BPI as early as 1952 started implementing a seed improvement program sponsored by the Mutual Security Aid (MSA) and the Philippine Council for US Aid (PHILCUSA). The program was aimed at providing the farmers with improved seeds of high-yielding varieties suitable for planting in specific regions of the country. In 1953 the program was expanded to include not only seed improvement, but also multiplication, certification, and distribution.

Multiplication and certification. Because of the limited facilities of the government to meet all the seed requirements of the country, the services of selected farmer-cooperators were obtained to carry on extensive seed multiplication. Three types of seeds are distributed to farmer-cooperators for the production of certified seeds, namely: (a) foundation seeds, (b) registered seeds, and (c) certified seeds. Foundation seeds are produced from breeder seeds, the initial increase of which is supervised by the sponsoring plant breeder. Registered seeds are the progeny of foundation seeds. These are distributed to selected farmer-cooperators for the production of certified seeds. Certified seeds are of two types: the first-generation certified seeds, which are the progeny of registered seeds, and the second-generation certified seeds, which are the progeny of first-generation seeds.

Farmer-cooperators of the BPI are those selected by the Bureau to grow and produce certified seeds. They buy the seeds from the Bureau and sign an agreement to follow certain approved production practices.

*The study was conducted by Mrs. T. V. Mina and Mrs. H. M. Ortico, under the supervision of Dr. F. A. Tiongson.

Table 14. Total distribution of certified seeds in the Philippines through the BPI program, crop year 1960/61 to 1965/66.

Year	Cavans distributed	Seeds required (%)	Price of certified seeds (P)
1960/61	4,343	0.14	12.50
1961/62	5,112	0.16	12.50
1962/63	20,823	0.66	12.50
1963/64	24,866	0.81	12.50
1964/65	14,926	0.47	19.00
1965/66	19,996	0.65	22.00

Only varieties approved by the Philippine Seedboard are eligible for seed certification. The factors considered by the Seedboard are high yield, resistance to lodging, good milling recovery, disease resistance, and good eating quality. On the average, the selection results from three to four seasons of preliminary yield tests, two to three seasons of general yield trials, and two to three seasons of regional adaptability tests conducted in the different parts of the country. However, for certain varieties that show unusual potential the time can be greatly reduced. IR8 was approved in April, 1967 after only three seasons of testing at different stations.

The purpose of seed certification is to maintain and make available to the public sources of high quality seeds. Seed certification is divided into two phases: field certification and laboratory certification. Field certification is the inspection of the field intended for seed certification by a seed inspector to determine if it is free from off-types, volunteer plants, weed seeds, etc. On the other hand, laboratory seed certification is the testing of the seed samples to determine whether or not they fall within the specific standards for purity, germination, moisture content, mixture with other varieties, red rice, weed seeds, etc. Samples that do not meet the requirements are rejected and therefore not certified.

Procurement and distribution. Procurement consists of direct purchases of certified seeds from the selected seed producers by the BPI through its seed inspectors. The procured seeds are then sold to the farmers, preferably the cooperators under the program. The BPI started distributing seeds in volume in 1960. During that year, it distributed 4,300 cavans of seeds and supplied .14 percent of the total seed requirements of the country. Since then, the number of farmers using certified seeds in the Philippines has increased. There was a corresponding increase in the volume of certified seeds sold by the BPI (Table 14), but this was still very small considering that the seed requirement of the country is about 3.2 million cavans. Why have so few farmers participated in the BPI program? To find the answer, a question survey was made of farmer-cooperators.

Survey of farmer-cooperators. Ninety-two cooperators in five provinces were interviewed in 1964 to 1965. Only one-half of the cooperators studied submitted samples of their seeds to the BPI for certification. On these 46 farms only 10 percent of total production was certified. Among cooperators yields averaged 55 cavans/ha on those hectares planted to certified seeds but only 46 cavans/ha on other hectares. Any price or yield advantage of certified seeds was apparently outweighed by other disadvantages, including higher costs. The problems most frequently mentioned were: (1) difficulty and delay in application, approval, and delivery of seeds; (2) lack of supervision—22 percent of the farms were not visited by seed inspectors; (3) labor and expense in following specified cultural practices; (4) delay in payment for seeds delivered to the BPI; and (5) lack of availability of seeds of desired varieties. These and other problems discouraged more than one-third of the interviewees from actively participating in the program.

The program of the RCPCC

The government decided that rapid multiplication and distribution was essential if the potential benefits of IR8 and similar varieties were to be achieved without delay. The RCPCC took a calculated risk in circumventing many of the requirements of the BPI certification system in favor of a speedier system of multiplication.

In July 1966, 50 tons of IR8 seeds from the Institute farm were turned over to the RCPCC for distribution to selected multipliers in those areas designated for IR8 multiplication. The rice was sold by the Institute to the Rice and Corn Administration (RCA) at P25 ($6.41)/cavan. Eighty percent of the seeds was sold to the 93 farmer-cooperators under the new program and 20 percent was channeled to the test plots of the Agricultural Productivity Commission (extension service) and the BPI.

Survey of farmer-cooperators. The 93 farmer-cooperators were located in six provinces of the Philippines (Nueva Ecija, 37; Tarlac, 24; Laguna, 10; Pangasinan, 9; Pampanga, 7; and Bulacan, 6). A random sample of 48 farmers, or slightly more than half of the cooperators were interviewed in a survey conducted in 1967. Of the group surveyed, 56 percent were owners, 20 percent part owners, 20 percent farm managers, and 4 percent tenants.

Table 15 shows the quantity of IR8 produced and sold as seed on 48 farms under the RCPCC program during the 1966 wet season and the 1967 dry season. Less than 50 percent of the initial crop was sold as seed following the 1967 wet season. Although cooperators expanded their planting of IR8 during the dry season, an even smaller portion was sold as seed in this season. This indicates that with competition from other sources the seed market was already saturated by the end of the 1967 dry season. Thus, within a year of the release of seed from the Institute, adequate supplies were available to meet local demand.

Seeds from the 1966-67 crop were sold by cooperators to a wide range of government agencies and also to private individuals. The largest government purchaser was the Agricultural Credit Administration which procured 54 percent of the IR8 seed sold by the farmers surveyed. Private sources accounted for 26 percent of IR8 seed sales. The average sale price was P29.34 ($7.52)/cavan.

RCPCC cooperators also mentioned several problems similar to those encountered by BPI cooperators, such as high cost of production and delay in procurement and sale of seeds to government agencies. Also, several commented on the lack of assurance that the government would purchase seeds. However, there was much closer farm supervision by seed inspectors, and almost all cooperators expressed the desire to continue with the program.

The future program of seed multiplication. The objectives of the BPI are: (1) approval and recommendation of superior varieties, and (2) multiplication and distribution of "good" seeds. This study examined the success with which the BPI has achieved the latter. Although the BPI's seed distribution program has been functioning for over a decade, by 1964 to 1966 less than 1 percent of the total seed requirements of the country was being supplied through this program. Thirty-five percent of the cooperators studied had ceased to be cooperators by the time of the survey. There appears to be a lack of interest among cooperators and a lack of supervision by the government. To improve the efficiency of the system within the scope of the existing resources, it would seem necessary to redefine the goals and objectives of the BPI program. Even with the introduction of improved high-yielding varieties, it is unlikely that the demand for certified seeds will increase in the near future since seeds will be readily available from neighbors. With proper roguing of fields, seeds of the dwarf indica varieties can be kept relatively pure. The BPI will gain cooperators only if it offers a package of technical or

Table 15. IR8 seed multiplication program of RCPCC, 48 RCPCC farmer-cooperators, Philippines, crop year 1966/67.*

Item	1966 wet season	1967 dry season
Total seeds used (cavans)†	553.70	1,174.10
Total area planted (ha)	546.80	1,162.30
Area planted per farm (ha)	12.71	33.20
Yield per hectare (cavans)	106.70	95.30
Total production (cavans)	58,354.50	110,797.00
Total volume sold for seeds (cavans)	27,637.00	23,439.00
Total volume sold for commercial use (cavans)	14,109.60	31,901.50
Total volume retained for seeds (cavans)	3,634.50	10,974.50

*Although 48 farmers were involved in the program, only 43 participated during the wet season and 35 during the dry season.
†One cavan = 44 kg.

management assistance which farmers consider valuable. It is unlikely that certified seeds alone will offer much attraction until such time when agriculture becomes more highly commercialized.

The RCPCC program in seed multiplication was based on a different objective. The purpose was to multiply IR8 as rapidly as possible. A few cooperators were enlisted and closely supervised. The farmers showed a better understanding and interest in the program. Seed demand for IR8 was met within two crop seasons. The RCPCC has recently selected IR5 and C_4-63 for multiplication following the success with IR8. Meanwhile the BPI has taken steps to produce a supply of certified seed from IR8(68).

The important question is how the RCPCC will decide in the future what variety merits rapid multiplication and distribution. As more varieties become available and the yield increases become less dramatic, it will become more important to establish some criteria for determining the variety and the quantity to be multiplied.

Rice Supply, Demand and Price Behavior

Because of the dominant position of rice in both production and consumption, rice price policy is of critical importance in the economies of most Asian countries. One cannot point to any other single agricultural commodity in the Western world that has such a far-reaching impact on the functioning of the national economy as rice.

Establishing appropriate rice price policy objectives requires knowledge about: (1) supply responsive behavior, and (2) changes in demand due to changes in price and income. Research is continuing in both areas with particular reference to the Philippines. However, this year's work has also been concerned principally with broader questions relating to rice policy in Asian countries. This subject is dealt with under three headings: (1) the function of rice price in the economy, (2) the anatomy of rice price support, and (3) an overview of rice price policies in several Asian countries.

The function of rice price in the economy

In an open economy, price influences the income levels of both producers and consumers and serves to allocate resources in production. Consider how the impact of an increase in rice price is felt throughout the economy:

1. *Rice producers*. For the rice producer, a higher rice price means more income and greater incentive to grow rice. He may decide to increase the hectarage planted to rice or the production per hectare.

2. *Agricultural sectors competing with rice*. If farmers decide to shift hectarage to rice, production and income from other crops will decline.

3. *Consumers*. A higher rice price means a higher cost of living and thus a lower standard of living. If consumers must spend more of their income for rice, there will be less money available for the other needs. They may choose to eat less rice and more of other foods.

4. *Businessmen*. A higher rice price may force labor to demand higher wages. Higher wages mean a higher cost of production. A high cost of production for export goods negatively influences the competitive position of these goods on the world market.

5. *The economy*. Higher rice production may mean a saving in foreign exchange for rice imports. It may also mean a loss in foreign exchange from other sources. The higher rice price can lead to higher wages and higher prices for goods other than rice. This places inflationary pressure on the economy.

In summary, a change in the price of rice benefits some segments of the economy at the expense of others. The government must balance the pros and the cons in arriving at a policy that is equitable and in line with national objectives.

The anatomy of rice price support

Governments normally find themselves under pressure from agricultural producer groups to raise the price of rice, from consumers to maintain low rice prices, and from both sides to reduce seasonal price fluctuations. The argument for a higher price in a developed economy may emphasize equity—the desire to see rice producers receive a standard of living comparable with that of other segments of the economy.

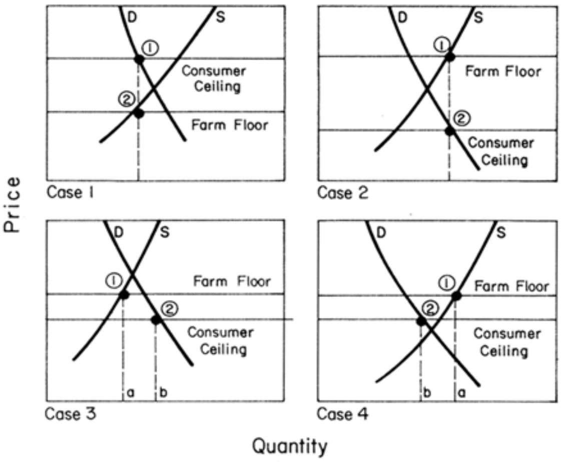


Fig. 8. Alternative situations in government price support.

However, developing economies are more likely to emphasize higher price, not as a means of income transfer, but as an incentive for increased production.

Governments are often faced with the problem of trying to guarantee a support level to both producers and consumers. This takes the form of a price *floor* to producers and a price *ceiling* to consumers. Depending on where the ceilings and floors are established, three groups stand to benefit or lose: (1) producers, (2) consumers, and (3) government. Figure 8 illustrates four possible situations. Case 1 (upper left) shows a situation where the consumer ceiling is set above the floor. The government buys low and sells high. In this case, the government may be taking money at the expense of the consumer who receives a price above the equilibrium and the producer who receives a price below the equilibrium. However, considering this situation in a more dynamic context, the supply function is likely to shift suddenly either to the left or the right due to changes in weather and other factors. The existence of a consumer ceiling protects the consumer from an excessively high price as a result of short supply. Conversely, the existence of a producer floor protects the farmer from a severe price dip due to a temporary glut on the market. The government normally is under pressure to adopt the situation shown in Case 2. Here the ceiling is above the floor and both producer and consumer benefit at the expense of government. This represents an income transfer from taxpayers to producers and consumers. The third situation is typical of the Philippines and other importing countries in the recent past where domestic equilibrium has in many cases been above both support prices. Allowing the domestic equilibrium price to prevail would be politically intolerable. Thus, the government imports the quantity a – b to meet consumer demand at the ceiling price. Both the government and the producer pay the cost of support and the consumer benefits. The producer pays if one regards the domestic equilibrium as the "fair" price. However, the competitive price in an open economy with uncontrolled imports and exports will be determined by world market prices. The actual cost will depend on the world price at which rice must be imported as well as the domestic subsidy. Recently, to close the gap between floor and ceiling and thus reduce the government subsidy, the Philippine government has allowed the consumer ceiling to rise. This has had the additional beneficial effect of reducing import requirements which at current world prices were above the consumer ceiling.

Case 4 is a situation which could prove serious in the decade ahead if efforts to increase rice supply are successful. Assume that the supply function for rice shifts to the right more rapidly than demand. Domestic equilibrium will fall below the support levels. There will be continuing pressure to maintain the farm floor. If this is maintained, the government will now transfer income to producers. The stimulation to production will lead to a surplus for export. If the world price is higher than the farm floor, the government can export at a profit. However, if world supply increases and price declines the export must be subsidized. The alternative is to let farm prices decline. Some Asian countries are already concerned that this situation may become a reality in the future.

A final word about rice self-sufficiency which is the goal of many of the developing economies and the primary objective of most support programs. Self-sufficiency can be achieved by: (1) prohibiting imports, (2) transferring hectarage from other crops to rice, or (3) increasing rice yield per hectare. For some countries, there has been a fourth choice, opening up new lands.

Table 16. Comparison of domestic retail rice price, June 1965, with farm rice price, 1964/65, in U.S. cents per kilogram, eight Asian countries.*

Country	Retail** (1)	Farm: Paddy† (2)	Farm: Milled equivalent‡ (3)	Farm/retail x 100§ (4)	Domestic marketable surplus procured by government (%) (5)
Burma	7	3	5	71	Most of crop
Ceylon¶‖	6	12	18	300	Most of crop
China (Taiwan)	15	10	15	100	50–60%
Japan	30	28	43	143	Most of crop
Korea (South)	17	10	15	88	small percent
Malaysia	15	9	14	93	60–80%
Philippines	16	8	12	75	small percent
Thailand	10	5	8	80	most of crop

*Farm milled equivalent ÷ retail price.
FAO, *State of Food and Agriculture,* **1966.
†FAO, *Production Yearbook,* **1965**, and FAO, *National Rice Policies,* **1966**.
‡Price of farm paddy ÷ .65 (65% milling recovery assumed).
§Retail price—price of milled equivalent.
‖FAO, *National Rice Policies,* **1966**.
¶The Ceylonese government has recently stopped purchasing the domestic rice but continues to import approximately 50% of total requirements which are given free to consumers.

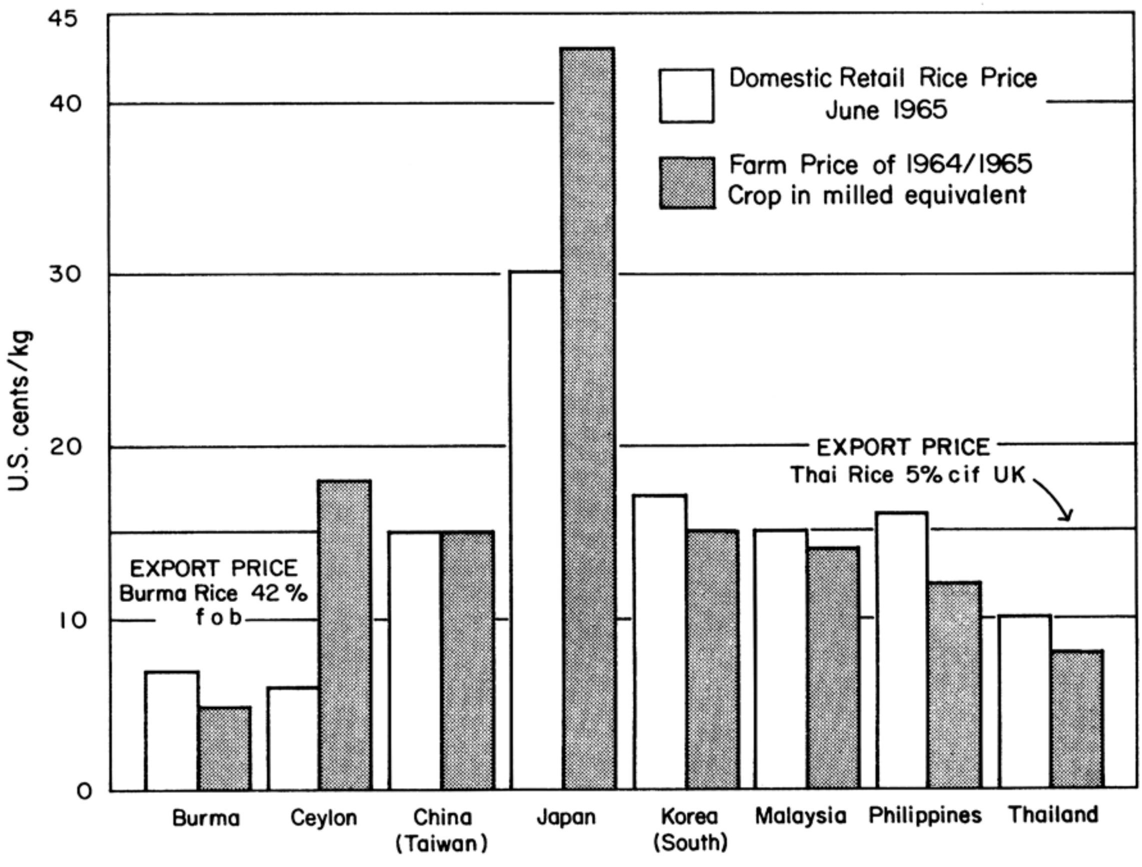


Fig. 9. Comparison of domestic retail and farm price of rice in eight Asian countries, 1964/65.

However, in most of South and Southeast Asia, this opportunity is very limited.

The first alternative would normally result in a politically unacceptable rice price. The second alternative leads to a reduction in output of alternative crops which may reduce foreign exchange earnings or increase spending for agricultural imports. Thus, in the minds of most people, rice self-sufficiency implies achieving adequate increases in production through a sustained increase in yield per hectare which will: (1) eliminate the current deficit in production, and (2) keep pace with a growing demand due mainly to population increase.

An overview of rice price policies in several Asian countries

Figure 9 and Table 16 provide information on rice prices at retail and farm levels for eight Asian countries. India and Indonesia have been omitted because of the wide differences in prices in the different regions of these countries, and likewise Pakistan because of major differences between East Pakistan and West Pakistan. The price levels in Fig. 9 show the obvious wide difference in the policies being followed. The exporting countries, Burma and Thailand, hold farm price below world export price and use the proceeds from the export of rice to finance government operations. Ceylon and Japan, both major importers, have a farm price support above the retail price. The high farm prices have stimulated production, but the cost of such operations has resulted in serious financial problems in both governments. Japan, the more highly developed country, can rationally view her policy as an equity measure. The purpose is not just to stimulate production, but to transfer income to rice farmers. However, Ceylon can ill afford the cost of such a policy. (The Ceylonese government has recently shifted to a policy of not procuring domestic rice, but distributing free to consumers the requirements normally imported. This amounts to 50 percent of the previously rationed quantity.) Three of the four remaining countries—Korea, Malaysia, and the Philippines—do not appear to have adopted rice policies which have been strongly beneficial or detrimental to either farmers, producers, or the government as of 1965. Domestic retail price in these countries is generally in line with world price and exceeds the farm price by the approximate cost of moving the rice from the farm through the market to the consumer. The situation in Taiwan is unique. The Chinese government has a monopoly on fertilizer. It employs a fertilizer-rice barter ratio which places the price of fertilizer more than 50 percent above the world market. In this manner, the government has been able to transfer income from the agricultural sector.

For most countries, rice price stabilization is another key objective of policy. To maintain price support levels and to stabilize prices,

Table 17. Rice price, nitrogen price, elemental fertilizer consumption in eight Asian countries.

Country	US¢/kg rice*	US¢/kg N†	Ratio N:rice‡	Consumption per ha arable land	
				N§	NPK§
Burma	3	29	9.7	—	—
Ceylon	12	25	2.1	24	46
China (Taiwan)	10	44	4.4	139	217
Japan	28	26	0.9	122	304
Korea (South)	10	27	2.7	96	166
Malaysia	9	29	3.2	9	18
Philippines	8	36	4.5	5	8
Thailand	5	28	5.6	2	3

*FAO, *Production Yearbook*, **1965**, and FAO, *National Rice Policies*, **1966**. Data for crop year 1964/65.
†Price for nitrogen obtained from ammonium sulfate. FAO, Fertilizers, An Annual Review of World Production, Consumption, and Trade, 1965. Table XVIII. Data for crop year 1964/65 except Burma, 1960/61.
‡US¢/kg N : US¢/kg rice.
§FAO, *Fertilizers, An Annual Review of World Production, Consumption, and Trade*, **1965**. Table 20. And FAO *Production Yearbook*, **1965**.

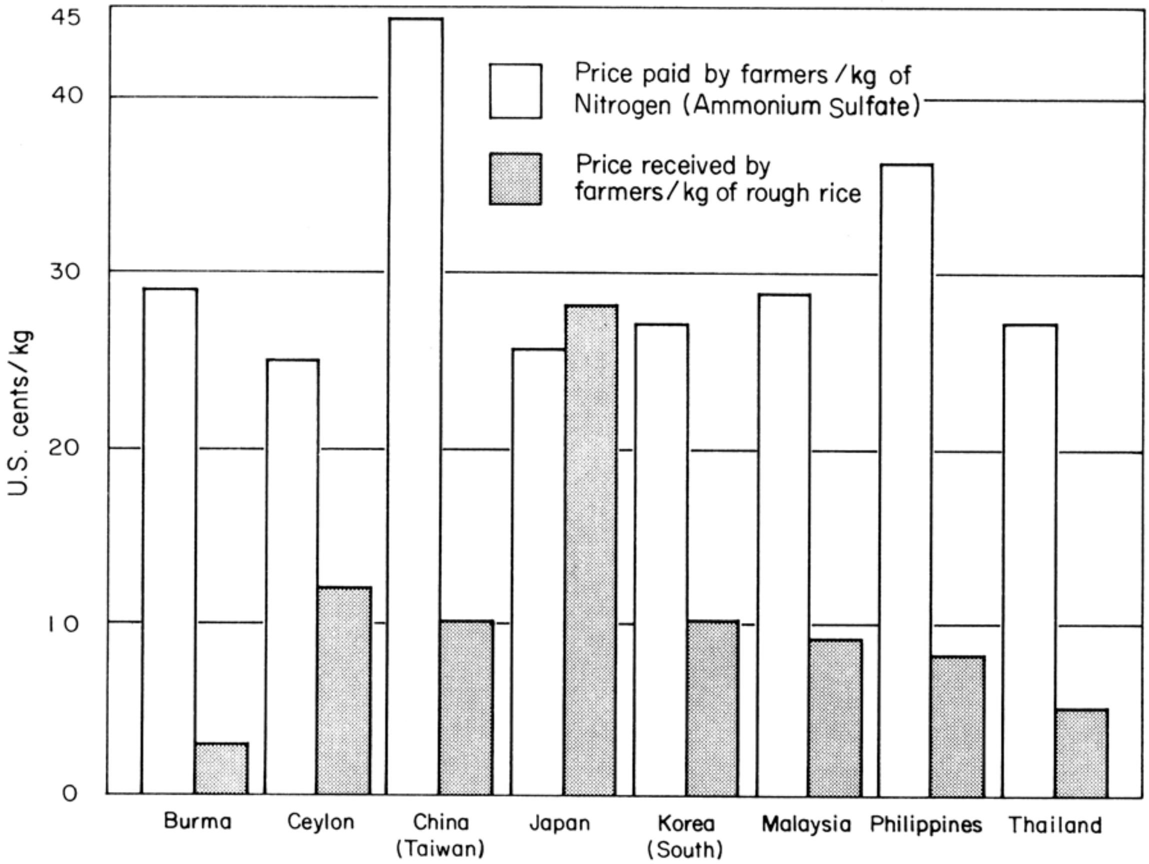


Fig. 10. Price of nitrogen and price of rice at farm level in eight Asian countries, 1964/65.

governments must exercise some control over the market. This is normally achieved through procurement of domestic supply and control of imports and exports. Nearly all governments in South and Southeast Asia control imports and exports of rice. The degree to which the government is engaged in domestic purchase is shown in Table 16, last column. One can see which governments control adequate supplies to carry out effective price stabilization. (Only about 10 percent of the total amount marketed probably would be needed to achieve this objective.) Those governments which do not have adequate control over the market may have a detrimental effect on price stability unless buying and selling operations are carefully planned and timed.

Another aspect of pricing policy is the rice-fertilizer price ratio. Figure 10 and Table 17 show the price relationships for elemental nitrogen and rice at the farm level. The most favorable ratios are for Japan and Ceylon due to a high farm level rice price support. The least favorable ratios are for the rice-exporting countries, Burma and Thailand.

Previous research results reported in 1966 have shown that a rise in rice price (or alternatively a reduction in fertilizer price) will not in and of itself lead to an increase in yield per hectare. A major impact on yield will be realized only if the price policy encourages a shift to a new production function involving changes not only in fertilizer, but also in other inputs and management practices. This indicates that timing is a crucial factor in the utilization of price incentives since this new technology must be available.

Technological advance may be more critical than favorable price policy in achieving yield increases. This point is illustrated in the case of Taiwan, where the government has penalized or taxed farmers by maintaining a fertilizer price more than 50 percent above the world market.

However, this has not discouraged farmers from using increasing amounts of fertilizer. The nature of the physical production function is such that an input of 100 kg or more of elemental fertilizer is profitable in spite of the high fertilizer price. Continuing investment in technological advance through such things as varietal improvement has benefited Taiwan farmers and has created a source of revenue which has been transferred from the farm to other segments of the economy.

In summary, price incentives, if properly timed, may encourage the shift to the higher production needed to achieve a major increase in yields. More often than not, however, governments adopt production-oriented price policies which: (1) result in major expense to the government, (2) misallocate agricultural resource, and (3) achieve little if any, of the desired yield increases.

Statistics

The Department of Statistics serves the dual role of providing statistical services to other Departments and of conducting research on statistical procedures. Special effort is made to utilize the information from current experiments to provide an insight into how future experiments may be conducted more efficiently.

During 1967, the department continued to (a) advise research workers on the design and analysis of experiments and surveys, (b) render computational services in the analysis of data and assist in the interpretation of results, (c) provide instruction on statistical techniques, and (d) conduct theoretical and experimental studies on statistical problems related to rice research.

Sampling Schemes in Estimating Leaf Area

This study, which is an extension of a previous one on leaf area measurements, was aimed at: verifying the recommendation that 5-width measurements be used in estimating leaf area (Annual Report, 1964), investigating the use of a multistage sampling scheme in leaf area study, and obtaining information concerning the magnitude of various components of variance.

The data used were obtained from the variety x spacing experiment conducted by the Agronomy Department. The study included five varieties: 6993, C-18, IR8, Chianung 242 and H-4, and 6 spacings: broadcast, 15 cm x 15 cm, 25 cm x 25 cm, 35 cm x 35 cm, 45 cm x 45 cm and 55 cm x 55 cm. Leaf samples were taken by using a multistage sampling scheme—3 hills from each experimental plot, 3 tillers from each sample hill, and 2 leaves from each sample tiller were drawn at random.

To account for the difference between the upper and lower leaves, the tillers were further divided into upper and lower strata. A leaf was drawn at random from each stratum. Seven-width and 5-width measurements were taken from each leaf blade, and the leaf area was computed accordingly.

The F-test from the analysis of variance showed non-significant difference between estimates of leaf area using 5-widths and 7-widths, confirming the recommendation that 5-width measurements be used in estimating leaf area.

The analysis of variance technique was used in estimating the components of variance. These estimates were derived for different varieties and for both methods of sampling—with and with-

Table 1. Estimates of variance components, by variety.*

Variance component	Variety					
	IR8	6993	C-18	H-4	Chianung 242	Overall
σ_l^2 (leaf)	135.90	99.60	99.46	181.89	103.44	124.05
σ_t^2 (tiller)	−23.32	−24.22	−22.12	−36.34	−0.20	−21.24
σ_h^2 (hill)	3.08	16.09	6.68	34.36	15.95	15.23
σ_e^2	4.52	7.72	1.59	13.31	14.79	9.39

* Multistage sampling with stratification of tillers was used.

Table 2. Variances of the means for selected sample sizes, by variety.*

n(x,y,z)	IR8	6993	C-18	H-4	Chianung 242	Overall
16(4,1,4)	7.95†	11.91†	3.95†	24.18†	25.19	14.64†
16(8,1,2)	10.48	12.92	5.87	24.43	23.22†	15.39
16(4,2,2)	10.86	14.94	6.91	28.72	25.21	17.30
12(3,1,4)	9.10†	13.31†	4.73†	27.81†	28.66	16.72†
12(6,1,2)	12.47	14.66	7.30	28.14	26.04†	17.73
12(3,2,2)	12.98	17.35	8.42	33.86	28.69	20.26
8(2,1,4)	11.39†	16.10†	6.30†	35.06†	35.60	20.89†
8(4,1,2)	16.45	18.14	10.16	35.55	31.66†	22.39
8(2,2,2)	17.22	22.16	11.83	44.14	35.64	26.20

Note: n = sample size (total number of leaves per experimental plot).
x = number of hills per plot.
y = number of tillers per sample hill.
z = number of leaves per sample tiller.
* Multistage sampling with stratification of tillers was used.
† Smallest variances of the means for a particular sample size.

Table 3. Combined analyses of variance for grain yield and percentage of white heads, 1966 dry and wet seasons.

SV	Grain yield			White Head (%) †			EMS (V fixed, S and L random)
	DF	MS	F	DF	MS	F	
Seasons (S)	1	5673566	<1	1	0.1951	<1	$\sigma^2+v\sigma^2_{(SL)R}+vr\sigma^2_{SL}+lvr\sigma^2_{S}$
Locations (L)	3	16796978	41.25**	1	1.0034	9.69*	$\sigma^2+v\sigma^2_{(SL)R}+svr\sigma^2_{L}$
S x L	3	27415061	67.32**	1	12.7720	123.40**	$\sigma^2+v\sigma^2_{(SL)R}+vr\sigma^2_{SL}$
Reps within L and S	8	407177		4	0.1035		$\sigma^2+v\sigma^2_{(SL)R}$
Varieties (V)	5	10838608	6.32**‡	5	0.2639	<1	$\sigma^2+r\sigma^2_{VLS}+rs\sigma^2_{VL}+rl\sigma^2_{VS}+rsl\Sigma v_k^2/(v-l)$
V x S	5	1374950	1.09	5	0.4172	1.65	$\sigma^2+r\sigma^2_{VLS}+rl\sigma^2_{VS}$
V x L	15	1607162	1.28	5	0.5544	2.19	$\sigma^2+r\sigma^2_{VLS}+rs\sigma^2_{VL}$
V x L x S	15	1256933	4.87**	5	0.2526	2.19*	$\sigma^2+r\sigma^2_{VLS}$
Pooled error	40	258263		20	0.1154		σ^2

† The original data is transformed to $\sqrt{X + 0.5}$.
‡ Satterthwaite approximation test is employed.
* Significant at the 5% level.
** Significant at the 1% level.

out stratification of tillers. Table 1 shows the estimates derived from the sampling plan with stratification of tillers. In all cases, the sampling plan with stratification of tillers gave smaller variances of the means than that without stratification, with an average relative precision of 200 percent. With this information, sampling plans that give the desired precision can be worked out for each variety. Various sampling plans based on multistage sampling with stratification of tillers for different sample sizes were therefore derived. Some of these are presented in Table 2 with the corresponding values of the variance of the mean. The results for all varieties, except Chianung 242, show that for a fixed sample size an increase in the number of leaves per sample tiller lowers the variance of the mean. A sample size of 12 leaves per plot for all varieties is recommended. The optimum combination of the sample number of hills, tillers and leaves for a certain sample size is that giving the lowest variance of the mean. For all varieties, except Chianung 242, the optimum combination for a sample size of 12 leaves per plot is (3, 1, 4), i.e., 3 hills per plot, 1 tiller per sample hill and 4 leaves per sample tiller. For Chianung 242 the optimum combination is (6, 1, 2).

The various sampling plans given do not take into account the costs involved. If the relative costs of obtaining the sample hills, tillers and leaves are known, then it will be possible to construct the most economical sampling plan with a desired precision.

Combining Data from Rice Experiments Over Locations and Seasons

By combining the results from experiments conducted over several locations and seasons, information about the effect of treatment under different conditions may be obtained to permit recommendations for future years over a wide area. A combined analysis of rice stem borer experiments over several locations was given in the 1966 Annual Report.

This study attempts to combine data from rice experiments involving both location and season. Data from Uniform Rice Variety Trials (URVART) conducted at eight locations with 12 varieties during the 1966 dry season and at 20 locations with six varieties during the 1966 wet season were used.

Table 3 shows the combined analyses of variance for grain yield and percentage of white heads of six varieties which are common at four locations and in both 1966 dry and wet seasons. The difference in the degrees of freedom for grain yield and percentage of white heads is due to the unavailability of records on white

Table 4. Estimates of the variance components.

Characteristic	Variance component						
	σ^2_S	σ^2_L	σ^2_{SL}	σ^2_{VS}	σ^2_{VL}	σ^2_{VLS}	σ^2
Grain yield (kg/ha)	−452,948	682,908	2,250,657	14,752	87,557	499,335	258,263
White head (%)	−0.5240	0.0375	1.0557	0.0412	0.0754	0.0686	0.1154

heads in some experiments. The models utilize linear forms which allow for the estimation of the variance components. Variety was considered as a fixed variate whereas location and season were considered as random variates in the analyses. Estimates of the variance components are presented in Table 4. The relative magnitudes of these components indicate the relative importance of the corresponding sources of variation which are very useful in variety evaluation procedures. They also can be used for determining the optimum plot allocation.

Both analyses of variance for grain yield and percentage of white heads showed non-significant results on the variety x location and variety x season interactions, but the variety x location x season interaction was highly significant for grain yield and significant for percentage of white heads. These results indicate that varieties respond differently when grown under different environments, but that there are no consistent effects of location or season on differential varietal response.

The combined analysis given here is only preliminary; various assumptions affecting the validity of the combined analysis of variance need to be studied. Lack of homogeneity in the experimental errors or in the interaction components of treatments with locations and seasons might vitiate the interpretation of the result to a certain extent. A study is being conducted to find out if any difficulties exist in combining rice experimental data, and if so, what modification need to be made in the combined analysis.

Recent Findings on the Use of Principal Component Analysis in Rice Experiments

The data on agronomic characteristics gathered from experiments conducted by the Plant Physiology Department have been utilized to describe the concept of principal component analysis. The data on sensory tests in rice also have been similarly analyzed. The initial findings were discussed in the 1965 and 1966 Annual Reports.

The results of the variety x nitrogen x spacing experiment (Annual Report, 1966) showed consistency in the three analyses with respect to the way the characteristics group into the different principal components. The eigenvalues and the percentages of variation accounted for by each principal component also were similar. The same conclusions were obtained from the analyses reported for the five treatments in the nitrogen x shading experiment. The consistency among treatments in the latter experiment was further confirmed by the results obtained from additional treatments, such as shading from planting to maturity and from maturity to flowering for Taichung (Native) 1 and Chianung 242. In all these cases, an average of 95 percent of the aggregate variability in all the characteristics was represented by the first three principal components.

Additional studies on the consistency of results among experiments having more or less the same set of characteristics and among treatments in the same experiment were made.

The data obtained from the monthly planting experiment of the Agronomy Department and from the experiment on Peta x Igt lines of the Varietal Improvement Department were used in the studies. In the latter experiment, three principal component analyses according to height groupings were made. The results are summarized in Table 5.

Most of the characteristics observed in the monthly planting experiment were the same as those in the variety x nitrogen x spacing experiment (Annual Report, 1966). However, the manner in which these characteristics group into

Table 5. Characteristics and percent variations (PV) accounted for by each principal component (Z), by experiment.

Description	Z_1		Z_2		Z_3		Z_4		Total variation (%)
	X ( )*	PV	X ( )	PV	X ( )	PV	X ( )	PV	
I. *Monthly planting experiment*†									
	Grain yield, kg/ha (—.34)	40	Number of unfilled grains/panicle (.43)	24	100 grain weight, g (.48)	15	Number of filled grains/panicle (—.68)	11	90
	Number of tillers (—.45)		Weight of straw/ m^2, g (.54)						
	Number of panicles (—.48)								
	Plant height, cm (.47)								
II. *Peta* x *Igt lines experiment*‡									
a] Short	Number of panicles (.63)	22	Plant height, cm (.38)	18	Grain yield, g/68 hills (—.47)	15	Growth habit, coded (—.64)	11	66
	Number of tillers (.63)		Heading date, days (.62)		Panicle: tiller ratio (—.47)				
			Leaf angle, degrees (.53)		Flag leaf angle, coded (.65)				
b] Intermediate	Number of panicles (.41)	32	Number of tillers (.48)	19	Plant height, cm (—.53)	14	Grain yield, g/68 hills (—.62)	11	76
	Panicle: tiller ratio (.36)				Flat leaf angle, coded (—.59)				
	Heading date, days (.40)								
	Growth habit, coded (.31)								
	Leaf angle, degrees (.38)								
c] Tall	Plant height, cm (.52)	28	Number of tillers (.36)	18	Grain yield, g/68 hills (.58)	12	Grain yield, g/68 hills (.58)	11	69
	Number of panicles (—.44)		Panicle: tiller ratio (.52)						
	Flag leaf angle, coded (.25)		Heading date, days (.47)						
	Leaf angle, degrees (.41)								

* The figure in ( ) refers to the weight attached to the standardized variable X.
† Source of experimental data: Department of Agronomy, IRRI, November 1963-December 1965.
‡ Source of experimental data: Department of Varietal Improvement, IRRI, 1966 dry season.

the different principal components was not consistent in the two experiments. Besides, in the monthly planting experiment, the first three principal components accounted for only 79 percent of the total variation in contrast to the average of 95 percent in the previously reported analyses.

In the experiment on Peta x Igt lines, the results also were inconsistent among the three analyses in the way in which the characteristics group into the different principal components. The total variation accounted for by the first four principal components was small, averaging only 70 percent.

Studies on the correlation matrices were made in an attempt to explain the above-mentioned results. Highly correlated characteristics generally are common to a single principal component. In a set of data where correlations among the characteristics are more or less the same, the eigenvalues, or variances of the principal components, do not drop off rapidly. Therefore, more principal components are needed to account for a major portion of the variation, and consequently, the real purpose of the principal component analysis is not attained. This was the case in the Peta x Igt lines experiment.

These results show also that the importance of each characteristic is relative to the other characteristics present in a set. Furthermore, it seems clear that not only can different results be obtained from experiments with more or less the same set of characteristics but also that differences can occur among groups or treatments within the same experiment, as in the experiment on Peta x Igt lines (Table 5).

Inconsistency of results among groups or treatments in an experiment stresses the necessity for testing the homogeneity of the variance-covariance matrices of the different groups before making an overall analysis. This task is greatly facilitated at present by modern electronic computers.

Tests on the homogeneity of variance-covariance matrices were made for several rice experiments involving different treatments. The results showed evidence of non-homogeneity of the variances and covariances among rice characteristics from one treatment to another. Similar results were obtained for the present experiments, hence no combined analysis was made. However, even if homogeneity prevails, it is recommended that a pooled analysis, pooled within treatments, be used instead of the overall analysis.

Generally, the principal component analysis is applied to a set of characteristics measured on a similar scale, but for rice plant characteristics this can hardly be attained. An alternative

Table 6. Results of the principal component analyses based on the correlation and the variance-covariance matrices.

Principal component	Correlation matrix		Variance-covariance matrix	
	Eigenvalue	Percent variation	Eigenvalue	Percent variation
Z_1	2.884	32.05	298,525.45	99.88
Z_2	1.751	19.46	222.53	0.07
Z_3	1.223	13.59	99.56	0.03
Z_4	1.009	11.21	28.84	0.01
Z_5	0.643	7.14	12.61	0.01
Z_6	0.578	6.42	1.37	0
Z_7	0.372	4.13	0.31	0
Z_8	0.367	4.08	0.21	0
Z_9	0.173	1.92	0.002	0

approach, in cases where unit measurements differ, is to standardize the variables by using the correlation matrix instead of the variance-covariance matrix, as was done in all the experiments discussed above.

The data from the intermediate group of the experiment on Peta x Igt lines were used to show how the results would have been had the variance-covariance matrix been used. The results are shown in Table 6.

The nine characteristics measured and their variances are:

Characteristic	Variance
Grain yield (g/68 hills)	298,490.940
Plant height (cm)	177.255
Number of panicles/plant	6.391
Number of tiller/plant	8.774
Panicle: tiller ratio	0.003
Heading date (days)	48.659
Growth habit (coded)	0.304
Flag leaf angle (coded)	0.356
Leaf angle (degrees)	158.333

The first characteristic, grain yield, with its relatively high variance will probably dominate the analysis if the variance-covariance matrix is used. Using the variance-covariance matrix, the first principal component which includes grain yield almost accounted for the total variation (i.e., 99.9 %), whereas in the analysis using the correlation matrix, six principal components accounted for only 90 percent of the total variation (Table 6).

Collection of Rice Statistics at the Farm Household Level

The initial findings in the collection of rice production statistics at the farm household level in Laguna, Philippines was given in the 1966 Annual Report. As a follow-up, a total of 68 sample farm households or 15 percent of the farm households surveyed in 1966 were interviewed. Also, the number of barrios was reduced from the 23 used in 1966 to 17. In addition to the data on production, information on area was obtained.

The sampling method employed is known as the two-stage sampling with complete replacement of the primaries. Here, the primary sampling unit is the barrio and the farm household within the barrio is the secondary unit.

Generally, the Philippine rice farmer reports total production as the total of three components: landlord share, tenant share, and seeds. In the 1967 survey, this total amounted to 77 percent of the total production or an underestimation of 23 percent (Table 7). The underestimation in the 1966 survey was 20 percent, resulting in a 2-year average of 21.5 percent. The unreported components consist of the harvester's share, extra share, gleaning, heaping, and other expenses.

The area reported by the farmer during the interview was compared with the actual measured farm area. The latter includes the planted area, which accounts for 98 percent of the total area, and the area reserved for the bunds or levees.

Palay area as obtained in the interview was, on the average, overestimated by 5.6 percent (Table 8). However, when the actual measured area was divided according to size into three strata, overestimation of about 12 percent and 5 percent were observed in the lower (below 2 hectares) and in the upper (above 4 hectares) strata, respectively; while an underestimation of about 4 percent was noted in the middle stratum (between 2 and 4 hectares).

These results show that great care must be exercised in collecting information from rice farm households by the interview method. To minimize bias in obtaining data on production, the farmers must be asked whether "production" includes the components given in Table 7. For hectarage, if the adjustment for bias is going to be made efficiently, the reported hectarage must be classified according to size. Special care must be taken in reporting areas below 2 hectares.

Since average underestimation of 21.5 percent in production (average of the 1966 and 1967 surveys) and overestimation of 5.6 percent in area can be expected from the interview method, the reported average productivity of 41.2 cavans per hectare for Laguna may be considered to have been underestimated by about 26 percent.

If this type of studies can be extended to other parts of the country, the findings will be relevant to the adjustments of national figures on rice production and hectarage. They can also indi-

Table 7. Components of palay (rough rice) production in percent, by barrio, Laguna, Philippines, 1967*.

Barrio	Total palay production (cavan)†	Components (%)						
		Reported‡	Unreported					Total
			Harvester share	Other expenses§	Gleaning	Heaping	Extra share given to relatives and friends	
1. Cuyab, San Pedro	465.54	68.2	13.8	12.6	1.3	1.7	2.4	100
2. Poblacion, Pañgil	232.11	78.1	13.7	3.0	2.8	1.7	0.7	100
3. Poblacion, Famy	188.82	70.7	13.7	10.1	2.5	1.7	1.3	100
4. Calabuso, Biñan	528.19	81.3	11.2	5.6	0.6	—	1.3	100
5. Sorosoro, Biñan	231.96	76.0	13.6	4.3	5.1	—	1.0	100
6. Aplaya, Sta. Rosa	1018.47	77.6	11.6	4.8	2.1	1.5	2.4	100
7. Bubucal, Sta. Cruz	348.58	69.3	15.6	5.2	4.5	2.0	3.4	100
8. Puypuy, Bay	298.89	80.9	13.8	1.3	2.0	1.7	0.3	100
9. San Francisco, Victoria	419.69	80.6	13.7	0.5	2.3	1.7	1.2	100
10. Pulo, Cabuyao	576.53	72.4	10.8	11.9	1.5	1.4	2.0	100
11. Ibabang Taykin, Lilio	133.50	76.4	22.5	—	—	1.1	—	100
12. Segunda Pulo "A", Lumban	250.16	78.8	14.9	1.6	1.6	1.4	1.7	100
13. Buboy, Pagsanjan	95.20	79.8	16.6	—	1.0	—	2.6	100
14. San Antonio, Luisiana	45.80	86.5	12.0	—	—	1.5	—	100
15. San Cristobel, Calamba	629.65	85.0	10.9	—	0.9	1.4	1.8	100
16. Sabang, Magdalena	80.40	83.3	16.7	—	—	—	—	100
17. Malaking Ambling, Magdalena	292.16	78.3	16.3	—	—	2.0	3.4	100
Total	5835.65	77.4	13.1	4.6	1.8	1.3	1.8	100
Cumulative percentage		77.4	90.5	95.1	96.9	98.2	100.0	

*Source: Statistics Department, IRRI. These barrios are sample barrios used in the Crop and Livestock Survey (CLS) by the Bureau of Agricultural Economics, DANR in 1965.
†Total of the sample farms in each barrio (1 cavan = 44 kilograms).
‡Include landlord and tenant shares and seeds. Usually reported as total palay (rough rice) production.
§Include irrigation fees, expenses, weeder and thresher shares and rent for the use of a concrete court.

Table 8. Palay area; comparison between interview and actual planted area, by barrio, Laguna, Philippines, 1967.*

Sample barrio	Number of sample farms	Range in number of paddies/farm	Average size of paddies $\overline{x}$ (sq. m.)	CV(X)%	Palay area (ha)		Bias
					Interview (I)	Actual (A)	$(\frac{I-A}{A})$ 100%
1. Cuyab, San Pedro	4	26–136	314	58	12.5	10.8	15.7
2. Poblacion, Pañgil	4	1–13	836	50	3.2	3.2	0.0
3. Poblacion, Famy	4	1–8	1837	86	3.4	3.3	3.0

4. Calabuso, Biñan	4	6–73	777	69	11.7	11.1	5.4
5. Sorosoro, Biñan	4	27–51	439	43	6.5	7.5	–13.3
6. Aplaya, Sta. Rosa	4	4–83	574	41	10.5	10.1	4.0
7. Bubucal, Sta. Cruz	4	14–34	792	37	7.0	7.4	–5.4
8. Puypuy, Bay	6	4–70	616	43	6.7	6.9	–2.9
9. San Francisco, Victoria	4	5–66	824	41	14.0	13.4	4.5
10. Pulo, Cabuyao	4	45–80	469	48	10.7	12.0	–10.8
11. Ibabang Taykin, Lilio	5	4–20	363	65	3.5	2.1	66.7
12. Segunda Pulo "A", Lumban	4	5–14	996	36	4.8	3.9	23.1
13. Buboy, Pagsanjan	4	3–10	869	68	3.8	2.3	65.2
14. San Antonio, Luisiana	4	1–4	1732	56	1.5	1.0	50.0
15. San Cristobal, Calamba	4	15–22	901	43	5.7	6.2	–8.1
16. Sabang, Magdalena	1	10	1210	53	1.8	1.2	50.0
17. Malaking Ambling, Magdalena	4	8–20	585	41	4.1	3.1	32.2
Total	68	1–136	602	72	111.4	105.5	5.6

[a] Source: Statistics Department, IRRI. These barrios are sample barrios used in the Crop and Livestock Survey (CLS) by the Bureau of Agricultural Economics, DANR, in 1965.

cate the strategy in the development of sampling schemes for rice productivity in farmers' fields.

Moreover, information about the size and shape of rice fields can assist in the development of efficient mechanical equipment or in the plan to alter the size and shape of paddy to suit commercial agriculture.

Cooperative Work

Least-cost rations for pork production

The concept of the least-cost rations for hogs and the results when rice bran and soybean oil meal were used as the basic feed ingredients were presented in the 1966 Annual Report.

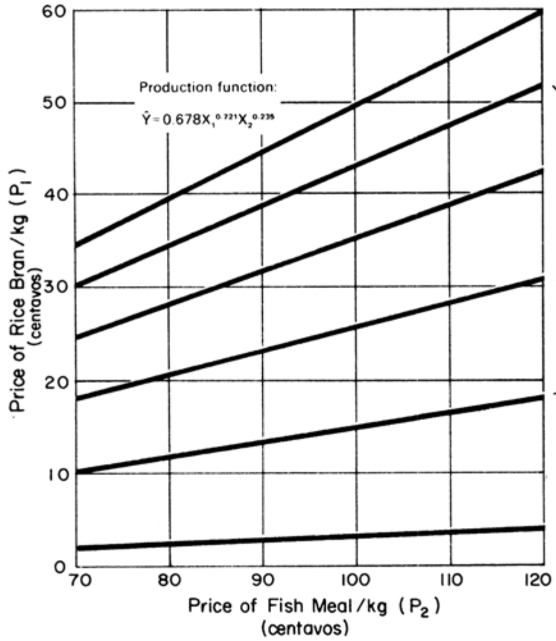
The study was extended to other feed combinations such as rice bran and copra meal, and rice bran and fish meal. The data on gain in weight of hogs collected by the UPCA Department of Animal Husbandry were used. Charts for obtaining least-cost rations for these combinations for existing ranges of market price for each ingredient are given in Fig. 1. Also shown are the Cobb-Douglas production function for each feed combination from which the charts were obtained. $\hat{Y}$ refers to the estimated biweekly gain in weight in kilograms while X_1 and X_2 are the feed ingredients in kilograms.

Rice farmers in the Philippines to whom copra and fish meal are easily available can utilize these findings in preparing a least-cost feed combination for pork production.

Miscellaneous

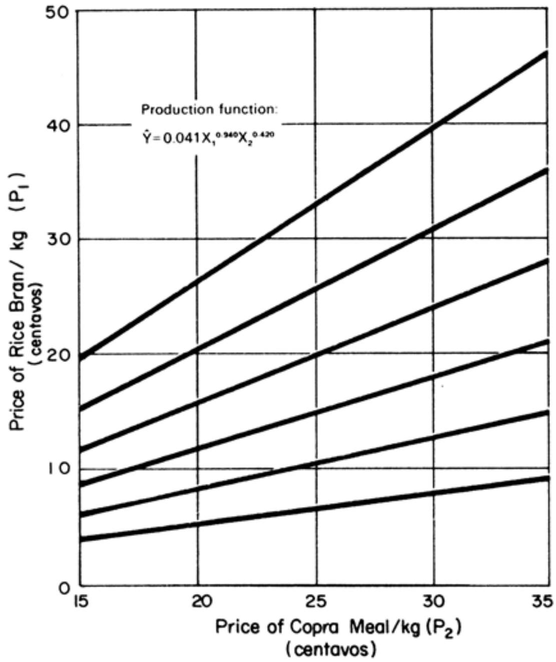
During the year, the Department participated in about 700 individual and group consultations with the Institute staff and scholars and with research workers from the UPCA. A total of 650 statistical analyses was performed for the other departments with an average of 12 variables and an average sample size of 50 observations. The nature of the analyses performed included: construction of an analysis of variance, comparisons among treatment means, correlation analysis; linear, curvilinear and multiple regression analyses; and multivariate analysis, such as principal component and path coefficient analyses.

The assistant statistician taught the following graduate courses at the UPCA: Statistics 207 (Design and Analysis of Experiments) and Statistics 272 (Sampling and Sample Surveys).



Price ratio P_1/P_2	Mixtures (100 kg basis)		
	Rice bran (X_1)	Fish meal (X_2)	Vitamin and mineral premix*
0.50	84.0	13.5	2.5
0.43	85.0	12.0	3.0
0.35	86.5	10.0	3.5
0.26	88.5	7.5	4.0
0.15	91.0	4.5	4.5
0.03	94.0	1.0	5.0

*0.5 kg salt
1.0 kg vitamin-mineral premix
remainder — bonemeal.

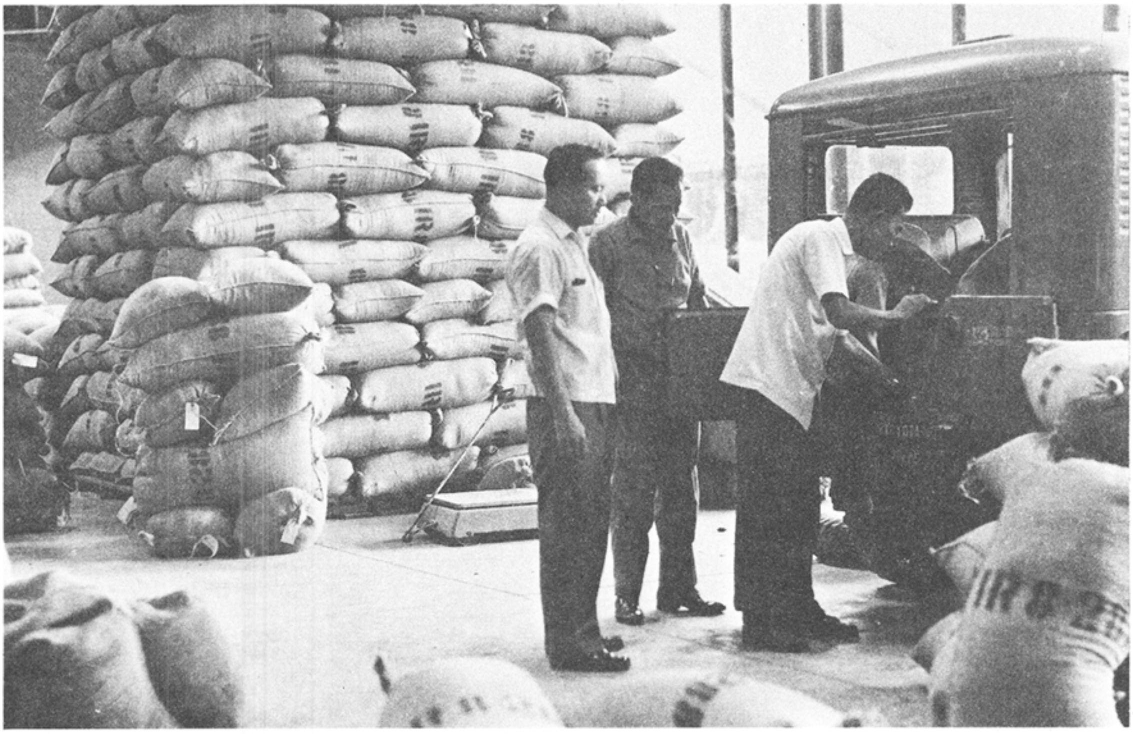


Price ratio P_1/P_2	Mixtures (100 kg basis)		
	Rice bran (X_1)	Copra meal (X_2)	Vitamin and mineral premix*
1.32	60	35	5
1.03	65	30	5
0.80	70	25	5
0.60	75	20	5
0.42	80	15	5
0.26	85	10	5

*3.5 kg bone meal
0.5 kg salt
1.0 kg vitamin-mineral premix.

Fig. 1. Least-cost ration for pork production.

Experimental Farm



Seed multiplication and distribution is a major activity of the Institute's Experimental Farm.

In 1967 about two-thirds of the 24-hectare area assigned to the Experimental Farm was planted to IR8, IR5-47-2, and IR8(68) primarily for seed multiplication or for eating quality tests. The remainder was planted to some 20 promising Institute strains, 2 indica and 2 japonica varieties, and to a cross made at Beaumont, Texas.

Three IR8 selections—IR8(40), IR8(41), and IR8(68)—were planted early in the year, with IR8(68) producing the highest yield. Therefore, it was again planted in the following season, and 50 cavans of the seed produced were sold to the Bureau of Plant Industry for further testing in BPI experiment stations and by farmer-cooperators. A total of 18 cavans of IR5-47-2 also was turned over to the BPI for testing. Two-kilogram quantities of seed of a glutinous rice strain, IR253-16-1, were distributed to a limited number of farmers.

More than 88 hectares of rice were grown in connection with experiments and demonstrations conducted by other departments. The area planted (in hectares) for each department was as follows: Agronomy, 20.8; Entomology, 9.5; Experimental Farm, 23.7; Plant Physiology, 5.3; Varietal Improvement, 20.4; Economics, 2.5; Plant Pathology, 2.2; Agricultural Engineering, 1.5; and Communication, 2.

The Experimental Farm collaborated with the Agronomy department in conducting two experiments on the nitrogen response of some Institute and UPCA selections, as well as some Philippine varieties, on farmers' fields in Calamba, Laguna. The results are given in the Agronomy section of this Report.

The Department constructed a concrete dapog seedbed to take care of the needs of the entire Institute. It is located such that watering and rat control can be done more effectively.

Animals are gradually being replaced by machines in land preparation, with small tractors being used where the bigger tractors cannot work effectively. These small tractors have the advantage over the water buffaloes of doing the job faster and at less cost.

TABLE 1. Measures of the importance of rice in Southeast Asian economies.[a]

Country	Primary (Agriculture, forestry & fisheries) net domestic product as a percentage of total net domestic product	Value of rice production as a percentage of: Total net domestic product	Value of rice production as a percentage of: Primary (Agriculture, forestry, and fisheries) net domestic product	Area devoted to rice as a percentage of total area cultivated	Value of rice exports (+)/imports (—) as a percentage of the value of all exports	Per capita supplies (gross) available for consumption (kg)	Calories derived from rice as a percentage of total daily calorie intake
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Burma	41.8	16.2	38.8	71.7	71.2	121	69.8
Cambodia	46.1	22.9	50.4	87.3	35.4	143	—
Indonesia	56.3	25.8	45.8	48.3	−10.7	91	41.9
Malaya	45.0	4.4	9.8	17.1	− 4.8	129	44.5
Philippines	34.0	7.3	21.3	41.9	− 1.3	88	49.9
Thailand	38.8	14.9	38.4	68.3	37.9	154	65.0
Vietnam (South)	29.2	13.7	46.9	84.0	22.8	168	62.0

[a] Tabulated from UN and national data.

Contributions of Acreage and Yield to Output Growth

The several factors which contribute to changes in rice production can be summarized as (a) changes in area devoted to rice, and (b) changes in yield or production per unit of land.

Most countries in South, Southeast, and Northeast Asia have continued to depend on *increased area* rather than *increased yield* as a source of growth in rice production (Table 2). Taiwan is the only country in the region which achieved its total increase in output between 1952-54 and 1960-62 from yield increases.

Japan depended on expansion of area for more than a quarter of its production increase; India depended on expansion of area for more than a third of its rice production increase; and, except for Malaya, all of the Southeast Asian countries depended on expansion of area for more than half of rice production increases that each achieved.

Rice Production, Area, and Yield in the Philippines

The long-term trend in rice production, area, and yield in the Philippines can be analyzed in four periods: (a) one of fluctuating but rapid growth from the early 1900's to the mid-1920's, (b) relative stability from 1926-27 to 1941-42, (c) rapid decline and recovery from 1941-42 to 1952-53, and (d) lagging growth since 1952-53 (Fig. 2).

A puzzling feature of rice production in the Philippines is the apparent long term stability in yield per hectare. Despite wide variations in yield among provinces (Fig. 3), introduction of new varieties, heavier application of fertilizer, and changes in cultural methods, the national average yields have remained at about 27-28 cavans per hectare[1] since the mid-1920's.

One possible explanation for this stability is that yield increases in some regions have offset the declines in other regions. The data presented in Table 3 and Fig. 4 are clearly consistent with this possibility. While the yield per hectare has been rising in the Bicol, Ilocos, and Central Luzon regions, it has been declining in the Cagayan Valley and Mindanao regions.

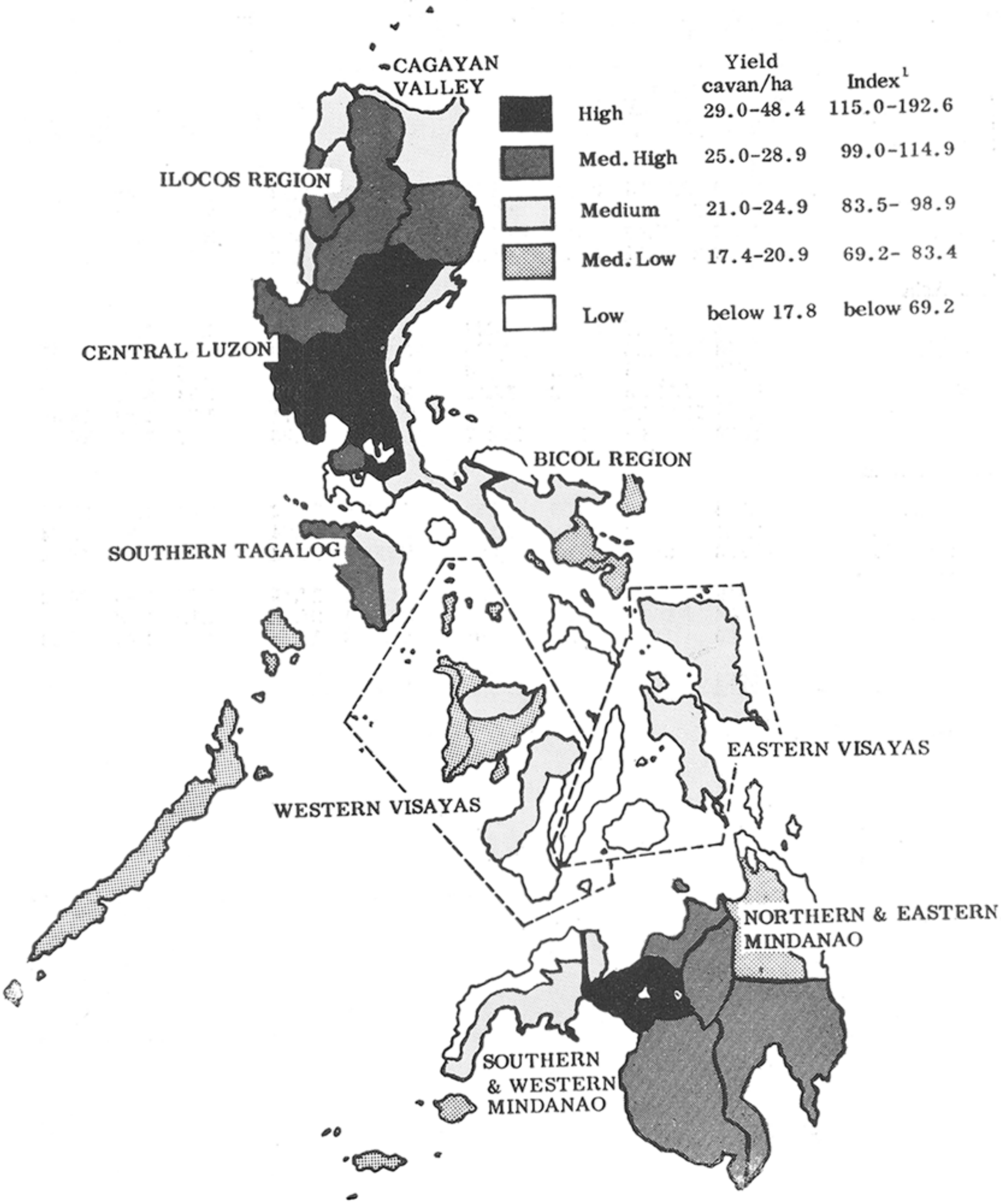
The divergent yield trends partially relate to changes in the area in rice

[1] About 1,188 — 1,232 kilograms per hectare (1 cavan = 44 kilograms).

Office of Communication

Communication activities in 1967 kept pace with, and reflected the rapidly expanding involvement of the Institute in cooperative research and training programs in several countries. While continuing to plan and execute communication activities in terms of behavioral change objectives for specific audiences, the communication staff emphasized the recognition of the interdependent roles of research, technology, education, extension, credit, markets, transportation, industry, and other supporting institutions in agricultural productivity programs.

The release and naming of IR8 at the end of 1966 stimulated a great demand for information about the new variety, how it was developed, and the appropriate cultural practices. These inquiries provided opportunity to focus attention on other important components in the production system, as well as on the nature of the problems of raising rice yields in the monsoon tropics and why many of the world's food problems today are rice-bound.



1 Philippine average yield of 25.1 cav/ha for 1956-57 to 1958-59 equals 100.

Fig. 3. Distribution of rice yields among Philippine provinces (3-year average, 1956-57 to 1958-59). (Division of Agricultural Economics, Department of Agriculture and Natural Resources.)

production in several regions. During the period 1952-54 to 1960-62, change in yield was inversely related to change in area (Fig. 5). Yields have declined in areas where area has expanded most rapidly and have risen in areas where area has declined.

The yield increases have occurred in regions where marginal rice lands have been transferred to other uses. Rapid expansion of the area planted to rice staff members the progress being made on the project.

Dissemination of Information

Publications

Production problems and delays with previous annual reports led to a decision to publish the 1966 Annual Report on a different basis. After several months of investigation, the decision was made to set the type for the report in Australia and to print it, by offset, in Hong Kong. The 302-page report was delivered in November.

Production of journal articles by the senior staff continued to increase and during the year, 27 manuscripts were processed. Upon publication, 300 or more reprints of each article were obtained for circulation in rice-growing countries.

The proceedings of the symposium on The Major Insect Pests of the Rice Plant were published in early 1967 by The Johns Hopkins Press. Later in the year, the manuscript covering the proceedings of the symposium on The Virus Diseases of the Rice Plant was forwarded to the same publisher.

Information materials

A revised edition of the Rice Production Manual, produced by the Rice Information Cooperative Effort (a project between the University of the Philippines College of Agriculture and the Institute), was edited and retyped in early spring. Subsequently, it was reproduced by offset at the Regional Service Center of the United States Information Agency in Manila. Nearly 15,000 copies of the first printing were rapidly sold within and outside the Philippines by the UPCA and by the Institute. Later, a second printing was necessary.

Concurrently, interested parties in other countries began adapting the contents to local conditions and translated versions in Urdu, Bengali, and Indonesian were produced in West Pakistan, East Pakistan, and Indonesia, respectively.

In October, a 13-minute film documenting the activities and approaches in the rice production training program was completed. This black-and-white film, "Changing the Change Agent," will be used in other countries to help introduce and explain this approach to training rice production specialists and trainers.

Numerous demands for visual materials to be used in training programs in rice-growing areas led to the development of a set of 58 slides covering the major insect and disease problems of rice as well as certain cultural practices. Orders for this totalled more than 175 sets, and in late December the first slide sets were distributed to former trainees in the Rice Production Training Program.

Information services

Handling of the ever-increasing volume of visitors continued to be a major challenge. Analysis of the types of visitors, their needs, relative lengths of visit, etc. helped in the development of some standard procedures for processing visitors with minimum interference with the research and training activities of the Institute. But the solutions adopted were considered temporary.

The field display plots near the administration building and those adjacent to the national highway were maintained with a succession of exhibits to show farmers and other visitors the benefits to be obtained from the new methods and varieties.

At the request of The Rockefeller Foundation, the Institute photographer went to India in September and to Thailand in November to make a series of photographs on rice improvement work in those countries.

Initial world-wide publicity about the new rice variety and other work of the Institute generated a large number of visits from representatives of news services, broadcasting companies, and film producers.

Considerable time was spent throughout the year helping representatives of Philippine government agencies, the Agency for International Development, and commercial firms prepare copy and illustrative material related to the growing of IR8. Much of this material was subsequently produced in dialects for use with farmers.

Other materials furnished in response to requests included colored transparencies for use at EXPO '67, milled IR8 for a men's club luncheon, potted live IR8 plants for various

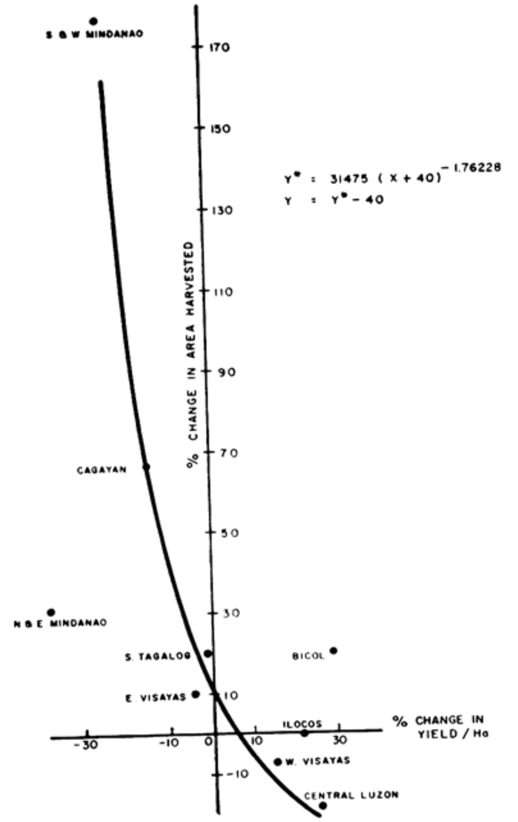


Fig. 5. Interaction of area and yield changes, 1952-54 to 1960-62. (Tabulated from Philippine sources. See Ernesto Venegas, "Rice Production, Area, and Yield in the Philippines," IRRI-AE-64 Staff Memo, July 13, 1964.)

(Fig. 6). In the Southern Tagalog and Northern and Eastern Mindanao regions, however, the area in upland rice is relatively large. The irrigated first crop accounts for as high as 20 percent of the area devoted to rice only in Central Luzon, Bicol, Southern and Western Mindanao, and Ilocos. The area accounted for by the lowland second crop (dry season), either irrigated or unirrigated, is above 20 percent only in the Bicol, Eastern Visayas, and Southern and Eastern Mindanao regions.

The data in Table 4 attempt to measure the effect of the different regional production patterns on regional average yields. Column 1 shows the actual average yields obtained in 1960-61 in each region. Column 3 presents the average yields that would have been reported for the region if the distribution of acreage in the region had been the same as the national average. The only year for which sufficient data are available to make this calculation is 1960-61.

In Central Luzon, for example, the actual average yield in 1960-61 was 1,574 kilograms of palay (rough rice) per hectare, or almost 36 percent above the national average. If the distribution of area between the wet and the dry season and among irrigated, rainfed, and upland areas in both seasons had been the same as the national average, the 1960-61 average yield in Central Luzon would have been 1,382 kilograms or only 19 percent instead of 36 percent above the national average.

This means that about 46 percent of the difference between the actual average yield in Central Luzon and the average national yield is accounted for (a) by the relatively favorable area distribution rather than (b) by actual yield differences under similar conditions with respect to season and water use. In the Ilocos region, about three-fifths of the margin of actual yield over the national average yield results primarily from the favorable area distribution.

In Cagayan Valley, Southern and Western Mindanao, and the Southern Tagalog region, the relatively high proportion of upland area accounts for the below average yield obtained in these three regions. If the distribution of area among different types of production had been the same as the national average, yields in these three regions would have approximated the national average.

The case of Western Visayas is particularly striking because of the close agreement between the actual and standardized yield. This implies that the higher than average yields are primarily the result of higher real yields rather than hectarage distribution. In Bicol, Eastern Visayas, and Northern and Eastern Mindanao, however, low

Table 1. Rice production related diagnostic and identification skills of various trainee groups, before and after 5 days of training (seven Training Programs, IRRI, January-July, 1967).

Category of trainee	Percentage of correct answers	
	First day	Sixth day
North Americans		
AID agriculturists in Southeast Asia (7)	26	85
County agents, agricultural teachers enroute to South Vietnam, after 5 months training in United States		
Group A (16)	8	75
Group B (25)	15	80
New Peace Corps volunteers (11)	3	72
Peace Corps volunteers with year of experience in Philippines (35)	14	87
Rice specialist (just arrived from U.S.)	17	73
Sociologist with seven years experience in rural development in Philippines	63	100
Filipinos		
Representatives of Commercial Firms		
Fertilizer Company A (12)	57	97
Fertilizer Company B (2)	36	88
Insecticide salesman	63	97
Aerial applicator	63	97
Community Development workers (33)	24	84
Extension workers (8)	57	92
Private growers, landlords, etc. (15)	27	77
Provincial governor	18	100
Institute photographer	96	100
Other		
IRRI research scholars at end of year's training in varietal improvement (5)	59	94
East Pakistan agriculturists at end of 10-month training program at the University of the Philippines College of Agriculture (9)*	34	85
East Pakistan agriculturists at end of 10-month training program at the University of the Philippines College of Agriculture (10)	56	83
West Pakistan agriculturists (2)	43	93

*November-December 1966

NOTE: The scores are based on performance in practical examinations at the beinning of 5-day training programs. Trainees, as individuals, inspected from 30 to 60 plant, insect, and mineral specimens, being allowed up to 1 minute per specimen. Different specimens, of approximately equal difficulty in diagnosis or identification, were used in the examinations on the sixth day.

had the highest score, 77, and his group of 12 had an average of 57.

Data in Table 1 make clear that: (1) Filipino field workers generally scored substantially higher on opening-day tests than did Americans; (2) "others" who had been enrolled in other than rice production programs for 6 months to a year at the Institute or the University of the Philippines College of Agriculture (UPCA) did about as well as the Filipinos; (3) all groups considerably improved diagnostic skills in 5 days of training.

Two Institute staff members who helped organize and conduct two 2-week training programs in West Pakistan in the spring of 1967 reported similar experiences. In each case, the Pakistanis enrolled failed the opening practical exercises. At the end of the training, none of them scored less than 80 percent.

Second long-term program

The second group of rice production trainees entered the Institute program in June, 1966, for a period of a year. The first 6 months of work emphasized practical paddy skills, the science of rice culture, rice problem diagnostic skills, applied research and field demonstration techniques, and principles and techniques of effective communication.

In January, 1967, this group was placed, in teams of two, into practical production situations throughout the Philippines. They made all of the management decisions incidental to growing a crop of IR8 under farm conditions, super-

TABLE 4. Effect of differences in regional production patterns on regional average yields (1960-61).[a]

Region	Actual Yield ton/ha (1)	Actual Yield Index (2)	Standardized Yield ton/ha (3)	Standardized Yield Index (4)
Philippines	1.159	100.0	1.159	100.0
Bicol	1.025	88.4	1.013	87.4
Central Luzon	1.574	135.8	1.382	119.2
Ilocos	1.278	110.3	1.201	103.6
Western Visayas	1.263	109.0	1.289	111.2
South. Tagalog	1.049	90.5	1.143	98.6
Eastern Visayas	0.891	76.9	0.891	76.9
Cagayan	1.087	93.8	1.174	101.3
S & W Mindanao	1.127	97.2	1.176	101.5
N & E Mindanao	0.847	73.1	0.851	73.4

[a] Tabulated from Philippine sources.

yields cannot be attributed to area distribution. Yields in these areas are low despite a distribution of area which is close to the national average.

The limited proportion of the total area devoted to palay that can be irrigated in both the wet and the dry seasons represents a major barrier to increased production and higher average yields in most regions. Even in Central Luzon, where yields are high compared to other regions, a shift of one hectare from production of one crop of rainfed rice to production of both a wet and dry season irrigated rice crop would add almost 54 cavans to total production, assuming 1961 cultural practices. This represents a 168 percent increase in palay production per hectare per year.[2]

Capital Formation and Agricultural Productivity

Many of the changes in either acreage planted or yield per hectare identified in Fig. 1 require increases in the level of fixed and working capital. During the year, a project was designed to explore the sources and implications of capital formation on small scale rice producing farms in Indonesia by a research fellow (Ir. A. Soeharjo) from Indonesia. The project is being conducted in cooperation with the Department of Agricultural Economics of the University of Indonesia (Bogor) and the Agricultural Development Council, Inc.

PRODUCTIVITY AND EFFICIENCY IN RICE PRODUCTION

A major focus of the biological research at the Institute is the development of new varieties or new practices designed to increase rice output or reduce costs per hectare of producing rice. To be accepted by farmers, these practices and varieties must possess some economic advantage relative to existing varieties and practices. Consultations with other departments on the economic analysis of experimental results represents an important area of activity.

Partial Budgeting of Costs and Returns Using Experimental Data

The economic analysis of experimental results has three primary functions. First, the applied research worker needs to select from among his several preliminary trials those which should be subject to more complete development and testing. To conserve his time and effort, he eliminates certain alternatives because they lack scientific, technical, or economic interest.

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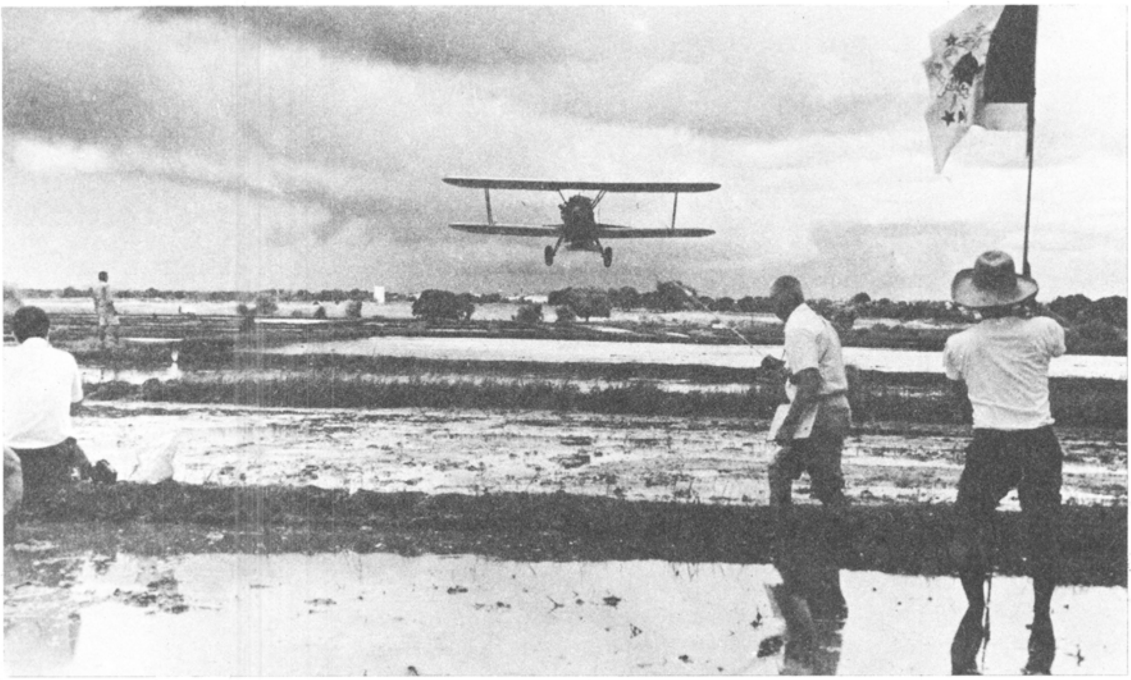
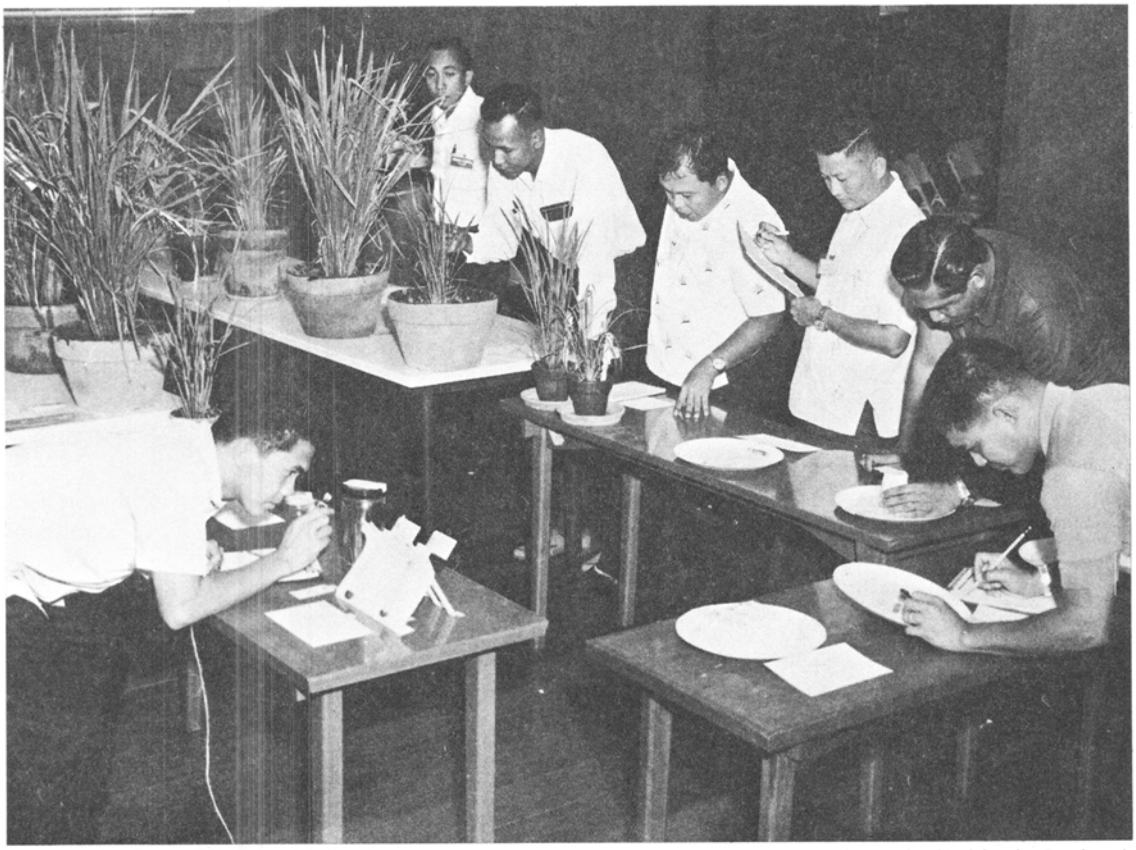
[2]
Wet season irrigated	—	44.7 cav/ha
Dry season irrigated	—	41.1 cav/ha
Total irrigated	—	85.8 cav/ha
Less: Wet season rainfed	—	32.1 cav/ha
Increase from irrigation	—	53.7 cav/ha

This is clearly a conservative estimate of the increased output that would accompany irrigation. Experimental evidence from the Institute and elsewhere indicates that with adequate irrigation water the dry season yield should exceed the wet season yield.



The Institute in 1967 initiated studies to determine the feasibility of using agricultural aircraft in tropical rice production.



The development of skills in identifying rice problems such as insect pests and diseases is emphasized in the Institute's intensive short courses in tropical rice production.

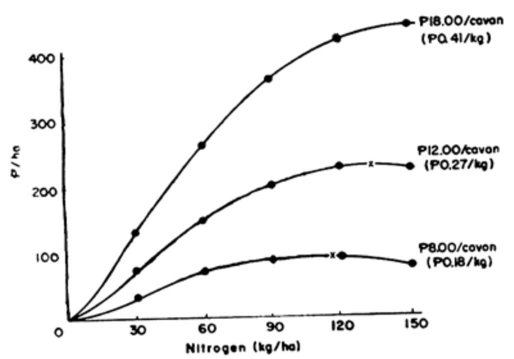


Fig. 8. Cumulative net return to fertilization at alternative prices for rough rice (based on the fertilizer response reported in Fig. 2).

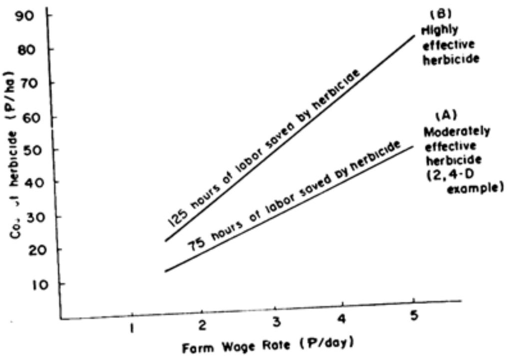


Fig. 10. Example of price map for screening herbicides.

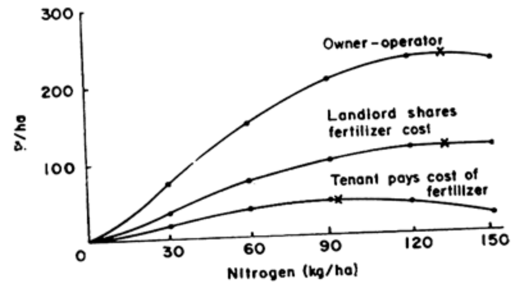


Fig. 9. Implications of tenure on net returns and optimum level of fertilization of palay (based on the fertilizer response reported in Fig. 2 and a price of P12/cavan for palay).

hand weeding at closing in time would be the least expensive form of weed control.

For some effective herbicides, such as some currently being tested by Agronomy, line B is the appropriate contour line dividing the herbicide-labor cost map into two decision regions.

Implications of Labor Intensity for Cultural Practices and Yields

Variations in yield among plots or fields, when other environmental factors have been controlled at similar levels, are frequently attributed to the intensity of labor utilization. Labor intensity can affect yields through increasing (a) the effectiveness of weed control, (b) the timeliness of irrigation and insect control, and (c) the effectiveness of control of rodent, bird, and other damage.

Studies involving both field experiments and case studies of operating farms have been initiated to determine the effect of alternative levels of labor intensity on (a) yield per hectare of rough rice, and/or (b) rice production practices.

An initial field experiment was completed during the 1964 dry season.

Rice Supply, Demand, and Price Behavior

Rice price policy is an important issue in most Southeast Asian countries. In general, the prices farmers receive for rice are lower in the rice-exporting countries than in the rice-importing countries of the region. Efforts to maintain rice prices at relatively low levels for consumers compete with efforts to offer farmers greater economic incentives. Some governments experience severe financial strains as a result of the subsidy program involved in attempts to achieve both objectives simultaneously.

Studies of the (a) price structure and (b) supply and demand forces for rice and corn in the Philippines have been initiated. The agricultural econoacquire valuable experience and knowledge pertaining to the new technology being tested, and are well prepared to discuss test results with local farmers during the subsequent extension demonstration phase and to have confidence in their recommendations to farmers. By using the applied research technique, the workers are, in essence, validating their recommendations before attempting to communicate, teach or demonstrate the practice. Under certain environmental conditions, a new finding may not be suited, and it is beneficial to have made this determination by means of applied research before recommendations for its use are made to farmers.

APC-IRRI cooperative applied research projects

During the 1967 dry season, trials involving IR8 and eight fertilizer treatments each replicated three times were conducted at over 40 locations in cooperation with the Agricultural Productivity Commission. During the subsequent wet season the selection IR5-47-2 was substituted in the fertilizer trials to obtain data on its fertilizer responsiveness in numerous locations, prior to its being released to the public.

Twenty-three variety trials were installed in each season of 1967, each trial including nine varieties or selections and two replications. Data obtained from these trials indicated that IR8 can produce high yields (6 to 7 ton/ha) over a wide range of environmental conditions in the Philippines, and that IR5-47-2 was equally well adapted and on the average produced only slightly lower yields (5 to 7 ton/ha).

Results from fertilizer and variety applied research trials such as these are reported to Institute scientists to assist them in their research activities.

BPI-IRRI cooperative stem borer plots

Applied research trials, begun in 1965, continued throughout the year in cooperation with the Bureau of Plant Industry in 16 provinces from north to south. Two varieties, two treatments involving the timing of the first application of granular insecticide, and three replications, made up the plot layout. Additionally, an adjoining observational trial was installed to ascertain if an application of methyl-parathion spray shortly after heading, in addition to several applications of granular gamma-BHC during the vegetative phase, would provide more complete stem borer control than only the vegetative phase treatments. Grain yields from all treated plots were significantly better than those from the non-treated ones, but on the average no one insecticidal treatment was significantly better than another. Results of these applied research trials in the provinces have helped BPI representatives develop meaningful recommendations for stem borer control in their local communities.

Bureau of Prisons-IRRI cooperative applied research trials

During the 1967 dry season, 2-man teams of rice production trainees were assigned to each of three Bureau of Prisons farms to help develop applied research information which could be used effectively to further increase rice yields on the colony farms. Both fertilizer and variety trials were installed at the Iwahig Penal Colony (Inagawan Sub-Colony), Palawan, at the Sablayan Penal Colony, Mindoro, and at the Davao Penal Colony, Davao. Bureau of Prisons agricultural officers at each location continued the applied research activities during the wet season.

Use of aircraft in tropical rice production

A 2-hectare rain-fed paddy field of puddled soil near Alabang, Rizal province, was fertilized by air on September 14, 1967, at the rate of 70 kg/ha nitrogen (using urea) and 43 kg/ha P_2O_5 (using triphos 40%). The fertilizer was incorporated into the puddled soil, and on September 18 the field was air-seeded with pre-soaked IR8 seed at the rate of 93 kg/ha, dry weight basis. Subsequent applications of granular gamma-BHC, granular diazinon, nitrogen topdressing, MCPA herbicide spray, and two applications of thiodan spray for pre-harvest insects were made by aircraft. So far as is known, this is the first field scale aerial-seeding of IR8 to be done. An area of about 2 hectares immediately adjoining the air-seeded field was transplanted with IR8 seedlings starting September 18 and given similar treatment

Harvest samples were taken from both the air-seeded and the transplanted areas 109 days after sowing, and yields of 5,065 kg/ha from sults in a more complex interaction of price and income effects on the quantities produced, consumed at home, and marketed than is the case for commodities which do not have such a large subsistence demand. Analytical procedures to deal with this problem have been developed. The empirical work has not been completed.

INSTITUTIONAL FACTORS IN AGRICULTURAL DEVELOPMENT

The rate of acceptance of adoption of technological change is affected by a number of institutional factors which modify the incentives to adopt new technology. The institutional factors do not directly affect production possibilities but rather modify the efficiency of the input-output linkages depicted in Fig. 1.

The data summarized in Fig. 9 indicate that share tenure arrangements, as practiced in some parts of the Philippines, reduce the incentive to use fertilizer as compared to an owner-operator or a leasehold situation. A similar analysis for herbicides indicated, however, that share tenancy could be expected to have a positive or neutral effect on the substitution of herbicides for hand or mechanical weeding. In general, share tenure (a) will act to inhibit the adoption of innovations, such as fertilizer in which additional costs are incurred to obtain increases in output (i.e.. output increasing innovations), but (b) will be neutral or will encourage innovations, such as herbicides, which permit the same level of output to be achieved with a lower cost or with labor. The net effect of these two forces can be evaluated only under actual farm conditions.

Data from the province of Laguna (Table 5) indicate that the small owner-operators (under 2 hectares) were at some disadvantage relative to share tenants, part-owners, and leases. For farms above 2 hectares, these disadvantages tended to disappear.

Similar data for Malaysia indicated that areas characterized by fixed rent (leasehold) arrangements obtained higher yields than areas characterized by share tenure arrangements. The yield differences were smallest for farms under 3 acres but widened for larger sized farms.

Apparently, in both the Philippines and Malaysia, share tenants on small farms achieve relatively high productivity levels, as compared to fixed rent (leasehold) or owner-operator farmers because of (a) the pressure to produce enough rice for subsistence, and (b) credit and supply support by the landlord. The share tenure system restricts productivity, primarily after the tenant has satisfied his subsistence requirements, because it reduces the value to the producer of increased output in comparison to owner-operator or fixed-rent systems.

TABLE 5. Relation of farm size and tenure to production per hectare of lowland rice, Laguna, Philippines, 1962 (wet season).[a]

Farm Size (ha)	TENURE				
	Tenant	Part-owner	Lessee	Owner-operator	All Farms
	cavan/ha				
Less than 2	50.15	54.73	54.65	44.90	50.49
2 & above	50.47	51.59	50.45	51.10	50.70

[a] Tabulated from "an Economic Study of Laguna Province," a project in progress in the Department of Agricultural Economics, U.P. College of Agriculture, Los Baños, Laguna.

ance of three distinct populations, i.e., 30 "high score" individuals with considerable experience and training in rice; 52 field extension workers; and 28 "low score" individuals, freshman students at the UPCA. Scores of the "high score" group were significantly higher than either the extension workers or the freshmen. The mean score of the extension workers was significantly higher than that of the freshmen.

More than 80 percent of the upper 27 percent of all testees were individuals from the "high score" group and none of them were from the college freshman group. Conversely, more than 80 percent of the lower 27 percent of all testees were freshmen. None of the lower 27 percent came from the "high score" group.

Such variables as years of service in present employment, years from college graduation, and length of exposure to previous training programs in rice production did not correlate with test scores.

The pooled analysis of all testee scores showed a highly significant correlation between scores on the terminology test and scores on specific facts and information; scores on terminology and scores on understanding of principles and generalizations; and scores on specific facts and scores on understanding. The average index of discrimination of the test instrument was .46 while the item difficulty was 52.11 percent. Sixty-five percent of the 122 items had an index of discrimination of .40 or higher.

Information gained and methodologies tested in this study will be useful in the selection of new extension employees, in determining in-service training needs, and in evaluating training impacts.

Further, with a means of assessing at least some aspects of the extension worker's technical competency in rice, this variable can be taken into account in future diffusion studies related to rice varieties and technology.

Adoption of IR8

Activities of a private individual to multiply the seed of IR8 and his efforts to promote a farm management plan to help farmers become established with the new variety provided an unusual opportunity to study certain factors associated with the diffusion of the variety and the acceptance of the management plan.

This study, carried out by a graduate student at the UPCA, involved a barrio composed of 75 rice farmers living within the area of primary concern to the individual seeking to establish the management program. The particular barrio was selected because none of the land was owned by the aspiring manager or his immediate family, and all of the land was irrigated, thus permitting continuous rice culture.

The barrio was under surveillance during three consecutive crop seasons, beginning with the May-September period, 1966. Each farmer was interviewed twice, the interviews being approximately 3 months apart.

The rapid adoption of IR8 on all or part of the available land of each of the 75 farmers can be plotted as follows:

	May-Sept. 1966	Nov.-March, 1967	May-Sept. 1967
Knew about IR8	59	75	75
Growing IR8	15	46	65
Not growing IR8	44	29	10

Sources	Information about: Usual agricultural matters (percent)	Information about: IR8 rice variety (percent)
Expert agents	44	10
Self, own experience	32	—
Other farmers	19	35
Landlords	4	12
Radio	—	4
Management plan promoter	—	39

Of the 15 persons growing IR8 initially, 38 percent said they had "heard" it was high-yielding; 25 percent said that they had "seen" its high-yielding performance.

Of the 46 farmers growing the new variety in the second season, 70 percent said their reason for so doing was that they had seen its high-yielding performance. Another 19 percent mentioned the high price currently being paid for the seed.

The principal reason cited, by 38 percent, for not planting the variety in May, 1966, was their belief that it was "expensive to grow". Another 32 percent said that they wanted to wait to see its performance first. Another 17 percent said that the landlord advised them not to, and

THE Department of Statistics serves the dual role of providing services to other departments and of conducting research on statistical procedures. These functions frequently overlap, for an effort is made to utilize the data from current experiments to provide an insight into how future studies may be made more productive. Detailed tables concerning the variability of a number of plant characteristics are being prepared for use in the design of experiments and the selection of precise sampling procedures in future investigations. Since the work of the Institute is directed so strongly at one crop, it is possible to bring considerably more precision into the statistical aspects or plant measurements than is frequently the case.

During 1964, the department continued to (a) consult with research workers on the design and analysis of experiments and surveys and render computational services in the analysis of data; (b) provide instruction on statistical concepts and techniques with special reference to their applications to agricultural research, and (c) conduct theoretical and experimental studies on statistical problems associated with rice research.

Consultation and Computation Service

The department extended 820 individual or group consultations to the Institute staff and scholars, and to research workers at the University of the Philippines College of Agriculture. A total of 241 analyses was performed for the other departments. Each analysis had an average of 14 variables and an average sample size of 712 observations.

Instruction

The statistician taught the following graduate courses at the UPCA which were attended by Institute scholars, research assistants as well as graduate students of the UPCA: Statistics 272, Sampling and Sample Surveys; Statistics 207, Design and Analysis of Experiments; and Statistics 260, Probability and Elementary Statistical Methods.

As basic instructional material for these courses and as a general reference book for agricultural research workers, the statistician prepared an 807-page manuscript titled "Statistics in Rice Research" which consists of three parts: I, Basic statistical concepts, probability and elementary statistical techniques; II, Comparative experiments; and III, Absolute experiments: sampling and sample surveys.

Upon request, copies were furnished to agricultural research workers in 14 countries. So far, 151 copies of Part I, 108 copies of Part II, and 80 copies of Part III have been distributed.

Studies of Statistical Problems

Variability and Size of Sample

Work was continued on the evaluation of the variability of seven characteristics of the rice plant and on the sample size necessary to measure these characters with suitable precision. The preliminary results of these studies for one season work were presented in the 1963 Annual Report. In 1964, data for two or three seasons, and for greenhouse as well as field conditions, were available. Table 1 presents the results for the characteristics studied in the experiments on growth duration, the screening of the Institute's world collection of rice varieties, and in experi-

Library and Documentation Center

Growth of the Collection

As in previous years, the acquisition of rice literature was pursued vigorously. Particularly, arrangements for securing materials from the Chinese Mainland and Russia were speeded up and improved. Libraries in Great Britain have proved useful secondary sources of such materials.

Systematic development of the collection has led to both the completion of runs of periodicals and the extension, both current and retrospective, of periodical coverage.

Volumes of books and pamphlets acquired from all sources numbered 2,583, bringing the total collection of monographs to 19,842. Other acquisitions included 1,091 maps, 18 theses in microfilm, and 94 translations.

As of November 30, serials currently being received totalled 1,539 titles. Of these, 411 were received as the result of exchange made with government organizations and research institutions in 62 countries and 563 were acquired as gifts. The remainder were purchased by subscription.

The accelerated growth of the collection is further reflected by the 2,238 titles that were cataloged during the year. About 28,000 cards were filed in the card catalog of the library.

Bibliographical Services

The 1966 supplement to *The International Bibliography of Rice Research* was published in 1967 and the 5-year cumulative index to the 1961-1965 supplements was completed. Consisting of 296 pages including indexes, the 1966 supplement contains 2,355 references to scientific rice literature selected from numerous sources, with the bulk taken from journals printed in 1966. An additional 98 serial titles were scanned in the compilation. References missed in the 1964 and 1965 supplements were also included. The coverage is worldwide, and includes literature written in 23 of the world's major languages.

As in previous supplements, the citations in the 1966 supplement are arranged according to subject matter, and an author and a manually produced keyword index are provided. A list of 94 rice literature translations into English is included.

The 5-year index, which is divided into three sections—author, subject, and geographic—is a comprehensive guide to the world literature on rice reported in the 1961 through 1965 supplements.

With the cumulative index, the research worker can cover each area of rice research quickly and efficiently. He can see years of progress in its entirety and is afforded a better perspective of the progress made in the last five years of rice research. Also he will have a clearer view of the references important to his work.

The International Bibliography of Rice Research has proven an indispensable tool for rice researchers. Demands for copies have increased, necessitating the reprinting of the major volume (1951-60) and the 1961, 1962, and 1963 supplements.

Reference and Circulation Services

The library handled 256 major reference inquiries during the year with, as in previous years, the greatest number coming from India and Japan. The demand was mostly for information and the photocopying of papers and articles on rice breeding, genetics and entomology, although a few requests were received for short biblio-

TABLE 1 (Continuation)

	Characteristic	Range (R) of sample means ($\bar{x}$)	Overall mean ($\bar{\bar{x}}$)	Form of equation for (s)	Coefficient of variability [cv(X) %]	Sample size (n) needed for cv($\bar{x}$) =5%
16.	Width of grain (mm)					
	a.	3.0- 3.6	3.4	$s = 0.043\bar{x}$	4	1***
	b.	2.3- 3.3	2.8	$s = 0.056\bar{x}$	6	1***
17.	Culm diameter of 1st basal internode (mm) [B_1]					
	b. d_1 (outer dia.)	5.1- 9.3	7.2	$s = 0.075\bar{x}$	8	3
	d_2 (inner dia.)	3.2- 6.6	5.0	$s = 0.100\bar{x}$	10	4
	c. d_1	4.6- 6.9	5.7	$s = 0.090\bar{x}$	9	4
	d_2	2.7- 4.5	3.8	$s = 0.100\bar{x}$	10	4
18.	Culm diameter of 2nd basal internode (mm) [BI_2]					
	b. d_1	4.4- 8.9	6.6	$s = 0.090\bar{x}$	9	4
	d_2	3.2- 6.4	5.0	$s = 0.096\bar{x}$	10	4
	c. d_1	4.1- 6.4	5.2	$s = 0.102\bar{x}$	10	4
	d_2	2.7- 4.6	3.8	$s = 0.105\bar{x}$	10	4
19.	Culm area (sq mm)					
	b. BI_1	10-16	21	$s = 0.207\bar{x}$	21	18
	BI_2	6-30	15	$s = 0.268\bar{x}$	27	29
	c. BI_1	7-23	14	$s = 0.268\bar{x}$	27	29
	BI_2	4-16	10	$s = 0.277\bar{x}$	27	29
20.	Internode length (cm)					
	b. BI_1	3-13	7	$s = 0.318\bar{x}$	32	41
	BI_2	7-26	14	$s = 0.282\bar{x}$	28	31
	c. BI_1	2-18	6	$s = 0.320\bar{x}$	32	41
	BI_2	4-18	11	$s = 0.250\bar{x}$	25	25
21.	Slenderness ratio (l/r)					
	b.	324-794	563	$s = 0.131\bar{x}$	13	7
	c.	198-415	284	$s = 0.122\bar{x}$	12	6
22.	Lodging index					
	b.	1-16	8	$s = 0.379\bar{x}$	38	58
	c.	1-9	4	$s = 0.478\bar{x}$	48	92

[a] Sources of experimental data: Departments of Plant Physiology and Varietal Improvement, IRRI, 1962–63.
* (a) 1962 dry season, (b) 1963 wet season and (c) 1963 dry season.
** All cv(X)% values were obtained using the overall mean ($\bar{\bar{x}}$).
*** Take n=2 to have a measure of variability.

ments for varietal improvements. The size of sample needed to attain a level of precision equal to cv($\bar{x}$) = 5 percent also is given in this table. If the range (R) for n is large, then (R/2) may be used as a compromise value for n. For example, the size of sample for grain yield (Table 1) is (36-9)/2=14 samples or plants.

For grain yield, the model is

$$s = a + b\bar{x}$$

and the coefficient of variation is

$$cv(X)\% = [(a/\bar{x}) + b]\ 100\%.$$

The range (R) of the sample means ($\bar{x}$) will be useful in evaluating the range of cv(X)%.

For the model

$$s = b\bar{x},$$

the coefficient of variation is a constant given by the equation

$$cv(X)\% = (b)\ 100\%$$

for all $\bar{x}$'s. In this case, the range (R) of the sample means ($\bar{x}$) will give an idea of the variability of the plant material used in the experiments.

Estimation of Leaf Area

Leaves of rice varieties Peta and PI 215936 were used in a study on methods of estimating leaf area. The estimation procedure was accomplished

International Activities

The international activities of the Institute have been financed principally by two grants from the Ford Foundation. The first of these covered the period from January 1, 1962 to December 31, 1964 and the second, the period from January 1, 1965 to December 31, 1967.

Activities under these grants fall into several categories, principal among them being (a) the training of young scientists from rice-growing countries, (b) cooperative studies at other rice research centers, (c) international symposia, and (d) staff travel to rice-growing countries. A summary of developments in each area during 1967 is given in subsequent sections.

More recently, the international activities have entered a phase in which rice scientists employed by the Institute or by the Ford or Rockefeller Foundations are stationed at key rice research centers in other countries. The work of these scientists is defined by specific agreement with the host country and it varies from place to place. In all cases, however, the focus is on the national agency concerned and upon its needs and wishes. While the staff scientists look for ways in which Institute findings and resources, physical or in expertise, may be put to use in the host country, the projects are in no way sub-stations of the Institute or branch activities of programs headquartered at the Institute. Ideas and materials are passed both ways and, in fact, direct linkages are developing between these country projects quite apart from the Institute. As time passes this may prove to be one of the most productive features of the international program. To foster such developments, it is planned that international meetings between Institute staff and their colleagues and cooperators in other countries will be held from time to time.

No attempt will be made to detail the progress and prospects of these various cooperative projects, but in later sections brief descriptions of each will be given.

TABLE 2. Estimate of the regression coefficient (b), standard errors and variation accounted for by regression of leaf area to different forms of linear measurements with varieties Peta and PI 215936 as indicators, IRRI, 1964.

$[m_3 = 1/(WL)_i^2]$

Variety and position of leaf	Form of measurements	b	s_b	s_E	r^2
Peta					
Flag leaf	WL	0.800	0.016	0.011	0.989
	$\overline{W}_1L$	.874	.002	.055	.996
	$\overline{W}_2L$	.944	.014	.101	.989
	$\overline{W}_3L$	.936	.008	.055	.987
	$\overline{W}_4L$	.949	.015	.108	.987
Middle leaf	WL	0.822	0.007	0.048	0.996
	$\overline{W}_1L$	.912	.007	.051	.997
	$\overline{W}_2L$	.991	.008	.058	.997
	$\overline{W}_3L$	.986	.008	.054	.997
	$\overline{W}_4L$	1.011	.007	.049	.998
Lower leaf	WL	0.788	0.009	0.061	0.996
	$\overline{W}_1L$	.883	.006	.046	.997
	$\overline{W}_2L$	.970	.008	.057	.997
	$\overline{W}_3L$	.961	.006	.044	.998
	$\overline{W}_4L$	.983	.006	.043	.998
All leaves	WL	0.810	0.011	0.079	0.990
	$\overline{W}_1L$	.890	.008	.054	.996
	$\overline{W}_2L$	.969	.011	.077	.994
	$\overline{W}_3L$	.960	.008	.055	.997
	$\overline{W}_4L$	.980	.008	.076	.994
PI 215936					
Flag leaf	WL	0.837	0.013	0.092	0.998
	$\overline{W}_1L$	.933	.006	.044	.998
	$\overline{W}_2L$	1.001	.002	.025	.999
	$\overline{W}_3L$	.994	.004	.029	.999
	$\overline{W}_4L$	1.012	.004	.029	.999
Middle leaf	WL	0.835	0.008	0.055	0.996
	$\overline{W}_1L$	.950	.004	.098	.990
	$\overline{W}_2L$	1.021	.011	.075	.995
	$\overline{W}_3L$	.994	.029	.208	.959
	$\overline{W}_4L$	1.025	.036	.255	.999
Lower leaf	WL	0.826	0.001	0.011	0.998
	$\overline{W}_1L$	.931	.004	.030	.999
	$\overline{W}_2L$	.991	.004	.030	.999
	$\overline{W}_3L$	.983	.008	.054	.997
	$\overline{W}_4L$	1.001	.004	.026	.999
All leaves	WL	0.839	0.009	0.062	0.998
	$\overline{W}_1L$	.930	.009	.066	.995
	$\overline{W}_2L$	1.004	.012	.087	.997
	$\overline{W}_3L$	.940	.018	.124	.984
	$\overline{W}_4L$	1.013	.005	.033	.999

to 4 rows x 10 hills) for straw yield, and 2 to 4 square meters (4 rows x 12 hills to 4 rows x 25 hills) for whitehead count. On the basis of the required cultural or management practices, the size of plot may be increased to twice x_o without departing from the optimum solution.

As grain yield is the most important characteristic, the x_o for grain yield will also apply for straw yield and whitehead count. The results in Table with them during the organizational phase of their short-course program and perhaps through the first cycle of training. Obviously, this requires a considerable amount of coordination with the national agencies and is usually possible only where the Institute has a resident adviser or other close liaison.

The rice production training program differs from the research training area in that it is tending to create a new specialty, that of the rice extension specialist. It is a field where very large numbers of qualified persons are required and the Institute can expect to train only a small part of them. Perhaps the next step will be to emphasize the training of people to offer similar courses in their home countries rather than to focus directly on the short-course type of activity. This, of course, will require a more thorough grounding in basic agricultural sciences and a close tie with the research staff at the home institution.

Following is a list of participants in the training programs of the Institute during this period:

Scholars

Agronomy

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.

CHAI-FA LIN, *junior specialist*, Taichung District Agricultural Improvement Station, Taiwan. Major research: Not selected.

SABUROU MATSUMOTO,* *assistant in agronomy*, Tokyo University of Agriculture, Japan. Major research: Irrigation practices and direct seeding.

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.

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.

PONNAMPALAM YOGARATNAM, *agricultural instructor*, Ceylon. Major research: Weed control in lowland rice.

Chemistry

NATIVIDAD B. 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.

Communication

MUHAMMAD AFSARUDDIN, *Principal*, Farm Mechanization Training Institute, East Pakistan. Training in rice production, applied research, and 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.

REX ALOCILJA,* 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.

APOLINAR ASENCION, Philippines. Training in rice production, applied research, and communication.

FRANCISCO BABAC,* *secondary school teacher*, Mindanao Institute of Technology, Philippines. Training in rice production, applied research, and communication.

TIMOTEO BANDONG,* *instructor*, Community Development Center, College, Laguna (PACD). 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.

RUBEN BORJA, 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 Com-

*Completed training.
†Completed Master of Science degree.

TABLE 4. Size and shape of plot by characteristics.

[Range of $(C_o/C_{b.u.}$ is 5 to 10]

Characteristic and variety	Size of plot	Dimensions of plot	Recommended size of plot
Grain yield			
Peta (.30 m x .20 m)	3 rows x 11 hills (1.98 sq m)	.9 m x 2.2 m	2 to 5 sq m
	7 rows x 11 hills (4.62 sq m)	2.1 m x 2.2 m	
BPI-76 (.25 m x .25 m)	4 rows x 8 hills (2 sq m) to	1.0 m x 2.0 m	2 to 4 sq m
	4 rows x 17 hills (4.25 sq m)	1.0 m x 4.25 m	
Straw yield BPI-76 (.25 m x .25 m)	4 rows x 5 hills (1.25 sq m) to	1.0 m x 1.25 m	1 to 2 sq m
	4 rows x 10 hills (2.25 sq m)	1.0 m x 2.5 m	
White head count Chianung 242 (Lindane) (.20 m x .20 m)	4 rows x 6 hills (.96 sq m) to	.8 m x 1.2 m	1 to 2 sq m
	4 rows x 12 hills (1.92 sq m)	.8 m x 2.4 m	
Chianung 242 (Endrin) (.20 m x .20 m)	4 rows x 8 hills (1.28 sq m)	.8 m x 1.6 m	1 to 3 sq m
	4 rows x 17 hills 2.72 sq m)	.8 m x 3.3 m	
Taichung (Native) 1 (Lindane) (.20 m x .20 m)	4 rows x 12 hills (1.92 sq m) to	.8 m x 2.4 m	2 to 4 sq m
	4 rows x 25 hills (4 sq m)	.8 m x 5.0 m	
Taichung (Native) 1 (Endrin) (.20 m x .20 m)	4 rows x 5 hills (8 sq m) to	.8 m x 1.0 m	1 to 2 sq m
	4 rows x 10 hills (1.6 sq m)	.8 m x 2.0 m	

$$\text{or } \sum_{i=1}^{L} \bar{q}_i Y_i;$$

Combined ratio (st)

$$= \tilde{T}_C(st) = q(st)Z \quad \text{or} \quad q(st)Y;$$

and the

Unbiased ratio $= \tilde{T}_U$.

The variance of T_X is

$$N(N-n)\, S^2(X_{ij})/n$$

and the variances of the other five estimators are derived and compared.

The variances of the different estimators and their relative efficiencies for the province of Bulacan are shown in Table 7. The results for the other provinces also indicate that the group of ratio estimators is better than either the simple random or stratified (optimum) estimator. In turn, the separate ratio estimator [$\tilde{T}_Q$ (st)] is more efficient than the ratio of means [$\tilde{T}_Q$] or the combined ratio estimator [$\tilde{T}_C$(st)].

Hectarage is a more efficient concomitant variable than number of

D. W. SIRINAYAKE, *manager*, Central Research Station, Ceylon. Training in rice production, applied research, and communication.

TEJ PRATAP SINGH,* *student*, Allahabad Agricultural Institute, India. Training in rice production, applied research, and communication.

T. E. SRINIVASAN,* *assistant botanist*, All-India Co-ordinated Rice Improvement Project, India. Training in rice production, applied research, and communication.

ALFREDO T. SUENAN,* *farmer*, Tiruray Cooperative, Philippines. Training in rice production, applied research, and communication.

ANGELITO TABING, *research assistant*, College of Agriculture, University of the Philippines. Training in rice production, applied research, and communication.

T. M. A. TENNAKOON,* *agricultural instructor*, District Agricultural Extension Office, Kurunegala, Ceylon. Training in rice production, applied research, and communication.

PRABOWO TJITROPRANOTO,* *research staff member*, Division of Plant Physiology and Seed Technology, Central Research Institute for Agriculture, Bogor, Indonesia. Training in rice production, applied research, and communication.

JOANNE TOMPKINS,* U.S.A. Training in rice production, applied research, and communication.

JOHN TOMPKINS,* U.S.A. Training in rice production, applied research, and communication.

ROGELIO TRIA, *barrio development worker*, PACD, Philippines. Training in rice production, applied research, and communication.

GHULAM NABI UNAR,* *agricultural assistant*, Department of Agriculture, West Pakistan. Training in rice production, applied research, and communication.

MELITON 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 and use of fertilizers.

PAUL R. WALTHER,* *agricultural missionary*, United Church of Christ, United States. Training in rice production, applied research, and communication.

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.

SHENG HUI-LIAO, *graduate research fellow*, UP-Cornell Exchange Program, Taiwan. Major research: Factors affecting the spread of new rice varieties.

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.

RODOLFO D. REYES, *research assistant*, Agricultural Engineering Department, The International Rice Research Institute, Philippines. Major research: The economics of pump irrigation.

MOISES L. SARDIDO, *instructor I*, University Research Center, University of Eastern Philippines. Major research: Factors affecting the spread of new rice varieties.

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.

Entomology

SHAMSUL ALAM,* *assistant entomologist*, Directorate of Agriculture, Dacca, East Pakistan. Major research: Population dynamics of leafhoppers and planthoppers and stem borers.

CARLOS R. VEGA, *research assistant*, The International Rice Research Institute, Philippines. Major research: Mating habits and 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.

AART VAN SCHOONHOVEN,* Netherlands. Major research: Feeding habits of the leafhopper (*Nephotettix impicticeps*).

CHING-HUAN CHENG, *junior entomologist*, Department of Plant Protection, Chiayi Agricultural Experiment Station. Taiwan. Major research: Not selected.

SYED GHULAM JILANI SHAH, *research assistant*, Ayub Agricultural Research Institute, West Pakistan.

MARGARITA FORTUNO, *plant pest control officer*, Bureau of Plant Industry, Philippines. Major research: Screening of rice varieties and hybrid lines for resistance to the brown planthopper.

Plant Pathology

MOHAMMAD QUAMARUZZAMAN, *research assistant*, Division of Mycology and Plant Pathology, East Pakistan Agricultural Research Institute. Major research: A study of the number and seasonal population shifts of physiological races of rice blast disease (*Piricularia oryzae*) in the IRRI blast nursery.

GERD FRANCK, *attendant*, Laboratory of Phytopathology, Hohenheim, Germany. Major research: Bacterial leaf streak disease of rice.

MOHAMMAD IQBAL CHOHAN,† *research assistant in* Plant Pathology, Ayub Agricultural Research Institute, Lyallpur, West Pakistan.

SUNETRA EAMCHIT, *second grade officer* in the research staff of the Rice Pathology Branch, Rice Department, Bangkok, Thailand. Major research: Not selected.

Plant Physiology

SU BONG AHN,* *senior technician*, Crop Experiment Station, Korea. Major research: Photoperiod and growth analysis of rice varieties.

A. BHADRACHALAM, *senior scientific assistant*, Agricultural Chemistry Division, Central Rice Research Institute, India. Major research: Improvement of lateritic soils.

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.

TZE-SHUN LEE, *junior specialist*, Taiwan Agricultural Research Institute, Taiwan. Major research: Influence of calcium carbonate in chemical and electro-chemical changes and the growth of rice in an acid latosolic soil.

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*Completed training.

†Completed Master of Science degree.

TABLE 7. Variance of estimator and relative efficiency of estimates for palay production, Bulacan Province, July 1959 to June 1960.

(20 percent sample)

Type of Estimators	Concomitant variable					
	Number of farms			Hectarage		
	Variance (000,000)	R.E.%*	cv %	Variance (000,000)	R.E.%*	cv%
Simple random = $\bar{T}_X$ (X-only)	538,744	100	32	538,744	100	32
Stratified (optimum) = $\bar{T}_X(oa)$	369,087	146	26	369,087	146	26
Ratio of means (r) = $\tilde{T}_Q$	44,037	1,223	9	31,639	1,702	8
Separate ratio (st) = $\tilde{T}_Q(st)$	26,939	2,000	7	8,078	6,669	4
Combined ratio (st) = $\tilde{T}_C(st)$	33,767	1,595	8	30,840	1,747	8

*R.E. is relative efficiency with the variance of $\bar{T}_X$ as numerator.

[Y_{ij}] is 0.92. With these correlations, the average R.E. of the ratio estimators will be comparable with those given in Table 7.

The increased statistical efficiency with the use of ratio estimators can improve the results of censuses and surveys. The following are recommended:

(a) As the Philippine 1960 agricultural census was a sample census, these ratio estimators can improve the results of the census itself.

(b) These findings may also be incorporated into the estimation procedures of the current Philippine Palay Survey (Crop and Livestock Survey) of the Bureau of Agricultural Economics, Department of Agriculture and Natural Resources.

Preliminary results in estimating rice production from the 1962 Crop and Livestock Survey for Laguna using hectarage as the concomitant variable have shown that the separate ratio estimator can be 8,000 percent more efficient than the X-only estimator. The estimated pooled sample correlation coefficent between production and hectarage is 0.97. Results of crop-cutting studies will be integrated with results from interview surveys from farmer's paddy field in estimating rice production.

OTHER ACTIVITIES

The statistician also served as First Vice President of the Philippine Statistical Association (PSA) and a member of the Board of Directors of the University of the Philippines College of Agriculture Alumni Association (UPCAAA).

capacity, exchangeable bases and total nitrogen. Further analyses are intended to measure available plant nutrients. The final objectives are to determine if long-time rice culture results in a characteristic soil profile, to describe the chemical properties of soils under lowland rice and finally, to relate these characteristics to soil productivity. To achieve the latter objective, the project is making use of crop response data obtained by other agencies working in the countries concerned.

In addition to the data mentioned above, the scientists working on this project completed preliminary surveys of Ceylon, Cambodia and the Philippines during the past year. Samples which were collected during the year are now undergoing laboratory analyses.

A cooperative project on communication is being carried out with the University of the Philippines College of Agriculture using funds from the grant. This is the "Rice Information Cooperative Effort" (RICE) which collects current rice information from all centers in the Philippines and circulates it to the public through national media and through agencies such as the Agricultural Productivity Commission (Philippine Extension Service).

Another activity of the RICE project has been the publication of a "Rice Production Manual". This was prepared with the close cooperation of Institute scientists and those from the College of Agriculture. It is finding wide use, not only in the Philippines but throughout Asia. Abstracted versions of it have been prepared for use in other countries, including one in the Bengali language prepared and distributed in East Pakistan.

In the field of genetics and cytogenetics, the Botanical Institute of Academia Sinica in Taiwan has succeeded in obtaining several interspecific hybrids which contain the chromosome complement of the cultivated rice (*Oryza sativa*) plus an extra chromosome from one of three wild forms included in the project. A series of such "alien additional" lines would aid in understanding the distribution of genetic factors among the chromosomes of different species. Meanwhile, the National Institute of Genetics in Japan is conducting phylogenetic studies on the Asian cultivated rice (*O. sativa*) and the African cultivated rice (*O. glaberrima*) by crossing the two geographically distant groups and analyzing the hybrid progenies. This study is aimed to provide information on the evolution of the cultivated rices.

Research on the control of suffocation disease in Taiwan, initiated in 1963 as a cooperative project between the Institute and the Joint Commission on Rural Reconstruction (JCRR), is being continued by Taiwan scientists to ascertain the long-term effects and the economics of the use of manganese dioxide as a soil amendment.

At the request of the Office of Rural Development, Suwon, Korea, a scheme for the joint investigation of the Akiochi problem was initiated in September, 1967. Akiochi is a physiological disorder of rice characterized by a rapid decline in the health and vigor of the plant in mid-summer which results in a considerable reduction in grain yield. It is invariably accompanied by *Helminthosporium oryzae,* a disease that indicates adverse soil conditions. This disease affects 200,000 hectares or one-sixth of the rice area of South Korea.

The scheme drawn up jointly by Korean and Institute scientists calls for (a) greenhouse and field experiments in Korea and (b) laboratory and greenhouse studies at the Institute by a Korean research scholar on a typical Akiochi soil shipped here from Korea.

International Travel

One of the important means of keeping close contact with rice research activities in other parts of Asia is to have the senior staff visit and confer with scientists at their home institutions. In fact, this provides the basic framework on which the international activities depend. Scholars are interviewed and selected, research programs are studied and plans drawn, information is exchanged on current research and so on. During 1967, all staff members participated in such travels as follows:

In January the agronomist visited Darwin, Australia, on returning from vacation leave in New Zealand. In April he visited Ceylon to become acquainted with the rice research program there. In June he attended the Pacific Weed

THIS year marked the first full year of operation of the Office of Communication under the direction of the communication specialist who arrived in April, 1963. With further training of the expanding staff, it was possible to begin demonstrating the practical differences between a behavioral science approach to information dissemination and training and the more traditional concepts associated with most publication, public relations, information, and extension programs.

Communication, as a behavioral science, is not only concerned with the flow of information from sources to receivers, whether these be persons or organizations, but, more significantly, with the interpersonal, inter-organizational, and person-to-organization interactions which precede, become part of, and result from communication activities. A communication practitioner, so oriented, views his objectives not as messages for transmission but as responses to be elicited or behavioral changes to be effected in a specific audience.

Essentially, a communication specialist asks, "How do we wish this person or these people to be different as the result of this message or this training?" He must be able to identify the nature and level of the changes desired and to develop means of determining the success of his efforts. Typically, he defines or expresses behavioral objectives as changes in level of knowledge, in degree of understanding, in nature and intensity of attitude, and in levels of ability to perform designated tasks or operations.

To bring about these changes, a communication specialist may manipulate a number of variables. These variables include the content and form of the messages, the selection of media or channels for transmitting messages, and the frequency with which he exposes the same message or a series of messages to a given audience.

Consideration of the possibilities of failure is an essential step in communication planning. Communication problems vary with the subject, the objectives, and the audience. When a message does not produce the results intended, a communication specialist asks at least these questions:

> Did it fail to reach or to arouse the attention of the intended audience? If so, why?
>
> Did the audience understand the message as the originator intended it to be understood? If not, why not?
>
> Did the audience fail to accept or believe either the message or the source? If so, why?
>
> Did the audience fail to respond because it did not know how, where, or when to act?
>
> Did the source fail to communicate with the facilitating audiences — those responsible for necessary inputs or other resources?

The parallels of these questions, when asked in advance of communication efforts, help identify factors important to the planning and conduct of effective programs.

Such an approach to understanding, predicting, and influencing human behavior has practical applications in information dissemination, organizational administration, academic instruction, in-service training, and agricultural extension. Growing recognition of the utility of this approach, both within and outside the Institute, created more production, consultation, and training opportunities than the limited staff could handle. This necessitated a selection of those activities and services of high priority which, at the same time, would train others and thus multiply efforts in support of the total mission of the Institute.

tungro disease of rice and visited several experiment stations. He spent October in India as a member of a rice pest survey team. En route back to the Philippines he visited the Breeding and Technical Divisions of the Thailand Rice Department.

In March and April the plant physiologist went to Taiwan to inspect the suffocation disease and to Japan to attend the annual meeting of the Society of the Science of Soil and Manure. In September he went to East and West Pakistan and Thailand to observe nutritional disorders of the rice plant.

The soil chemist visited Korea to inspect Akiochi-affected rice fields and to confer with Korean scientists on the possibility of initiating a joint investigation on the Akiochi problem. He attended the 59th Annual Meeting of the American Society of Agronomy held in Washington, D.C., and presented a paper on the influence of carbon dioxide on the pH values of aqueous carbonate systems.

In August, the soil microbiologist returned to the Institute to evaluate the progress of the research projects he initiated before leaving in April to take up his new position with the University of Queensland, Brisbane, Australia.

In April, the head of varietal improvement went to India to attend the All-India Rice meeting in Bangalore where he presented a paper on the Institute's breeding program and visited important rice-growing areas of the country. In May he went to Thailand to observe breeding plots and to arrange for virus testing of breeding lines in Thailand. He stopped in Pakistan in June while returning from home leave and conferred with rice research personnel at Karachi and Lahore. In East Pakistan he conferred with Ford Foundation officials and visited rice varietal plots at Savar Farm and Comilla, making arrangements to send new breeding lines for testing.

In Thailand he observed rice varietal improvement plots at the Bangkhen Station, Khonkhaen, Sakol Nakorn, and other locations. A trip was made to Malaysia in August to assist Malaysian officials in making selections from a breeding nursery of IRRI lines. In September he travelled to Korea to observe IRRI breeding lines being tested in that country and to advise returned trainees. On the same trip he attended a Symposium on Breeding for Disease Resistance at the request of the Japanese Government and presented a paper on the progress of the Institute's breeding program on disease resistance.

In November he returned to Thailand to observe the virus nursery of over 1,500 breeding lines from the Institute that were being evaluated at the Bangkhen Station.

The geneticist attended the FAO/IAEA research review meeting on rice breeding held in June and reported on the uniform yield trials of mutants and hybrids which were conducted at the Institute as a cooperative project. In September he participated in a FAO/IBP technical conference on the exploration, utilization and conservation of plant gene resources which was held in Rome. While in Rome, he also participated in the working sessions of the FAO/IAEA committee on international standardization in crop research data recording and retrieval. On his return trip, he visited cooperative variety trials at the Bangkhen, Rangsit and Chainat Experiment Stations in Thailand. In November, during his home leave, he visited several experiment stations in southern and central Taiwan where Institute lines were being tested.

In January the director left for New York to discuss with the Ford Foundation matters pertaining to the future program of the Institute. In April, he travelled to Madras to attend the All-India Coordinated Rice Improvement Project Workshop as well as the meeting of the Scientific Advisory Committee of the All-India Coordinated Rice Improvement Project, of which he is a member. In September he went again to India to discuss with Ford Foundation officials various phases of the Foundation's agricultural program in India. He also visited the All-India Coordinated Rice Improvement Center and the Central Rice Research Institute in Cuttack. From India, he flew to Bangkok to observe experimental fields of the Thailand Rice Department.

In October, the director participated in a symposium at the University of Illinois on the subject, "The Land Grant University and World Food Needs". From Urbana he went to New York to discuss the Institute budget proposal for 1968 with officials of the Ford and Rockemethods and materials. Frequently, major pre- and in-service training efforts fail to produce field workers willing and able to perform the farm practices they expect to teach farmers.

Objectives associated with the third group, the supporting and facilitating agencies, must be as diverse as the public and private operations involved. Some of the objectives to be achieved include: (a) Recognition of the value of empirical research; (b) awareness of current research results, along with an understanding of the implications of these for each agency's operations; (c) participation in planning, conducting, and evaluating field or applied research plots; (d) establishing of manufacturing, procurement, installation, distribution, financing, and related schedules timed to the needs of extension agencies and farmers, and (e) accurate, timely reporting of research results, practice recommendations and resource availabilities.

Efforts of the Office of Communication toward achieving these objectives are reported in four categories although many activities overlap: (a) Dissemination of information through publications and other media; (b) training of selected agricultural officials in rice production and communication; (c) research and evaluation, and (d) consultation and liaison.

Communication and training activities were expanded and accelerated during the year through the work of Mr. William G. Golden, Jr., who came to the Institute as a visiting scientist in February while on sabbatical leave from the Agricultural Extension Service, University of California.

Mr. Rogelio D. Feliciano, employed in March as an assistant editor, assumed most of the technical editing responsibilities for symposia papers and journal manuscripts. Late in the year, the office employed a second assistant in photography and an assistant offset operator to keep pace with the growing volume of photographic and reproduction work.

Projections of expanded workloads and additional operations led to a decision to remodel and expand the office facilities needed for editorial services, copy preparation, artwork, reproduction, publication storage, and mailing. This work was completed in late December.

Dissemination of Information

Publications

During the year, publications were the most visible information output. Most of the office staff worked on the publication program.

Established scientific journals are the principal channels for disseminating results of individual research projects to the scientific community. Since the staff began producing journal articles in mid-1963, they have forwarded nearly 40 manuscripts for editing. When accepted for publication, the Institute purchases reprints of each article for distribution to interested persons and libraries in rice-growing countries.

The Institute's annual report is another publication channel, but the research reports here are limited to a year's work. Consequently, the Institute this year established a technical bulletin series, the first two being published in the fall. The third was edited and sent to the printer in October, with delivery expected in early 1965.

To keep scientists, administrators, educators, and others advised of current Institute activities, the staff decided to establish a scientific newsletter to be issued on a monthly or bi-monthly basis beginning in 1965. This newsletter will circulate to the entire mailing list which now totals more than 1,500.

Some 40 scientists from the Institute and 11 countries participated in the Symposium on the Virus Diseases of the Rice Plant held in April, 1967.

The Institute engages in cooperative activities with other Asian rice research centers in various ways, ranging from grants-in-aid or other financial contributions to separately-funded research projects that are tied closely to the national research programs of the cooperating countries.

scopic studies of rice viruses (E. Shikata).

Session VII. Control: 1. Ecology of insect vectors, forecasting and chemical control (R. Kisimoto). 2. Varietal resistance to stripe, dwarf, yellow dwarf, and black-streaked dwarf (Y. Sakurai). 3. Testing rice varieties for resistance to tungro disease (K. C. Ling). 4. Varietal resistance to hoja blanca (H. A. Lamey). 5. Genetics of and breeding for resistance to rice virus diseases (K. Toriyama).

The proceedings have been edited and processed by the Institute's Office of Communication, and will be published by the Johns Hopkins Press in 1968.

Cooperative Country Projects

The newly formed cooperative projects in other countries have the objective of assisting national centers to accelerate their rice research activities. The projects vary widely from country to country and their principal characteristics in common are the stated goals, the relatively long-term nature of the undertakings, and the fact that a liaison officer of the Institute is located in the host country to facilitate interchange and generally to assist in developing the program. Because of the national character of these programs the present report is not an appropriate place to chronicle the activities and results in any detail. Hence, only a summary is given.

East Pakistan. The Institute's involvement in this type of project started in March, 1966 when a grant was made to East Pakistan by the Ford Foundation. The purposes of the grant were to provide training opportunities for young rice scientists, to test new rice research results in Pakistan, and to reinforce the local research facilities by importation of certain equipment and supplies not available in the country. Provisions were made for an Institute-employed scientist to be stationed in East Pakistan as an adviser in the acceleration of rice research.

Although East Pakistan has a relatively long history of involvement in rice research, the level of activity in recent years had declined sharply due to the loss of the main experimental farm which was taken as the building site of the second capital of the nation. From 1963 onwards many activities were suspended or drastically reduced. In 1967 the Government purchased a site for a new agricultural research complex. Government funds have been appropriated for the construction of a physical plant for rice research and these have been supplemented by a substantial second grant from the Ford Foundation for the purchase of building items and research equipment not available in the country. The Institute is responsible for management of these grant funds and for arranging certain engineering and architectural services.

A temporary experimental field was provided to the rice research group and in 1967 a number of varietal improvement, agronomy, and entomology tests were run. These and other results disclose the existence of several important disease and insect problems which seriously limit production at times. The results give urgency to the program of improving research facilities and of organizing a team of scientists to improve rice production.

Results in the breeding program at IRRI offer strong encouragement to the belief that major breakthroughs are possible, but experience in East Pakistan emphasize the need for on-the-spot studies as contrasted to dependence on research done elsewhere. Introduced varieties such as IR8 and IR5 offer promise, and significant increases in acreage of these varieties are expected after limitations are defined. Varieties with more disease resistance are needed, however, and increased tolerance of the cool weather encountered in November-December should be incorporated in varieties to be grown under irrigation during the dry "boro" season. Changes in growth duration would also be advantageous in certain situations. A number of lines in the breeding program offer promise in one or more of these directions and all indications are that favorable results can be expected. The need for accelerated action on a number of fronts, recognized by the Pakistan authorities, cannot be overemphasized.

Training of rice scientists has proceeded at a fair pace, although less rapidly than had originally been anticipated. Some delays have been encountered in identifying qualified participants and having them cleared by appropriate local authorities for study abroad. The names of participants abroad in 1967 are included in the general list of trainees given in another part of this report.

West Pakistan. Rice is not the major cereal crop of West Pakistan, yet there are more than 3 million acres of rice grown there. The province is self-sufficient both in coarse and fine rices and it exports significant quantities of basmati rice to the near east. When irrigation is supplied, the climate during the June to October period is excellent for rice and the high sunlight conditions during ripening provide a basis for exceptionally good yields.

The Institute's involvement in rice activities in West Pakistan dates from October, 1966 and is based on an agreement between the Government of Pakistan and the Ford Foundation. Again, the training of rice scientists and the supplying of technical counsel and research equipment form the core of the agreement. These activities are proceeding on schedule.

In tests and new lines and varieties, results have been obtained which have led the Government to increase the acreages of IR8 rapidly and to program supplies of fertilizer, insecticides, and other inputs for increasing rice production. Plans call for one million acres of IR8 to be planted in 1968.

The highly dynamic situation in West Pakistan makes it imperative that rice research be carried on at an intensive level so that problems may be solved promptly and new innovations tested rapidly. Certain soil problems have been identified in the region and some of these intensify as heavy rates of fertilizer are used. Also, high-yielding lines of slender translucent grain type are being identified in tests being conducted in the area. A thorough research effort in this direction has a particularly rapid pay-off in West Pakistan where certain diseases are less serious than in many other countries. Disease problems cannot be forgotten, however, and thorough testing for blast reaction is essential. Insect problems, particularly stem borers, can be acute and active research and extension work must be emphasized.

Training activities in West Pakistan deserve mention. During 1967 two short courses were held for extension workers from rice-growing parts of the province. The subsequent success of farmers in growing IR8 was due in no small part to the efforts of this group of trainees. Four members of the group came to the Institute for six months intensive training and at year's end they were back on the job in West Pakistan drawing plans for a strong local training effort in 1968.

India. The association of the Institute with Indian rice research is through the All-India Coordinated Rice Improvement Project (AICRIP) headquartered at Hyderabad. This organization was established in 1965 by the Government of India to bring a degree of coordination into the rice research efforts of various State and Central Government agencies. It is structured in such a way that new findings in one part of India may be rapidly evaluated and adopted in all parts of the country. Likewise, new materials or information from abroad may rapidly find their way to practice in India if testing proves them to be useful.

Institute participation came initially in the form of seed stocks of breeding material and advisory services of several of the Institute scientists. The Institute director is a member of the advisory committee of the AICRIP. The Rockefeller Foundation has been associated with AICRIP from the beginning and one of the staff members of the Foundation is Joint Coordinator of the AICRIP and serves as a member of the Institute staff.

More active participation by the Institute was made possible in 1967 by a contract between the Institute, the United States Agency for International Development, and the Government of India. Through this support, the Institute has posts for four rice scientists and provisions for one man-year per year in short-term consultations. These men are expected to conduct research in their fields of specialty and to assist in the development of these fields under the AICRIP program.

Results which have been obtained in India with responsive rice varieties such as Taichung (Native) 1 and IR8 have been described elsewhere and need not be discussed here in any detail. Suffice it to say that efforts to introduce these varieties and the cultural practices necessary for high yields have been successful to the point that goals of Government officials, research workers, and farmers have been dramatically raised. It is now recognized that yields far higher than those traditionally obtained are possible. As a result, research objectives have become more sharply focussed and varieties with high yield potential and good disease resistance are being actively sought under the AICRIP program. Grain characteristics of higher market value are receiving similar attention, but with the stipulation that they must go along with high yield potential. The old-fashioned low-yielding variety will not answer India's needs no matter what the grain-type might be.

As the sights of the rice breeder have been raised, so have those of the agronomist, the entomologist and the pathologist. There is a recognition that cash-requiring inputs can be used profitably in an integrated program with the right variety and a major effort is being made to assure that these inputs will be effective. Not only the nature of the input, but how it is managed is important and studies on timing and placement of fertilizers, methods and kinds of insecticides and similar factors are under study.

The outlook for improvement is highly promising and all indications are that a sustained research program is to be expected.

Ceylon. In July, 1967 an agreement was made between the Government of Ceylon and the Ford Foundation which resulted in the establishment of a cooperative program between the Institute and the Ceylon Agricultural Research Institute. Under this project, arrangements are to be made to provide scholarships to a number of Ceylon's rice scientists to permit them to study abroad. Attention will focus on rice research training at the Institute, but degree programs at US universities are also provided for.

While emphasis is on training, funds are also available for equipment and supplies not locally available and provisions are made for a rice scientist from the Institute to be in residence in Ceylon as an adviser. The regular head of the Institute's agronomy department has taken this assignment for a two-year period beginning October, 1967. He will participate in the rice research programs, assist in selecting scholars for study abroad and offer suggestions on means of accelerating production-oriented rice research.

Thailand. In Thailand the Institute does not have a formal responsibility to participate in rice research, but it works closely with the Thailand Rice Department and with the staff of The Rockefeller Foundation's Agricultural Program which includes a full-time rice breeder, and two part-time staff members—an agronomist and an agricultural economist—whose task is to work in various phases of the Foundation's program.

Efforts to increase production with new varieties and new practices are predicated on the existence of high quality grain for both domestic and export markets. Environmental conditions are such that disease and insect problems are of major significance and research, both basic and applied, is required.

High yield potential has been shown to be closely associated with plant type and relatively short stature. On the other hand, water supplies are uncontrolled in a fairly large proportion of Thailand and hence further experience is necessary to determine in which areas the shorter, more responsive types can be used. Perhaps, the first variety of this plant type to be used in Thailand will be one of the glutinous lines which in starch type is the opposite extreme from the high-amylose export rice of the country. Glutinous rices are a major item for local consumption in Thailand and a high-yielding, fertilizer responsive variety should find ready acceptance in certain areas. Longer term breeding objectives will call for developing lines of similar plant type with high grain quality and incorporating higher levels of disease and insect resistance in both non-floating and floating rice.

Colombia. In July 1967, The Rockefeller Foundation posted a regular staff member to Colombia to work with the Institute Colombiano Agropecuario in its rice program. The scientist in this post was former head of the Institute's varietal improvement program. He will also have the responsibility of developing cooperative activities in other Latin American countries. In this capacity he will serve as the principal link between the Institute and developments in rice research throughout Central and South America.

Publications and Seminars

Staff Publications

Plant Physiology

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Seminars

The following topics were the subjects of seminars held at the Institute during 1967. Unless otherwise stated the speakers were staff members.

Suggested strategy for an attack on the world food problems. *Dr. Forrest F. Hill*, consultant, The Ford Foundation, and chairman, Board of Trustees, IRRI.
Plant hormones, *Dr. J. van Overbeek*, plant pathologist for the Shell Chemical Development Corporation, Modesto, California, and director, Institute of Life Science at Texas A & M University effective August 1, 1967.
Some aspects of rice price policy in the Philippine economy. *Dr. Leon Mears*, visiting professor, UP School of Economics.
Programmed learning as an aid in technical communication. *Mr. John H. Lindt, Jr.*, area rice farm advisor, University of California, and consultant, Training Materials Project, Taiwan.
Selectivity of 2, 3, 5-tricholoro-4-pyridinol for weed control in flooded rice. *Dr. Moomaw*.
Attempts to control bacterial blight of rice. *Dr. Ou*.
Some aspects of role adjustments among professional workers engaged in development activities. *Dr. Byrnes*.
Adaptation of the rice plant to submerged conditions. *Dr. S. Yoshida*.
Sources of the tungro virus. *Dr. P. Narayanasamy*, research fellow, IRRI.
Persistence and biodegradation of benzene hexachloride in submerged soils, *Dr. MacRae*.
Some biochemical approaches to 1-histidine-induced sterility in the rice plant. *Dr. Kashiwamata*, visiting scientist, IRRI.
Plant type, competitive ability and yield in rice. *Dr. Jennings*.
New experiences in the collection of agricultural statistics. *Dr. Oñate*.
The effects of agricultural investment on the post-war economic growth of Japan. *Dr. Masao Hisatake*, visiting professor of Economics, Ateneo de Manila University.
Photoperiodism and seasonal development of insects. *Dr. Edward H. Glass*, visiting professor, UPCA.
IRRI, today and tomorrow, *Dr. Chandler*.
A new cabbage disease: its nature and control. *Dr. J. C. Walker*, professor emeritus, University of Wisconsin.
Varietal differences in physicochemical properties of rice starch. *Dr. Juliano*.

Two years of study on the biological control of the rice stem borers. *Dr. M. A. Kamran*, research fellow, IRRI.
Mechanization of rice production in tropical areas. *Mr. Johnson*.
Man, meteorites, and emotions. *Dr. Irving A. Breger*, chemist, US Geological Survey.
Sensory evaluation of foods with special references to rice. *Dr. Luz U. Onate*, assistant professor, UPCA.
UP-Cornell program—objectives and accomplishments. *Dr. George W. Trimberger*, leader, UP-Cornell Project, UPCA.
Recent results of multiple cropping experiments. *Dr. Bradfield*.
Case studies in rice production. *Mr. Drilón*.
Agricultural education and training in Asian countries. *Dr. Chi-Wen Chang*, visiting professor, Agricultural Education, UP-Cornell Project, UPCA.
Hybridization vs. mutation in rice breeding. *Dr. Chang*.
Management practices and nitrogen response of flooded rice. *Dr. De Datta*.
Weed control in upland and lowland rice culture. *Dr. Marcos R. Vega*, assistant professor, UPCA.
Some thoughts on the Asian Development Bank's future work. *Dr. George Rosen*, deputy director, Economic and Technical Division, Asian Development Bank.
Future demand and production input requirements for rice and other cereal grains in the Philippines. *Dr. Frank Golay*, Department of Economics, UP-Cornell Project, UPCA.
Some interesting findings on the effect of photoperiod and temperature on the rice plant. *Dr. Vergara*.
Diffusion of recommended farm practices in Western Nigeria. *Dr. Robert C. Clark*, director, National Agricultural Extension for Advanced Studies, University of Wisconsin.
The concept of seed dormancy and some possible mechanisms in rice. *Dr. D. S. Mikkelsen*, visiting scientist, IRRI.
Computer simulation in genetic analysis, *Dr. Charles Gates*, professor of statistics, Texas A & M University.
The rat problem in the Philippines. *Dr. Lowell D. Uhler*, professor, Entomology Department, UP-Cornell Project, UPCA.
Indian agricultural development: plan and practice. *Dr. John W. Mellor*, professor, Agricultural Economics, Cornell University.
Retrieval of research project information. *Dr. R. B. Harrington*, associate professor, Statistics, Purdue University.
An economic analysis of the interrelationships between land preparation and weed control. *Dr. Barker*.
Response criteria in the bio-assay of vitamin K. *Prof. Chester I. Bliss*, biometrician, Connecticut Agricultural Experiment Station, New Haven.
Economic aspects of rice mechanization. *Dr. S. Johnson*.
Insect population dynamics. *Dr. David Pimentel*, head, Department of Entomology, UP-Cornell Project, UPCA.
Research on soybean-based foods. *Dr. K. H. Steinkraus*, visiting professor, Chemistry Department, UP-Cornell Project, UPCA.
Cytogenetics and breeding of tomatoes. *Dr. Khush*.
The UNSF soil fertility project: its results and conclusions. *Dr. M. F. Chandraratna*, manager, United Nations Special Fund Soil Fertility Project.
The ultrastructure of the tobacco mosaic virus. *Dr. Max A. Lauffer, Jr.*, professor, Biophysics, University of Pittsburgh.

Soil nitrogen availability in tropical northern Australia (non-flooded conditions). *Dr. R. Wetselaar,* Coastal Plains Research Station, Australia.

An integrated system for power, water and food production in coastal areas. *Dr. Carl N. Hodges,* University of Arizona.

Coconut culture—some of its problems in the Philippines. *Prof. Martin S. Celino,* agricultural research consultant, Philippine Coconut Administration.

The effects of radiations on variability for quantitative traits in wheat. *Prof. Renzo E. Scossiroli,* University of Bologna, Italy.

Where does change begin? Communication strategies in a development program. *Dr. Byrnes.*

Rice drying situations in the Philippines. *Mr. Theodore Wasserman,* chemical engineer, United States Department of Agriculture, California.

National development through science and technology. *Dr. Juan Salcedo, Jr.,* chairman, National Science Development Board.

Approaching maximum productivity—biological limits of production. *Dr. S. H. Wittwer,* director, Agricultural Experiment Station, Michigan State University.

Tungro resistance mechanisms in Pankhari 203. *Dr. Ling.*